UNIVERSITÀ DEGLI STUDI DELLA TUSCIA

DIPARTIMENTO DI ECONOMIA, INGEGNERIA, SOCIETÀ E IMPRESA

IAQUIS

International Association for Quality, Innovation and Sustainability

AISME ACCADEMIA ITALIANA DI SCIENZE MERCEOLOGICHE

Iaquis Conference Proceedings

Fostering organizational transformation for a sustainable future:

Enhancing synergies between quality, innovation and sustainability

Iaquis International Conference
11th – 13th September 2024
Viterbo, Italy

IAQUIS

International Association for Quality, Innovation and Sustainability

Iaquis Conference Proceedings

Iaquis Conference 2024

Fostering organizational transformation for a sustainable future:

Enhancing synergies between quality, innovation and sustainability

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International Conference

IAQUIS 2024

Viterbo, Italy

2024/09/11 – 2024/09/14

www.iaquis.com

Foreward

The current economic, social, and environmental landscape is marked by a profound crisis, underscoring the urgent need for a paradigm shift in production and consumption patterns. The interconnectedness of these domains has become increasingly evident, with the effects of unsustainable practices rippling through economies, societies, and ecosystems.

Recent environmental and geopolitical events have further highlighted the fragility of the existing production system. Climate change, resource depletion, and geopolitical tensions have exposed the vulnerabilities of traditional economic models and the imperative for transformative action. Organizations must adapt to these challenges by embracing sustainable practices and innovating to create more resilient and equitable systems.

A synergistic contribution from academics, practitioners, and policymakers is essential to navigate this complex landscape. Academics can bring their research expertise to identify emerging trends, develop innovative solutions, and inform policy decisions. Practitioners can offer insights into the practical challenges and opportunities faced by organizations in their respective sectors. Policymakers can create enabling environments that support sustainable practices and incentivize innovation.

Academia, in particular, can play a pivotal role in driving the development of new ideas through research activities. The International Association of Quality, Innovation, and Sustainability (IAQUIS) can serve as a valuable platform for aggregating, coordinating, and mediating these efforts. By fostering collaboration among professors, researchers, doctoral students, and practitioners from around the world, IAQUIS can facilitate constructive discussions and knowledge sharing.

The choice of the main themes, "Quality, Innovation, and Sustainability," reflects the interconnected nature of these concepts and their critical importance for a sustainable future. Quality, as a cornerstone of excellence and customer satisfaction, is essential for long-term organizational success. Innovation, as the driving force behind progress and adaptation, is crucial for addressing emerging challenges and creating new opportunities. Sustainability, encompassing environmental, social, and economic dimensions, is a fundamental imperative for ensuring the well-being of future generations.

By adopting a cross-cutting and synergistic perspective, organizations can unlock the full potential of quality, innovation, and sustainability. This involves integrating these elements into all aspects of business operations, from product design and production to supply chain management and customer relationships.

The First IAQUIS Conference provides a unique opportunity to initiate a network of relationships and connections among key stakeholders from academia, industry, and policymaking. Through collaborative discussions and knowledge sharing, participants can explore innovative approaches, identify best practices, and develop strategies for fostering organizational transformation.

By focusing on quality, innovation, and sustainability, IAQUIS aims to contribute to a more equitable, resilient, and sustainable future for all.

Viterbo, Italy

Alessandro Ruggieri

Preface

The first Iaquis Conference was held in Viterbo (Italy) from 11th to 13th September 2024. It was promoted by the International Association for Quality, Innovation and Sustainability and hosted by the Department of Department of Economics, Engineering, Society and Business Organisation of University of Tuscia in Viterbo, Italy.

The objective of the Conference was to stimulate and foster collaboration and knowledge exchange in the areas of Quality, Innovation and Sustainability among researchers, educators, practitioners, and doctoral students hailing from diverse countries and backgrounds.

Over the course of the three-day Conference, the participants had the opportunity to present their research in both plenary and parallel sessions.

The central theme that permeated all discussions revolved around the synergies between Quality, Innovation, and Sustainability, embracing an interdisciplinary perspective and a cross-cutting approach.

A pre-conference Doctoral Consortium was held. During the Doctoral Consortium the PhD Students presented their research program and findings, and received suggestions by the mentors. Moreover a seminar on how to develop an impactful paper was held to provide young scholars with in-depth feedback from experienced lecturers on their ongoing research.

The Conference collected a total of 83 Papers from 15 countries. Some of the authors asked not to be publish their paper in these proceedings, thus some contributions will not appear, besides being counted.

The great number of papers and the variety of the topics allowed us to organize numerous parallel sessions, by dividing the papers into 18 tracks, plus the Doctoral Consortium:

1) Circularity
2) Healthcare
3) Sustainability in Tourism
4) Sustainability in Agri-Food
5) Sustainability
6) Life Cycle Assessment
7) Quality and Innovation in Food Sector
8) Innovation Industry 4.0
9) Quality Management
10) TQM and Sustainability
11) TQM and Employees
12) Quality Management and Improvement
13) Management Systems
14) Life Cycle Assessment
15) Sustainability and Service Innovation
16) Sustainability
17) Sustainability in Energy Sector
18) Innovation.

Due to the conspicuous number of the papers which fell under the topics of “Sustainability” and “Life Cycle Assessment”, each of these parallel sessions were split in two sessions, allowing all the authors to present their contribution.

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Abstract

Background: The circular economy and industrial symbiosis are essential for industrial sustainability. Industry 4.0 technology integration encourages productive material reuse and cross-company collaboration. The current landscape presents noteworthy prospects and obstacles for advancing sustainable practices and mitigating environmental impacts, hence bolstering the advancement of inventive and sustainable industrial frameworks.
Objectives: The research project aims to study and analyse the concept of industrial symbiosis in relation to the circular economy, deepening it with a real case study. Therefore, it will focus on identifying the main enablers and barriers to the implementation of industrial symbiosis, examining how Industry 4.0 technologies can facilitate integration between different companies and improve the efficiency of material reuse. The industrial district known for its sustainability endeavors will serve as the source of the case study. The study will gather empirical data using surveys, interviews, and material flow research to create a reference model that can be applied to different industrial situations.
This project is to provide useful insights for businesses and governments interested in supporting the circular economy through industrial symbiosis, therefore aiding in the spread of sustainable practices and the mitigation of environmental damage. The ultimate objective is to show how successfully combining Industry 4.0 with the circular economy may be a plan for reaching industrial sustainability.

Keywords: Industrial Symbiosis, Circular Economy, Industrial Ecology, Industry 4.0

Research area

Industrial Ecology: integration of circular economy and industrial symbiosis through industry 4.0 technologies.

Research topic

Research on the interplay between industrial symbiosis and the circular economy, particularly as it relates to Industry 4.0 applications, is an important and developing field. According to Ghisellini et al. (2016), the circular economy advocates for a closed production cycle model that minimises resource waste and lessens its negative effects on the environment. Conversely, industrial symbiosis relies on collaboration between several businesses to maximise resource utilisation, converting one business's waste into resources for another (Chertow, 2000). A highly effective and sustainable manufacturing system may be created by combining these two ideas with cutting-edge Industry 4.0 technologies like the Internet of Things (IoT), artificial intelligence (AI), and big data analytics (Stock & Seliger, 2016). The goal of this research project is to investigate how these technologies might help apply industrial symbiosis and circular economy principles, enhancing material flow management and encouraging increased inter-firm cooperation. An industrial district that exemplifies sustainability excellence will be examined in this context, offering a real-world case study that will enable the creation of a reference model that can be applied to other industrial contexts.

Research Question

The adoption of novel approaches like the circular economy and industrial symbiosis is a result of the increased concern for environmental sustainability. However, combining these practices comes with several difficulties, such as maximising material reuse and coordinating across many businesses (Lombardi & Laybourn, 2012). Prior studies have frequently addressed industrial symbiosis and the circular economy as distinct concepts without properly examining their potential for cooperation (Zhu et al., 2010). Furthermore, the ways in which Industry 4.0 technologies might help with this integration are not well understood. Reducing the total environmental effect and advancing towards a more sustainable sector depend on finding a solution to this issue. Though their exact significance in this context is yet unknown, the integration of Industry 4.0 technologies presents new prospects to enhance the effectiveness of material reuse and promote company cooperation. By examining how the incorporation of Industry 4.0 technologies might support the cooperative adoption of the circular economy and industrial symbiosis, this research project seeks to close these gaps. Achieving industrial sustainability goals requires a successful combination of the circular economy and industrial symbiosis. There may be major advantages for the environment, the economy, and society if we have a better grasp of how Industry 4.0 technology may be used to integrate and improve these practices (Ellen MacArthur Foundation, 2015).

A dearth of research has examined the combination of the circular economy and industrial symbiosis, with most of the extant literature focusing on both topics independently (Mathews & Tan, 2011). Additionally, while research is being done on the implementation of Industry 4.0 technology in industrial practices, not much of it has been carried on specifically to evaluate how these technologies will affect the way that the circular economy and industrial symbiosis work together (Rajput & Singh, 2020). By offering a more thorough knowledge of the processes at work and suggesting workable solutions based on empirical evidence, this research initiative seeks to close this gap.

Methodological approach

The study hypothesis suggests that the incorporation of Industry 4.0 technologies into the circular economy and industrial symbiosis will enhance material reuse efficiency and encourage company collaboration, ultimately resulting in lower operating costs and better environmental performance. Specifically, the use of the Internet of Things (IoT) will provide ongoing, instantaneous material flow monitoring, hence improving recycling and reuse procedures. Large-scale data analysis and the ability to forecast production and consumption patterns will be made possible by artificial intelligence (AI), which will enable more effective resource management and planning. Furthermore, big data analysis will enable the discovery of business symbiosis prospects, encouraging the development of cooperative networks that may share resources and cut down on waste. This claim will be investigated through a case study in an industrial area renowned for its sustainability initiatives, examining the potential effects of these technologies' adoption on material flows and intercompany cooperation. Anticipated outcomes encompass a notable decrease in waste, enhanced operational efficacy, and a rise in the industrial district's overall sustainability. To determine the primary obstacles to and enablers of industrial symbiosis adoption, the research project will combine bibliometric and systematic literature analysis.

While systematic analysis will offer a thorough summary of previous studies and their major conclusions, bibliometrics will monitor research trends and identify important contributors in the area (Van Eck & Waltman, 2014). (Tranfield et al., 2003). After that, a case study in an industrial area renowned for its eco-friendly initiatives will be carried out. Material flow research, interviews, and questionnaires will be used to gather empirical data. Using this method will enable the development of a reference model that can be used in many industrial settings. The potential of Industry 4.0 technologies to enhance the transparency, traceability, and efficiency of material reuse operations will be examined. The data gathered will be examined to confirm the influence of incorporating Industry 4.0 technology on the suggested model's efficacy. The outcomes will be evaluated in terms of gains in material reuse efficiency and inter-firm collaboration by comparing them with current practices. Waste reduction, energy savings, and operational cost improvements will be measured using key performance indicators (KPIs). The goal of the project is to create a framework that uses Industry 4.0 technology to support industrial symbiosis in the context of the circular economy. According to Bressanelli et al. (2018), this framework will contain tools for tracking materials inside industrial networks utilizing IoT sensors and big data platforms, as well as tools for monitoring material movements and enhancing transparency and recycled material management. Additionally, cooperative platforms for businesses will be created to facilitate resource, information, and best practice exchange, encouraging collaboration and the development of synergies (Yang & Feng, 2008).

To standardize material reuse procedures and increase their efficiency and reproducibility across sectors, operational standards will also be developed (Yuan et al., 2006). A theoretical model explaining the successful integration of the circular economy and industrial symbiosis through Industry 4.0 technologies is one of the project's primary anticipated contributions (Geissdoerfer et al., 2017). To optimize the environmental and operational advantages of these practices, enterprises and governments will be provided with practical guidance on how to put them into practice (Geng et al., 2012). An empirical case study will provide specific and reliable data for upcoming applications while showcasing the model's usefulness in a real-world setting. Furthermore, specialised technology tools will be created to oversee and control material flows, enhancing process efficiency and transparency.

Positive effects will be seen locally and worldwide because of the noteworthy contribution to trash reduction, energy savings, and enhanced industrial sustainability (Korhonen et al., 2018). The study will offer a thorough grasp of how Industry 4.0 technologies may be utilised to successfully integrate the circular economy and industrial symbiosis (Pagoropoulos et al., 2017). According to Lehmann et al. (2014), the anticipated outcomes will have a big influence on industrial sustainability by providing workable and scalable ways to lessen environmental effect and encourage company cooperation. Results will be widely discussed and utilised to guide future industrial policies and practices if they are disseminated through papers, conferences, and workshops (Lieder & Rashid, 2016).

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Circularity in Construction and Demolition Waste: a Management System for C&D waste.

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Keywords: Construction and demolition waste, recycled aggregates, industrial symbiosis.

Abstract

Construction and demolition is high impact activity from environmental and economic point of view (Eurostat, 2024; Legambiente, 2021; Mehra et al., 2022; Shooshtarian et al., 2020), which exponentially attracted the attention of researcher and practitioner, especially from 2017 (Benachio et al., 2020).

Circular economy practices, including the development of Industrial Symbiosis networks, can help to mitigate the impact of construction and demolition activity, especially if a multidisciplinary approach is adopted (Pomponi & Moncaster, 2017).

For this reason, the project, which has the aim of creating a management system with a set of indicators and best practices, is divided into various steps. These steps will allow to: acquire a wide and multidisciplinary knowledge on the topic with the help of practitioners connected to construction and waste recovery companies; study the regulations and best practices of various European countries; put this knowledge together to reach the scope.

This project will help lawmaker and companies to improve the CDW recovery and recycling practices also by enhancing the network potential of Symbiosis.

This project will be based on various methodologies which will include literature review, direct interviews, primary and secondary data analysis.

Research area

Construction and demolition waste management.

Research topic

Analysis of CDW practices and laws, and development of a management system to be used by companies along with a toolkit composed by best practices and a set of indicators useful to measure the impact and effectiveness of the proposed solution.

Introduction, research hypothesis and aim

Construction and Demolition Wastes (CDW) produce 37.5% of non-hazardous waste in Europe every year (Eurostat, 2024). At the same time 2.46 million tons of sand, rocks and gravel are excavated to produce building materials, such as ornamental stones or aggregates (UEPG Aggregates Europe, 2024), leading to high consumption of natural resources and land consumption (Legambiente, 2021).

Various authors highlighted that there will be a global shortage of natural aggregates, especially sand, in the long term (Habert et al., 2010; Mehra et al., 2022; UNEP, 2014).

Despite the composition of CDW is various and can change according to the different architectonic characteristics of the buildings (Asgari et al., 2017), it includes materials like concrete, mineral stones, bricks, metal, plastic, glass, gypsum, wood (Kucukvar et al., 2014; Mah et al., 2016; Scolaro et al., 2021). The highest amount in weight and volume is mostly given by concrete, mineral stones and bricks, thus scholars and practitioners focused on these major components for their studies on recovery and recycling.

Particularly, many authors discussed CDW recycling from a technical point of view (Bravo et al., 2015; Gu & Ozbakkaloglu, 2016; Meyer, 2009; Ortiz et al., 2021; Segre & Joekes, 2000; Siddique & Naik, 2004), despite a cross-disciplinary approach being suggested (Pomponi & Moncaster, 2017).

In Italy 80% of CDW are recovered and prepared for reuse or recycling (ISPRA, 2023), but according to Legambiente (2021) these numbers only come from the data obtained by the monitoring of controlled waste flows, which are collected using the MUD information system (MUD - Modello Unico di Dichiarazione ambientale). The MUD is mandatory only for a small number of companies with specific characteristics based on size and hazardous or non-hazardous waste production. For this reason, a great part of the data are only estimated and not directly obtained by the waste producers. Moreover Legambiente (2021) disputes the fact that this percentage represents the wastes collected and stocked for future use, but not the wastes which are actually used after being processed and transformed in recycled aggregates.

Therefore, given the aforementioned state of the art and the fact that there are still various regulatory and organisational inefficiencies (ANPAR, 2022; Legambiente, 2021), there is still room for improvement.

For these reasons I chose to perform my PhD research in the area of Construction and Demolition Waste with multiple aims in order to optimize the production-recovery-recycling process of CDW. The main objectives of this research are:

1) Creating a management system to optimize the production, recovery and recycling process of CDW.

2) Collecting a set of best practices to be used with the management system.

3) Creating a set of indicators that allow the companies and law maker to evaluate the economic, environmental and social impact of recovery and recycling activities and the performance of the management system.

4) Identifying the regulatory gaps and inefficiencies that reduce the effectiveness of the aforementioned solutions.

The project is divided into various phases, as represented in Table 1, which will be spread over the 3 years of the PhD course. The phases are organised in order to build a growing knowledge on the topic, with a wide view on the mechanisms of the industry and its actors and stakeholders. This will allow to capture useful details that can be used during the last phases in which the management system and indicators will be created alongside with regulatory and best practice improvements. The schedule includes the period necessary to write the final thesis.

Table 1: Research plan

Phase	1st year				2nd year				3rd year			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
1. Normative analysis												
2. Market analysis												
3. Producer and recovery company survey												
4. European country analysis												
5. Law and practice improvement												
6. Creation of management system and indicators												
7. Thesis												

Methodology

During this project various methodologies will be used, also in combination, to achieve the pursed results. Both desk and field research will be conducted.

Literature review (Webster & Watson, 2002), based on scientific and grey literature, will be performed to uncover the state of the art on the topic and create a starting point to better address the research. Moreover, the LR will be used to make a comparison between the European countries, focusing on the differences in building architecture, CDW production, regulatory system.

The desk research will be constantly accompanied by field research, which will include case studies (Yin, 1994) and structured and unstructured interviews (Wethington & McDarby, 2015) to experts from construction, recovery and recycling companies. During these interviews might be also collected primary and secondary data which can be relevant according to the results achieved during the various phases. It worths to mention that the collaboration with the companies will be held during the whole period of the PhD and not only for the first phases.

While primary data will be collected directly from the companies, secondary data can be collected from public databases (eg. ISTAT) or directly from the companies which have historical data in their archive.

The aforementioned methods, such literature review, interviews, data collection, are those which will surely be adopted during the research, but other methods can be used if the evidences and the results of the research suggest that other methodologies can be useful to obtain better or wider results.

During the last phases, which will lead to the realisation of a set of indicators and a management system, there will be a constant confrontation with the experts from the involved companies.

Each proposed solution will be evaluated with the participation of practitioners involved in the interested processes, to assure that these solutions fit the needs of the enterprises. The management system with the indicators will also supposedly be tested with the contribution of a small sample of companies.

Finally, the research outputs will be formalised in papers presented at national and international conferences and the whole work will be formalised in the final thesis which will be examined by a commission.

Expected contribution

The aim of the project, as stated above, is to create a management system along with a toolkit which includes a set of indicators and best practices that can improve the companies' performances and enhance the Symbiosis network potential. This management system will be implemented in the recovery & recycling companies and in the construction companies and will also help to identify the inefficiencies of the current regulatory system.

Various useful contributions can be obtained by achieving the objectives of the research. Firstly, this research will contribute to improve the state of the art in terms of academic research, especially by adopting the desired multidisciplinary approach (Pomponi & Moncaster, 2017).

Secondly this research will give new tools both to the recovery & recycling companies and to the construction companies, to improve their waste management system and measure their performance and impact using a wide range of indicators which take several factors into account. Moreover, a shared tool can boost the growing of Industrial Symbiosis networks, which emerged from the analysis performed to date. In this regard, it seems promising to deepen the analysis on the Industrial Symbiosis which currently is not formalised in this industry in Italy.

Finally, this research can help the policy maker and law maker to adopt more efficient regulations and to measure the effectiveness of these measures with the help of new tools and indicators.

Discussion and conclusions

At present day the research reached the third phase according to the program represented in table 1. This allowed me to present the first findings on a paper which will be presented during the 2024 Aisme Conference. The market and normative analysis, along with the interviews performed with some practitioners and a specific case study, led me to detect the existence of an informal Industrial Symbiosis network, which can be identified as "self-organising symbiosis model" (Chertow, 2007). This Industrial Symbiosis reunites various stakeholders.

Few authors investigated the Industrial Symbiosis in this field and according to the interviews performed during the Case Study, the companies are still not aware of the IS network that is taking shape. Despite this the performed analysis still highlights a promising behaviour among the recovery & recycling centres, the waste producers and the building companies, which can be interpreted as Symbiosis network at its early days. Moreover, the involved companies seem to be interested in expanding their network to different waste producers.

These results suggest that the following research phases should be more focused on the symbiosis aspects more than on the organisational aspects of the single companies. Thus, the objective should slightly slide from the creation of an adaptive management system that can be applied to recovery companies and to building companies, to the creation of a management system that can accelerate the agglomerating process that leads to the creation of Industrial Symbiosis networks. Alongside to the management system, the toolkit composed by best practices and indicators should also be focused on the implementation and measurement of the Industrial Symbiosis network.

According to the achieved results to date, some issues and questions emerge.

The first issue regards the fact that the composition of CDW is various and can change according to the different architectonic characteristics of the buildings. This can lead to two consequent limits of this research: the results will be built on the system taken as a reference which may differ from other systems ubicated in regions with different architectonic characteristics and thus the management system might be more suitable for the companies that insist on a similar system and less suitable for the companies in a strongly different one.

Similarly, since the symbiosis networks are distance-sensitive and pivot around recycling centres, their composition change according to the companies that insist around the recycling centres. Thus, the presence of particular waste producers (e.g. steel mills and paper mills) may lead to specific advantages for the specific symbiosis networks, given by the variety of waste and resource flows.

Finaly, this sector is highly regulated, thus there is small room to implement organisational changes that can't go past the borders set by the regulation.

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Sustainability and circular supply chain in the tourism sector

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Abstract:

The present project explores the concepts of sustainability and circularity in the tourism field and provides a set of indicators allowing to measure the impact of all practices in the tourism supply chain. It can be states that there is still a fragmented knowledge of how circularity principles can be applied in the tourism sector and how they can contribute to its sustainable development. Evaluating the components of a tourism supply chain by integrating circularity and sustainability aspects allow for a comprehensive assessment of the overall impact of a tourism experiences. Given the cross-sectoral and dynamic nature of tourism, it is crucial to consider not only individual activities and services, but also the interactions and synergies between the various actors in the supply chain (Gruchmann et al., 2022).

The project is structured in two steps: conceptual and empirical. The conceptual part is essential to deepen the body of knowledge, delineate the phenomenon of interest, and identify research gaps and priorities. The empirical part involves a mixed-method approach with an exploratory phase (qualitative analysis) and a descriptive phase (quantitative analysis).

By conducting a comprehensive literature review on relevant issues, analysing the behaviours and practices of tourism stakeholders along the supply chain, and assessing environmental and social impacts, this project aims to develop a theoretical framework and corresponding metrics (indicators) that align tourism with sustainability principles and circular supply chain practices. Moreover, recommendations will be provided for businesses and policy makers for contributing to a more sustainable and circular tourism industry.

Research area

Sustainability and circularity in the tourism.

Research topic

Exploring sustainability and circularity practices in tourism and developing indicators to measure and enhance impacts across different levels of the supply chain.

Introduction and research aim

Tourism is a rapidly expanding and economically significant sector. It determines multiple positive impacts on various parallel fields, contributing significantly to global GDP growth and representing a valuable solution for the social and economic development of several countries, creating jobs, reducing poverty levels and enhancing international cultural and natural heritage (UNWTO, 2020). However, in recent decades, there has been an increase in scientific literature addressing the serious sustainability issues related to its activities. Indeed, tourism is a resource-intensive sector, and its constant growth causes significant pressure on destination resources, including land use, excessive consumption of water, energy and food, leading to a large amounts of waste, as well as noise and air pollution (Rico et al., 2019). Moreover, the touristification of places also has negative impacts on the preservation of a destination's authenticity and identity, with detrimental consequences for both the host communities and the quality of the tourist experience itself, due to congestion of space and infrastructure, real estate speculation and, in general, the rising cost of living and tourist services (Benner, 2019).

In line with these considerations, sustainable tourism is defined as 'tourism that takes full account of its current and future economic, social and environmental impacts, meeting the needs of visitors, industry, the environment and host communities' (UNWTO and UNEP, 2005). It promotes (i) the optimal use of environmental resources, maintaining fundamental ecological processes and contributing to the conservation of natural heritage and biodiversity, (ii) respect for the socio-cultural authenticity of host communities, preserving their cultural heritage and contributing to cross-cultural understanding and exchange and, (iii) ensuring profitable, long-term economic operations that provide socio-economic benefits to all stakeholders, with stable employment and income opportunities and quality services to host communities (Girard and Nocca, 2017).

Moving towards a transition to a more sustainable future, the circular economy model is seen as an essential approach to replace the linear economy model, where the promotion of unlimited growth in production and consumption – that does not take into account the finite nature of resources, the increase in waste and the deterioration of the natural ecosystem – is certainly not consistent with the aspiration of sustainable development of socio-economic system (EMF, 2015). The CE model aims to decouple economic growth from resource exploitation, promoting circular value creation in which continuous resource flows replace unsustainable conventional supply chains (Florido et al., 2019).

The literature on the circular economy has mainly focused on the manufacturing sector and the concept remains underexplored in services research, despite the growing commitment of service operators in implementing more sustainable systems and the strategic positioning of services between manufacturers and end-users (Heyes et al., 2018; Karpen et al., 2023). Accordingly, circular economy in tourism research is still in its infancy and its principles and measurements along the tourist supply chain remains relatively fragmented (Gruchmann et al., 2022). This gap hinders the ability of researchers and practitioners to assess and improve tourism experiences. Specifically, the lack of a comprehensive indicator system to measure circularity and sustainability performance throughout the tourism supply chain makes it even more difficult to develop integrated and coherent strategies.

Against this backdrop, an adequate knowledge of sustainability and circularity principles in the sector as well as a comprehensive system of indicators can yield useful tools and insights to improve the environmental and socio-economic performance of the tourism supply chain.

This research project aims to answer this need by providing an in-depth understanding of the phenomenon and implementing a set of indicators for the entire tourism supply chain, contributing to the transition towards more sustainable and circular economic systems.

Methodology

To achieve the research objective, a mixed-method approach will be used. As stated by multiple authors (Creswell, 2009; Bryman, 2007) the use of a mixed approach allows for the development of a broader and more articulate analysis of a specific phenomenon, providing coherent answers to complex research questions (Hesse-Biber and Johnson, 2013).

Specifically, the research is divided into two phases: a first phase of conceptual analysis is conducting to deepen the body of knowledge, delineate the phenomenon of interest, and identify research gaps and priorities. Then an empirical phase involving both exploratory (qualitative) and a descriptive (quantitative) analysis will be carried out during the final year of the PhD programme.

The details of each stage are described below.

Conceptual analysis (ongoing)

1. General literature review

- Perform a bibliometric analysis on sustainability and circularity in services to identify new trends and subject areas and explore the intellectual structure of the phenomenon of interest (Donthu et al., 2021). The bibliometric analysis identified the tourism sector as one of the major subject areas investigated in terms of sustainability and circularity in service field.

2. Tourist-specific literature review

- Provide an analysis of the context.
- Undertake a systematic literature review on the concepts of circularity and sustainability in tourism with the aim of understanding current practices, theoretical approaches and different levels of analysis

investigated. Notably, the results showed how multiple records in the sample are focused on tourism supply chain, shedding light on a growing interest in the field.

- Explore and evaluate current circularity and sustainability measurement systems used along the tourism supply chain. The aim will be to map the various stages of the supply chain and develop an initial theoretical framework containing the main metrics and indicators currently used. To this end, the specific needs of the tourism supply chain will be identified. Both scientific and grey literature will be considered.

Empirical analysis

1. Phase 1

After defining the structure of the tourism supply chain and identifying the various actors involved, a panel of companies operating in the different stages of the supply chain will be created. In-depth interviews will be conducted with key stakeholders (e.g. hotel managers, tour operators, food and transport providers) to gather information on current practices and challenges in measuring sustainability and circularity and discuss further potential indicators. The interpretation of the data will be carried out through a *thematic analysis* based on the six steps identified by Braun and Clarke (2006). MAXQDA software will be used to process the data. The qualitative analysis will make it possible to study a complex context and to analyze and collect the different points of view of the stakeholders involved.

2. Phase 2

Furthermore, with the aim to explore and deepen tourists' views on circularity and sustainability practices in tourism and gathering information on their perceptions, preferences and behaviors, a structured questionnaire will be administered according to the literature review and results provided by the previous qualitative phase. by. The results could be useful to develop further relevant indicators measuring the effectiveness of these practices from the user's point of view, which will help to better understand how tourists perceive and react to sustainability and circularity practices and to implement actions for improvement. The data will be analyzed with the support of statistical software (e.g. SPSS).

Originality/value of the research

The originality of this research lies in the fact that few studies have offered a comprehensive analysis of how circular economy principles can be applied and measured within the tourism supply chain, and how these principles contribute to sustainable development. The outcomes of this project will provide valuable tools (concepts and indicators) that will benefit researchers and tourism practitioners in the pursuit of a circular and sustainable tourism system.

The expected contribution of the PhD research

The research allows to contribute to both theory and practice. Theoretically, it contributes to broadening the field of circular economy research by also considering the service domain. Specifically, it contributes to expanding knowledge in the field of sustainable and circular tourism by providing a detailed framework and specific metrics for the integration of these principles into tourism supply chain practices. Furthermore, it provides tools and recommendations for tourism businesses and policy makers to support sustainable and circular tourism practices, contributing to broader environmental and socio-economic objectives.

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Track 1: Circularity

Unravelling circular best practices in the pasta and bread supply chains: insights from Italy

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Abstract

The pasta and bread supply chains play a pivotal role in the global economy, producing essential nutritional foods as prominent sources of macronutrients, micronutrients, dietary fibre, and antioxidants. However, these chains are also notable for their significant waste production, generating substantial environmental impacts along the supply chain. In this scenario, adopting circular economy strategies emerges as a suitable solution to mitigate these problems. Considering the characteristics of pasta and bread products and their production process, many opportunities for applying the circular economy throughout the supply chain occur, encompassing both pre-consumption and post- consumption phases.

Academic literature has started exploring the possibilities of applying circular practices within these supply chains, primarily focusing on environmental impacts and food loss and waste assessments. Furthermore, research on the bread industry has mainly analysed the opportunity to valorise wasted bread as feedstock for biofuel production.

To the best of the authors' knowledge, comprehensive studies on circular best practices specifically tailored to the pasta and bread industries are still missing despite these developments.

Accordingly, the present research aims to fill this gap by conducting an exploratory analysis of circular economy best practices in the Italian pasta and bread industry. More specifically, by conducting an in- depth literature review and a detailed content analysis of circular economy practices adopted by Italian companies, this research aims to outline the state-of-the-art practices and assess the maturity level of these supply chains in the circular transition. Furthermore, challenges, improvement opportunities, and managerial implications will be discussed.

Keywords: circular economy; best practice; circular practice; pasta; bread.

Relevant Topic: Circular Economy and sustainability

Introduction

Pasta and bread supply chains (PBSC) play a pivotal role in global nutrition, providing nutrient-rich essential foods that represent a significant component of the human diet (Principato et al., 2019; Baiano et al., 2023). Nevertheless, despite their significant contribution to ensuring a food supply for the global population, the pasta and bread industry came across relevant challenges in terms of loss and waste generation along the whole supply chain (SC) and its related environmental impacts. These challenges weaken the efficiency of the production processes and sustainability, exacerbating global environmental problems such as natural resource depletion, climate change and pollution (Narisetty et al., 2022).

More in detail, food loss and waste (FLW) generation are widespread problems across all stages of the PBSC production process, from agricultural raw materials cultivation to processing, packaging, and distribution of the final products (Kumar et al., 2023; Faggini et al., 2023). This FLW accumulation, on the one hand, implies a loss of valuable resources and, on the other hand, imposes additional costs for management and disposal, posing risks to human health and surrounding ecosystems. Therefore, addressing this issue vigorously and adopting innovative, sustainable solutions to reduce and potentially eliminate waste volume while mitigating adverse environmental impacts associated with pasta and bread production chains is imperative (Notarnicola and Nicoletti, 2001; Formentini et al., 2021).

In this context, implementing circular economy (CE) principles arises as a promising response to address environmental challenges and promote sustainability in PBSC (Faggini et al., 2023). The CE concept is associated with the reducing, reusing, recycling and recovering materials practices (R practices) in 'production/distribution and consumption processes, thus operating at the micro-level (products, companies, consumers), meso level (eco-industrial parks) and macro-level (city, region, nation and beyond), with the aim to accomplish sustainable development' (Kirchherr et al., 2017).

Within the challenging context of pasta and bread production, several opportunities emerge to adopt CE principles across the SC, encompassing both the pre-consumption and post-consumption phases. More specifically, circular practices can be adopted from early SC stages, integrating raw material selection, transformation processes, by-product and waste management. Moreover, circular strategies can also be extended to post-consumer stages, including food waste management and packaging recycling promotion (Gomez and Martinez, 2023). Accordingly, on the one hand, CE adoption could optimise operational efficiency and reduce waste within production stages. On the other hand, it could mitigate sector-wide environmental impacts.

Considering its relevance, researchers have started exploring strategies and opportunities for adopting CE principles in the PBSC. Scholars have predominantly focused their studies on assessing the environmental impacts of PBSC(e.g., Ruini et al., 2013; Bevilacqua et al., 2017; Zingale et al., 2022).

Other researchers, more oriented towards CE, have focused their studies on food loss and waste along the PBSC, also assessing the amount of food loss and waste generated through assessment standards such as the global Food Loss and Waste Accounting and Reporting Standard (e.g., Principato et al., 2019; Formentini et al., 2021). Furthermore, other scholars have explored the opportunities to recycle waste as feedstock for sustainable ethanol and biomethane production (e.g., Immonen et al., 2020; Narisetty et al., 2022). However, despite early research endeavours, to the best of the authors' knowledge, there still remains a paucity of in-depth studies on CE best practices tailored to these industries. In order to fill this gap, the present research aims to conduct an exploratory analysis of CE best practices in the Italian pasta and bread industry.

Indeed, Italy is recognised as a global leader in pasta production, reflecting its significant contribution to the worldwide pasta industry, with 3.7 million tons of pasta produced in 2022, representing 22.3% of the world's output. Furthermore, not surprisingly, the highest *per capita* pasta consumption has been found in 2022 in Italy, with 23 kg *per* year. Accordingly, this leadership is supported by Italy's significant durum wheat production, which stands at 3.8 million tons, equal to 12% of global production (Area Studi Mediobanca, 2024).

Furthermore, in the bread sector, despite a 65% decline in consumption over the past 40 years, 84.9% of consumers purchase fresh bread from around 20,000 artisanal bakeries, which produce approximately 1.5 million tons annually (Il Sole 24 Ore, 2024). The total bread production in 2022 reached 2,533,957 tons, encompassing a variety of bread types, from white bread to unleavened and toasted bread (ISTAT, 2024). Additionally, the industrial bread market has grown substantially, with sales of over 216 tons and significant increases in sandwiches, hamburger buns, and sliced bread (Il Sole 24 Ore, 2024).

In light of this trend, the economic importance and resilience of the pasta and bread industry in the Italian agri-food sector have emerged, justifying our choice to focus this study on the Italian country.

Accordingly, through a methodological approach combining a literature review and a detailed analysis of practices adopted by Italian companies, this research aims to delineate the state of the art of circular practices and assess the maturity level of these SCs in the transition from a linear to a circular production and consumption pattern. Furthermore, the study discusses challenges, opportunities for improvement, and managerial implications arising from the analysis.

The article is structured as follows. After the introduction, the research methodology is presented in section 2. The third section provided the principal results. In detail, subsection 3.1 briefly presents and discusses the prior research on CE in the PBSC. While subsection 3.2 provides a detailed map of the circular best practices in the Italian bread and pasta industry. Section 4 briefly discusses the main findings. Lastly, the conclusion, implications, and directions for future research are provided.

Methods

A best practice "implies that it is best when compared to any alternative course of action and that it is a practice designed to achieve some deliberative end" (Bretschneider et al., 2004). Accordingly, to identify and analyse the CE best practice in the PBSC, a structured methodological approach has been followed, divided into the following steps (Figure 1):

1) Research objectives definition;
2) Literature review and research gap identification
3) Web-based research.

After identifying the research objectives, a two-fold approach was undertaken to pinpoint the optimal circular practices within the PBSC. First, a literature review was conducted to analyse the circular best practices investigated within the PBSC literature. In order to do this, a structured search in the Scopus database was carried out using the following search string (("Pasta" OR "Bread") AND "circular economy") in the title, abstract and keywords fields. The database was consulted in May 2024 and retrieved 72 articles. Only English articles exploring circular opportunities in the pasta and bread industry have been selected (i.e., 40). After an in-depth full-text screening, a final sample composed of 13 articles useful for our research objective has been identified and detailed in Table 1.

Additionally, a web-based investigation was carried out to evaluate research goals. This involved identifying influential pasta and bread companies in Italy and conducting a qualitative content analysis of their sustainability reports and corporate websites. Moreover, supplementary research was conducted to include circular practices adopted by smaller organisations committed to the circular transition.
Based on the analysis carried out, best practices showing a high potential for impacting CE in pasta and bread production were identified. This selection was guided by the following criteria: effectiveness, scalability and replicability in different contexts. with the research group to ensure the soundness and reliability of the selected practices.

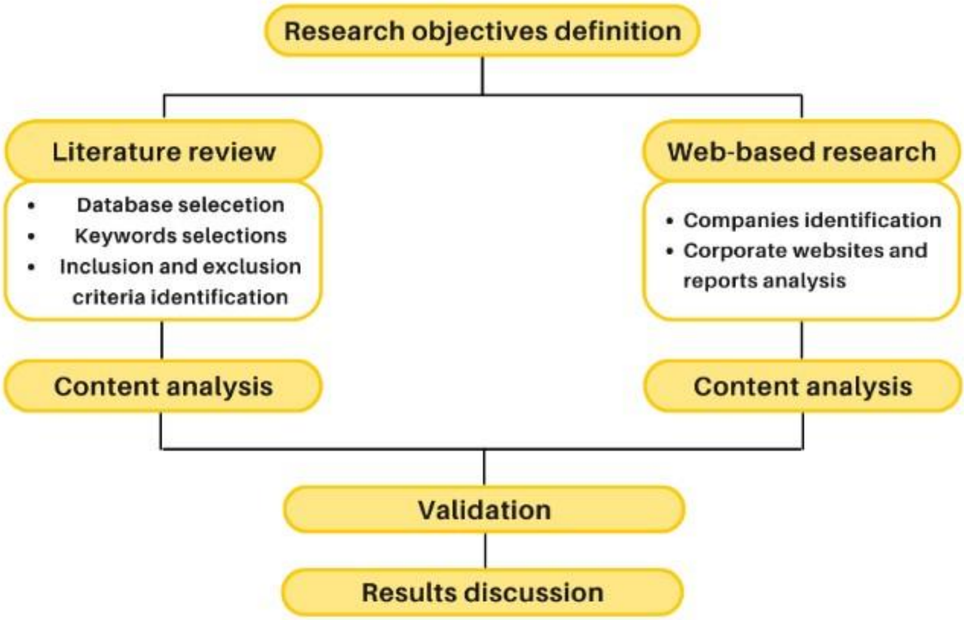


***Figure 1**. Research Methodology. Authors' personal elaboration*

Results

Prior research on circular economy in the pasta and bread supply chain

The following section systematically presents and discusses the existing literature on CE in the PBSC in order to provide a comprehensive picture of the state-of-the-art research. More in detail, prior studies have been analysed in order to extrapolate the circular solution proposed or investigated by scholars, reclassifying them into the CE dimensions of reusing, reducing, recovering and recycling.

Table 1, which summarises the main findings, shows that scholars have devoted attention mainly to the CE research applied to bread production and consumption SC and, more specifically, the opportunity to manage bread wasted (BW). Specifically, 79.9% of the articles (i.e., 10 articles) have focused on CE practices within the bread industry. Meanwhile, 15.4% (i.e., 2 articles) have addressed the pasta industry. Only one article, accounting for 7.69% of the total sample, has jointly analysed the circular opportunities within the PBSC.Most articles focused on by-product exploitation practices, such as transforming BW into biofuels, representing a resource recovery strategy. More specifically, Kumar et al. (2023) have analysed the availability of BW to serve as a feedstock for sustainable ethanol and biomethane production by biorefineries. Similarly, Narisetty et al. (2022) have conducted a Life Cycle Assessment (LCA) study to analyse the environmental costs and benefits of bioethanol production via fermentation of BW. Along the same line, Hakim Hafyan et al. (2024) investigated the role of BW- based biorefineries in promoting the circular bioeconomy concept, highlighting significant obstacles related to cost-effectiveness, efficiency, environmental sustainability, and social acceptance.

Another stream of research in the bread SC has focused on the opportunity to use BW as a functional ingredient in bread-making. More specifically, Baiano et al. (2023) have tested the partial replacement of wheat flour with brewers' spent grain. This circular practice significantly increases phenolic content and enriches bread's insoluble and soluble dietary fibres. Similarly, Iosca et al. (2023) have proposed an approach to valorise BW by cultivating lactic acid bacteria. Immonen et al. (2023), instead, have explored the potential of waste wheat bread recycling for fresh wheat bread production, showing however, as a result, a negative effect on bread quality. Other scholars have proposed the application of fermentation recycling BW into chemical building blocks (Narisetty et al., 2021).

Lastly, Formentini et al. (2021) have investigated how FLW-produced soft bread in a leading Italian bread and pasta company, Barilla, can be reused within a CE perspective for effective decision-making. More in detail, their findings provide an example of a circular management system where nothing is wasted, and resources are continuously recovered and reused. Developing an interconnected supply chain management has become crucial to establishing a comprehensive accounting framework to quantify and report the total waste generated throughout different stages of food production.

Only one paper has proposed a circular solution based on bread surplus redistribution back into the food SC as a food ingredient (Gomez and Martinez, 2023). The study underscores safety concerns and regulatory hurdles associated with using surplus bread as a food ingredient. Additionally, it highlights the potential of surplus bread flour as edible particles and its suitability for food biotechnological applications.

These initiatives are part of the recovery dimension, as they transform production waste into new marketable products, generating added value and reducing waste. At the same time, studies exploring waste reduction practices, such as production monitoring and responsible resource management, demonstrate a tangible commitment to optimising existing resources. These practices focus on minimising waste across the entire supply chain and could be valuable in transitioning to a more efficient and sustainable economy.

Only a few studies have focused on adopting CE principles in the pasta SC. More specifically, Principato et al. (2019) have quantified FLW along the pasta supply chain in the Barilla company, emphasising FLW valorisation from a CE perspective using the global Food Loss and Waste Accounting and Reporting Standard. Their study demonstrated that the pasta supply chain is a shining example of CE since waste is minimised at every step. The results suggest that food losses in the field are less than 2%. Furthermore, as an additional circular practice, they have proposed that the straw obtained during the harvest can be used as animal feed. Lastly, Faggini et al. (2023) have focused their research on using wasted pasta as animal feed and feedstock for biogas production and composting.

Only Capellini and Cini (2021) have investigated pasta and bread SC jointly from a CE perspective, investigating technological innovations and enhancement strategies to bolster the sustainability, productivity, and quality of pasta and bread goods. They have shown that LCA still represents one of the most valuable tools for developing eco-friendly improvement strategies. Furthermore, their results suggest that the adequate management of the wheat cultivation stage is essential for the environmental impacts reduction since it represents the most impacting phase for the environment.

Starting from this background, it emerges that, to the best of the authors' knowledge, no studies have focused on identifying best practices for the PBSC. Furthermore, despite their strong interconnection, only one article has jointly analysed these interrelated supply chains.

Accordingly, aiming to fill this gap, the following section will provide a comprehensive list of circular best practices that need to be integrated with practices available in the literature, starting from the assumption that an integrated approach combining different dimensions of the CE is essential to address environmental challenges and maximise the potential of sustainable practices.

Table 1. *Prior research on circular economy in the pasta and bread supply chain*

Author/s	Supply chain	Supply chain stage	Research objective	Main findings	Circular solution	CE dimension
Kumar et al., 2023	Bread	Production and distribution	To demonstrate the potential of BW as a feedstockfor sustainablebiorefineries.	The study analyses the availability of BW to serve as a feedstock for sustainable biorefineries. It provides a life cycle analysis of BW-based production compared with other feedstocks.	BW valorisation	Recycle
Narisetty et al., 2022	Bread	Biofuel production	To optimise the process of BW recycling into bioethanol and biomethane. To assess the environmental costs and benefits of bioethanol production via fermentation of BW carrying out an LCA study.	The study demonstrates the relevance of BW as feedstock for sustainable ethanol and biomethane production.	BW valorisation	Recycle
Narisetty et al., 2021	Bread	The whole supply chain	To examine the generation of BW throughout the supply chain, current methods for managing waste, and the logistical hurdles associated with waste collection.	The study suggests potential applications for fermentation recycling BW into its chemical building blocks.	BW valorisation	Recycle
Jung et al., 2022	Bread	-	To identify zero-waste strategies to valorise BW, used as a model compound of food waste.	BW was enzymatically hydrolysed to obtain a monomer sugar compound (glucose), and glucose was used as the carbon substrate in heterotrophic cultivation of Euglena gracilis. bread waste residue derived from enzymatic hydrolysis of BW was valorised into syngas.	BW valorisation	Recycle
Baiano et al., 2023	Bread	Production	To explore the use of brewers' spent grain as a functional ingredient in bread-making.	The partial replacement of wheat flour with brewers' spent grain resulted in significant increases in phenolic content, and insoluble and soluble dietary fibres of the enriched breads.	BW valorisation	Recycle

Iosca et al., 2023	Bread	Production	Bread waste and cheese whey can be valorised through cultivation of lactic acid bacteria.	The results obtained in this study suggest a novel strategy for cultivating selected starters with a bio-protection activity by valorising bread waste and cheese whey by-products, in a circular economy perspective.	BW valorisation	Recycle
Gomez and Martinez, 2023	Bread	Production and retailing	This review approaches the redistribution of surplus bread back into the food supply chain as food ingredient.	The review underscores safety concerns and regulatory hurdles associated with using surplus bread as a food ingredient. Additionally, it highlights the potential of surplus bread flour as edible particles and its suitability for food biotechnological applications.	Bread surplus redistribution	Recover
Immonen et al., 2020	Bread	Production	To explore the potential of waste wheat bread recycling for fresh wheat bread production.	Direct Recycling of bread had a negative effect on bread quality.	BW recycling as a baking ingredient	Recycle
Hakim Hafyan et al., 2024	Bread	The whole supply chain	To investigate the role of BW-based biorefineries in promoting the circular bioeconomy concept.	Implementing BW biorefinery technology encounters significant obstacles concerning cost-effectiveness, efficiency, environmental sustainability, and social acceptance.	BW valorisation	Recycle
Formentini et al., 2021	Bread	The whole supply chain	To describe how FLW produced in the soft bread production in Barilla is reused within a CE perspective for effective decision-making.	The examinations conducted within Barilla's soft wheat bread supply chain present a compelling illustration of a circular management system, wherein nearly every resource is utilised efficiently, leaving minimal waste behind. Through a meticulously integrated and systematic approach to measurement, these resources' value is preserved and recovered through reuse.	Circular management system implementation	Reduce
Cappelli and Cini, 2021	Bread Pasta	Cultivation and production	Offering technological innovations and enhancement strategies aimed at bolstering the sustainability, productivity, and quality of flours, pasta, bread, and bakery goods.	The use of life-cycle assessment analysis emerged as the best tool that can be used for the development of eco-friendly improvement strategies. The adequate management of the wheat cultivation stage is essential since it represents the most impacting phase for the environment.	-	-
Faggini et al., 2023	Pasta	The whole supply chain	To understand the potential impact of adopting a circular economy approach in addressing the sustainability challenges plaguing supply chains.	The study proposes an interpretative model for better recognising the enhancing actions that at each supply chain's stages can enhance process efficiency and output effectiveness.	Animal feed, biogas production and composting from FLW	Reuse/Remanufacturing/ Recycle
Principato et al., 2019	Pasta	The whole supply chain	To quantify FLW along the pasta supply chain in the Barilla company, emphasising FLW valorisation from a CE perspective using the global Food Loss and Waste Accounting and Reporting Standard.	The pasta supply chain stands as a shining example of circular economy principles since waste is minimised at every step. Food losses in the field is less than 2%. the straw obtained during the harvest is normally used as animal feed.	FLW valorisation	-

Mapping circular best practices in Italy's pasta and bread supply chains

In the Italian pasta and bread industry, an innovative array of CE initiatives has been found and classified in light of the four dimensions of CE: reuse, reduce, recycle, and recover. The following paragraph systematically summarises the best practices identified in both supply chains, showing how each stage is involved in implementing the identified circular solutions.

In particular, Table 2 is focused on the pasta supply chain, providing a comprehensive map of the circular best practices adopted by Italian pasta factories. The following section presents and discusses CE solutions identified according to the circular dimension uncovered.

Table 2. Best practices in the Italian pasta industry

Supply chain stage	CE practice	CE dimension	Company
Production	A new pasta format was produced with the scraps from long pasta production.	Reuse	Mancini Pastificio Agricolo
Production	Automated recovery system to lead production waste directly into the kneading machines where they become new dough ready to be formed.	Reuse	Giovanni Rana
Production ans transportation	Pallets are reused for outgoing logistics or sent to recycling companies	Reuse/Recycle	Giovanni Rana
Production	Organic waste used as animal feed (United States)	Recover	Giovanni Rana
Production	Organic waste from production is directed to the biogas production system (Italy and Belgium).	Recycle	Giovanni Rana
Production	Cultivation of Spirulina seaweed by recovering water from washing the dies used in pastification after special purification through an oxidation plant combined with reverse osmosis.	Reuse	Andriani
Production and consumption	Creation of paste straws from processing waste. Once used, they can be reused for biogas production.	Recover/Recycle	Pastificio Garofalo
Production	Leavened dough production obtained from dough processing waste	Recover	Pastificio Garofalo
Production	Production of beer with production waste	Reuse	Pasta Berruto e Biova
Production and consumption	Use of fully recyclable packaging	Recycle	Barilla/Granoro/F.lli Cellino
Production	Reduction of water consumption	Reduce	Barilla/De Cecco
Production and transportation	Use of circular flexible film	Recycle	Barilla e Ceflex
Production	Reduce waste during production by monitoring food losses and waste along value chains and identifying the causes and measures to reduce them.	Reduce	Barilla
Cultivation	Wheat co-product used as animal feed	Recycle	Barilla
Production	Cardboard production scraps used for energy recovery	Recycle	Barilla
Production and consumption	Pasta production scraps donation to a food bank	Recover	Barilla
Cultivation	Straw and grain field losses lost in the field, used as animal feed and for energy recovery	Recover/Recycle	Barilla
Distribution	Damaged and unsold pasta donated to food banks or used as animal feed	Recover	Barilla
Consumption	Dissemination of recipes for the recovery of leftover pasta	Recover	Barilla
Production	Efficient water and energy management	Reduce	Barilla/De Cecco/Garofaolo/La Molisana
Production	Use of materials from Recycling	Reduce	De Cecco
Consumption	App to recover unsold pasta	Reduce	F.lli Cellino

Recycling within the pasta industry is prominently highlighted by Barilla's initiative to use recycled plastics in their packaging. This strategic shift significantly reduces the reliance on virgin raw materials, often derived from non-renewable sources, and lowers the environmental footprint associated with packaging production. By incorporating recycled materials, Barilla contributes to closing the material loop, which is a fundamental principle of CE. This, on the one hand, facilitates a more efficient use of resources and, on the other hand, promotes a reduction in overall environmental impact.

Reduction strategies are evident in practices that minimise food losses along the value chain. Barilla, for example, employs rigorous monitoring and management techniques to identify and reduce the causes of waste. By doing so, Barilla not only improves operational efficiency but also significantly lowers the environmental impact of food production. By focusing on reduction, companies can minimise waste generation from the outset, ensuring that the maximum amount of raw materials is converted into final products.

Recovery is another vital dimension of CE, with companies like Pastificio Garofalo leading the way. Garofalo's initiative to utilise processing waste to produce pasta straws is a notable example. This approach transforms by-products that would otherwise be discarded into valuable new products, generating additional revenue streams and creating new market opportunities. This innovative use of waste materials not only reduces the amount of waste sent to landfills but also engages consumers by offering them environmentally friendly alternatives.

Furthermore, in the United States market, Giovanni Rana company has recovered value from organic waste by using it as animal feed. Lastly, Barilla manages pasta production scraps by donating them to a food bank.

Lastly, the reuse dimension is a cornerstone of CE practices. Some companies have adopted reuse strategies in order to manage pasta losses and scraps, maximising raw materials value and resources used to produce pasta. More in detail, Mancini Pastificio Agricolo reuses production waste by creating new pasta shapes from leftover dough. Giovanni Rana similarly reintegrates production scraps back into the manufacturing process. These practices not only minimise raw material waste but also ensure that the full value of resources is exploited. By doing so, these companies enhance raw material usage efficiency and bolster environmental resilience. The reuse of materials reduces the demand for new resources and decreases the environmental impact associated with their extraction and processing, embodying a crucial aspect of sustainability.

Among the investigated CE practices, the most innovative solutions have been identified as reducing solutions implemented by Andriani Pastificio Agricolo and Pasta Berruto in partnership with Biova Project, an innovative circular start-up.

In particular, Andriani Pastificio Agricolo has developed a CE project to cultivate Spirulina algae by reclaiming water from the production process, particularly from washing the dies used in pasta production. This reclaimed water is used to grow Spirulina, which is then incorporated into a special pasta product. More in detail, the cultivation of Spirulina algae, aligned with its natural seasonal cycle to minimise environmental impact, aims to market a highly nutritious product while conserving the planet's natural resources like water and air. The facility uses water sourced from Andriani's production process, particularly from cleaning the pasta dies, as a medium for growing Spirulina. This water is purified through an oxidation plant and a reverse osmosis system. Moreover, the algae's natural photosynthesis process absorbs CO_2 from the atmosphere, reducing greenhouse gases. About 2 kg of CO_2 are removed from the atmosphere for each kilogram of Spirulina algae grown.

The second innovative project involved a start-up, Biova Project, focused on reducing food waste by creating products that adhere to the principles of CE and upcycling. More specifically, in partnership with Pastificio Berruto, they have produced a beer using pasta scraps dry production surplus that is good for consumption but not aesthetically compliant. The remainder that has not been re-milled and returned to the production cycle has now been recovered by the Biova Project and transformed into a new value-added product: a blond beer. The pasta scrapes replace part of the barley malt used to make beer. This results in significant raw material savings and a reduction in food waste. Since the project's inception in 2022, Pastificio Berruto has recovered 200 kg of surplus pasta, producing 2500 litres of beer and reducing CO_2 emissions by 1365 kg.

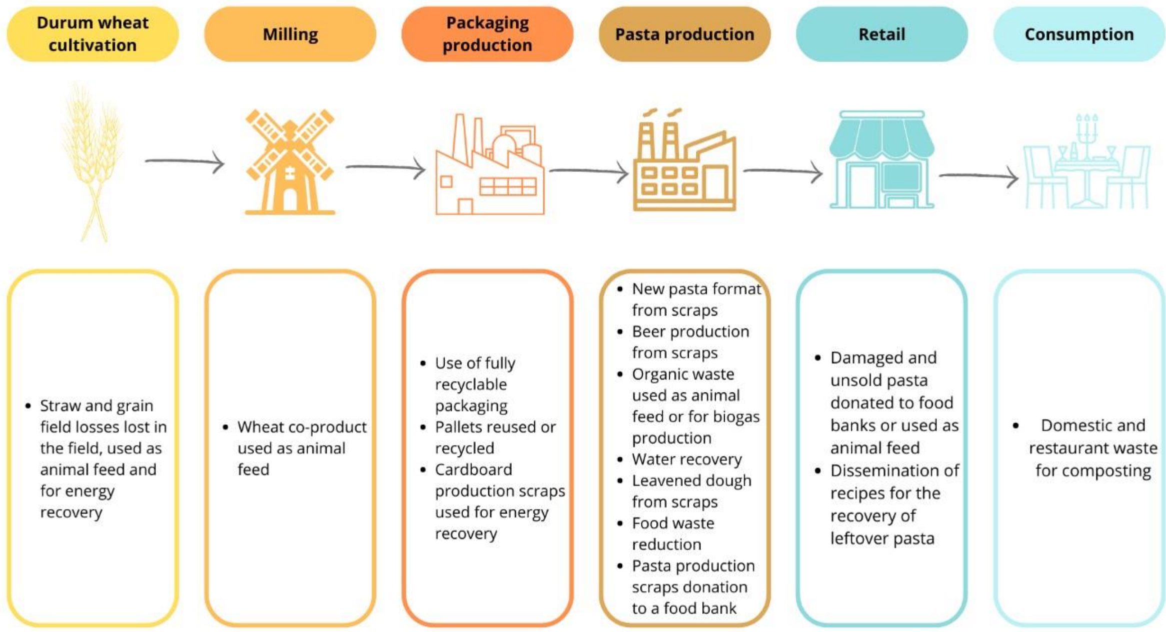


Figure 2. *Circular economy best practice in the pasta supply chain. Authors' elaboration adapted from Barilla food loss and waste report.*

Figure 2 provides a graphical representation of how each CE practice involves different stages of the pasta SC, showing the highest practices available in the production stage.

The analysis of CE practices in Italy's bread industry, as detailed in Table 3, highlights various innovative initiatives across different supply chain stages. Also in this case, the CE practices have been reclassified according to the 4-R CE dimensions.

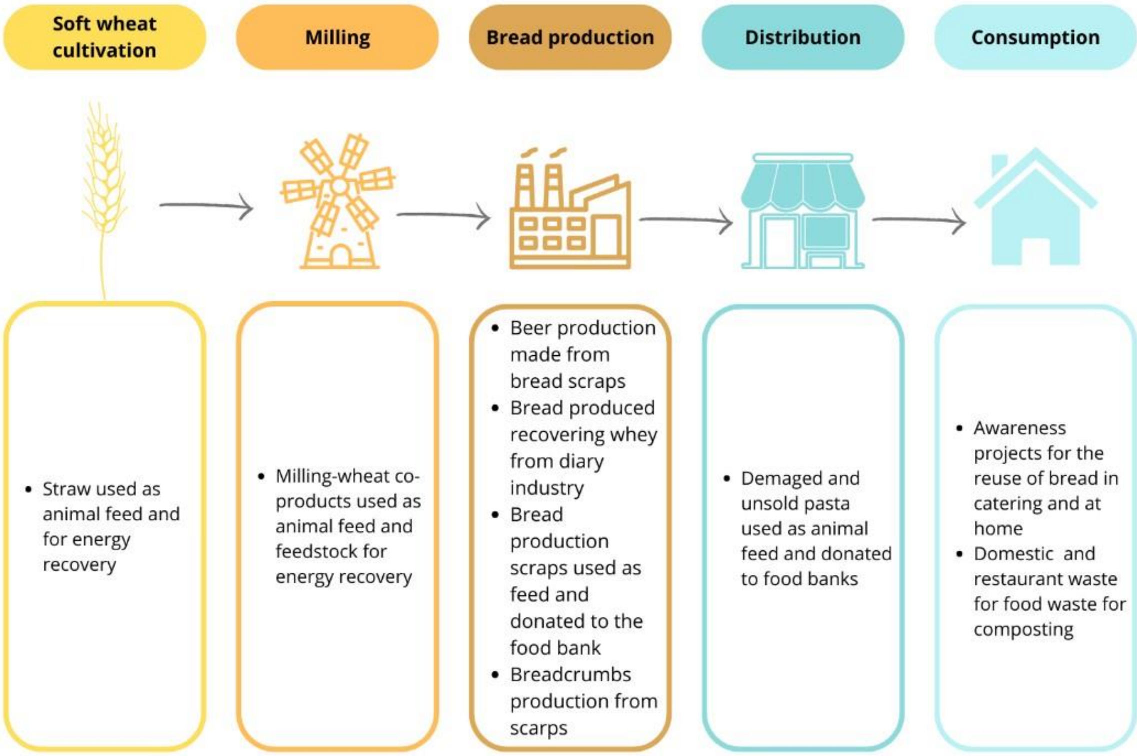
Table 3. *Best practices in the Italian bread industry*

Supply chain stage	CE practice	CE dimension	Company
Production	Beer production made from bread scraps	Reuse	Gianpietro Pizzo - Biova
Production	Production of protein bread, thanks to the addition of proteins and beneficial molecules derived from the whey of the dairy industry.	Recover	Progetto Provide
Production and consumption	Awareness projects for the reuse of bread in catering and at home with the publication of the book "Il pane è oro"	Reuse	Food for Soul
Production and consumption	Production of breadcrumbs from production scraps	Reuse	Gianpietro Pizzo
Cultivation and production	Milling-wheat co-products used as animal feed and feedstock for energy recovery	Recycle/Recover	Barilla
Production	Bread production scraps used as feed and donated to the food bank	Recycle	Barilla
Cultivation	Straw lost in the field used as feed and for energy recovery	Recycle	Barilla
Consumption and distribution	App to recover unsold and wasted bread from retailers and consumers	Recover	Breading App

Contrary to our expectations and the literature review findings, which indicated greater scholarly attention to CE solutions in the bread industry compared to the pasta industry, the Italian bread supply chain has demonstrated fewer circular solutions.

At the production stage, Gianpietro Pizzo, also in partnership with Biova Project, leads with an initiative to produce beer from bread scraps, aligning with the reusing dimension. This practice not only diverts bread waste from landfills but also creates a new value-added product. Similarly, Progetto Provide's production of protein bread incorporates proteins and beneficial molecules derived from whey, a by- product of the dairy industry. This approach exemplifies recovery by using another industry's by- products to enhance the nutritional value of bread. This cross-sectoral synergy exemplifies resource efficiency and innovation in food production.

Figure 3. *Circular economy best practice in the bread supply chain*



Source: Authors' elaboration adapted from Barilla food loss and waste report

In the production and consumption stages, Food for Soul, a cultural project founded by Chef Massimo Bottura and Lara Gilmore to shine light on the invisible potential of people, places and food, promotes reuse through awareness projects that encourage the reuse of bread in catering and at home, as highlighted in the publication "Il pane è oro." This initiative aims to reduce bread waste by educating consumers and food service providers on sustainable practices.

Additionally, Gianpietro Pizzo's production of breadcrumbs from bread scraps represents another practical reuse strategy, converting production waste into a valuable food product and thus maximising resource use.

Multiple stages and dimensions have been involved in Barillas' CE initiatives. The company recycles and recovers milling-wheat co-products for animal feed and energy recovery in the cultivation and production stages. This dual approach reduces waste and supports sustainable energy solutions. In the production stage, Barilla donates bread production scraps to food banks and uses these scraps as animal feed, emphasising the recycling dimension. These practices minimise waste and support community welfare and animal nutrition. Furthermore, Barilla's use of straw lost in the field as feed and for energy recovery in the cultivation stage further illustrates the effective recycling of agricultural residues.

Lastly, at the consumption and distribution stage, an innovative app, the Breading App, has addressed the recovery of unsold and wasted bread from retailers and consumers. This digital solution facilitates the redistribution of surplus bread, reducing food waste and promoting a circular consumption model.

Discussions

The analysis of the results concerning implementing CE practices in the Italian pasta and bread industries highlights significant strides towards sustainability, accompanied by substantial challenges and areas requiring improvement. Italy, renowned for its culinary traditions and gastronomic culture, faces unique circumstances and pressures in these sectors, necessitating meticulous consideration to address sustainability issues effectively.

A crucial aspect is the socio-economic context in which these industries operate. The pasta and bread sectors in Italy are deeply intertwined with the nation's cultural heritage and identity, with centuries-old traditions shaping production methods and consumer preferences. This cultural affinity with specific culinary practices can both impede and facilitate the adoption of CE principles. Despite a growing awareness of environmental issues and a willingness to embrace sustainable practices, resistance to change may emerge, particularly if it involves altering entrenched traditions or perceived notions of quality and authenticity.

Moreover, the structural dynamics of the Italian food industry pose specific challenges to the implementation of CE initiatives. The predominance of small and medium-sized enterprises (SMEs) in these sectors can create logistical and financial obstacles to adopting large-scale sustainability measures. Unlike larger corporations with greater resources and innovation capabilities, SMEs may struggle to invest in advanced technologies or reconfigure processes to minimise waste and optimise resource efficiency. Additionally, dependence on traditional supply chains and distribution networks may limit the flexibility and adaptability needed for successful CE practices.

Beyond these sector-specific challenges, Italy faces broader systemic issues impacting sustainability efforts. Regulatory frameworks and governmental policies significantly influence incentives and create an environment conducive to CE practices. While initiatives have been launched at both the national and EU levels to promote sustainability and circularity, the effectiveness of these policies in driving substantial changes within the pasta and bread industries has yet to be fully verified. Furthermore, issues such as food waste, a prominent concern in Italy and many other nations, require comprehensive strategies that extend beyond individual company initiatives to address systemic inefficiencies along the entire value chain. It is noteworthy that companies operating in Italy must delineate solutions for managing food surplus in accordance with Law n. 166 – the "Legge Gadda" on "Provisions concerning the donation and distribution of food and pharmaceutical products for social solidarity and waste reduction." Additionally, surplus pasta and waste valorisation practices must align with the EU Food Donation Guidelines as part of the Circular Economy Action Plan, facilitating the recovery and redistribution of safe, edible food to those in need.

Despite these challenges, there are encouraging signs of progress and innovation within Italy's pasta and bread industries. Companies embracing CE principles demonstrate the feasibility and advantages of transitioning towards more sustainable production and consumption models. However, realising the full potential of CE practices in these sectors necessitates concerted efforts from all stakeholders— including businesses, government agencies, consumers, and civil society organisations—to surmount barriers, foster collaboration, and drive systemic change.

As these practices evolve, they can significantly contribute to global efforts for a more sustainable future. The initiatives spearheaded by these companies underscore the importance of innovative thinking and proactive measures in tackling environmental challenges and ensuring the enduring sustainability of food production systems.

Conclusions

This present research has explored CE practices in Italy's PBSC, providing an in-depth analysis of current initiatives and assessing the maturity level of these industries in transitioning from a linear to a circular production and consumption model. The findings have highlighted several CE practices across various stages of the pasta and bread supply chains, suggesting innovative approaches that minimise waste, and add value to by-products, creating also new market opportunities.

Starting from our preliminary results, practical, managerial and theoretical implications could be drawn. Firstly, from a managerial perspective, this study underscores the importance of adopting CE principles to enhance sustainability and operational efficiency. Companies in the pasta and bread industry not already engaged in the circular transition can learn from the innovative practices highlighted in this research to reduce waste, optimise resource use, and create new value streams. Managers should consider integrating such practices into their operations to not only comply with environmental regulations but also to gain competitive advantages by appealing to eco-conscious consumers and reducing raw material costs. Moreover, the success of awareness projects and digital solutions suggests that companies can also benefit from engaging consumers in sustainability initiatives, fostering brand loyalty and community support.

Theoretically, this study contributes to the growing body of literature on the CE by providing empirical evidence of its application in the pasta and bread sector. It highlights the practical implementation of CE principles, offering a framework that can be used to study similar initiatives in other industries or regions. Furthermore, the research underscores the importance of cross-sectoral synergy, as demonstrated by the collaboration between the dairy and bread industries to produce a new empowered product. This points to the potential for broader systemic changes where by-products of one industry serve as valuable inputs for another, thus promoting a holistic approach to sustainability. The study also suggests the need for further theoretical exploration into the barriers and drivers of CE adoption, particularly in traditional industries that are typically resistant to change.

Lastly, our research could provide also implications for policymakers, providing useful insights into the types of regulations and incentives that can support the transition to a CE. Policies that encourage or mandate the recycling and recovery of waste, such as tax incentives for companies that implement CE practices or subsidies for research and development in this area, could accelerate the adoption of sustainable practices. Additionally, creating a regulatory framework that facilitates cross-industry collaboration can enhance resource efficiency and innovation. Policymakers should also consider enhancing public awareness campaigns to educate consumers about the benefits of a CE and encourage more sustainable pasta and bread consumption patterns. By supporting both businesses and consumers in these efforts, policymakers can help create an environment where CE practices are feasible and economically advantageous.

However, this study is not without limitations. The analysis primarily focuses on documented case studies from prominent companies, which may not fully represent the practices of smaller or less visible firms. Furthermore, the data is predominantly qualitative, relying on publicly available information and self-reported practices, which may introduce biases or inaccuracies. Another limitation is the geographical focus on Italy, which, while providing a detailed national perspective, may not capture the full diversity of CE practices globally. Additionally, the methodology used to identify best practices was based on secondary data sources and may not encompass all relevant initiatives. This approach could miss out on innovative practices that are not widely reported or are still in the nascent stages of development.

Future research should address these limitations by incorporating a broader range of companies, including SMEs, to provide a more representative overview of CE practices across the industry. Quantitative analyses could offer more precise measurements of these practices' environmental and economic impacts. Additionally, comparative studies involving multiple countries would enhance understanding of how different regulatory, cultural, and economic contexts influence the adoption and effectiveness of CE practices.

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Understanding the role of central public administration in transitioning towards a sustainable circular bioeconomy: an integrative review

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Abstract.

Circular bioeconomy is an intersection which merges circular economy and bioeconomy concepts; it is emerging as a concept which can propel the transition towards a sustainable and circular use of bio resources. Countries and various transnational bodies are now adopting circular bioeconomy policies and strategies to promote this transition. In this context, public administration should play a key role through implementation, management, monitoring and evaluation of these policies and strategies. However, although there is a growing academic literature in circular bioeconomy policies and strategies, there is still lack of research in understanding the general roles of central public administration in pushing and guiding this transition. In this context, this paper aims to shed light on the general role played by central public administrations by applying an integrative literature review method. Scoping literature review was used to conceptualize and characterise existing circular bioeconomy policies and strategies. Bibliometric literature analysis was used to visualize the networking of the key clusters in circular bioeconomy. Scopus and Web of science were used to identify relevant publications, then screened by using inclusion and exclusion criteria to select the most appropriate to be included in the final sample. This paper may contribute to a deeper understanding of the general role of central public administration, in accelerating the change towards a sustainable circular bioeconomy at the national and transnational level and provide a foundation for future research directions.

Keywords: circular bioeconomy, central public administration, policies, strategies, sustainability

Introduction

In the 21st century, the world is experiencing several environmental challenges which includes climate change effect, loss of biodiversity, environmental pollution, and overexploitation of natural resources due to the increasing world population (Arora et al., 2018). The Circular Bioeconomy (CBe) concept has been proposed by scholars as one of the solutions in addressing these environmental crises since it incorporates the principles of circular economy and bioeconomy while considering the sustainability aspects (D'amato and Korhonen, 2021). The concept is an intersection and a merge, between circular economy and bioeconomy. Although there are many comprehensive definitions of circular bioeconomy, there is not a common agreed definition of the terminology. However, for this article CBe definition has been adopted from the European Union bioeconomy strategy, which is the leading and progressive strategy and states that "circular bioeconomy deals with all sectors that produces, use, process, distribute or consume biological resources and includes the ecosystem services" (Patermann and Aguilar, 2018).

In addition, the updated EU bioeconomy strategy requires CBe strategies and policies to have an element of sustainability and circularity at its heart (Kardung et al., 2021). Relevant policies and strategies would help countries to transition to a sustainable CBe (Hilgartner, 2007). Indeed, several countries and transnational bodies are adopting sustainable CBe policies and strategies to provide guidance, accountability, clarity of governance and to increase efficiency in this transition. However, countries and transnational bodies have different approaches towards a CBe (Bößner et al., 2020) and this influences on how policy measures and strategies are applied in CBe sectors. For instance, CBe policies and strategies can be mapped into four main topologies, which are: bioenergy; agriculture based bioresources, biotechnology, biowaste streams (Dietz et al., 2018). It is the role of governments through public administration to involve citizens through public awareness, strategies and action plans, legislation and standard setting (Hinderer et al., 2021).

Implementing CBe policies and strategies needs understanding the key governance structure, characterisation of policy frameworks and strategies for an effective implementation (Dietz et al, 2018). Indeed, according to the Global Bioeconomy Policy Report (IV) (2020), a CBe policy strategy should contain the following key elements: "long-term consequences, a consequential relationship to its mission or purpose, a well-defined subject of action, and concerns actual choices and priorities". Following this perspective, identifying these elements in established CBe policies and strategies and understanding the literature of national and transnational CBe policies and strategies, will allow the characterisation and mapping of CBe strategies, and consequently improve the understanding of the key roles of the central public administration.

The aim of this study is therefore to understand the role of central public administration in accelerating the transition towards a sustainable CBe. Therefore, the research question for the study is: What is the role of central public administration in transitioning towards a sustainable circular bioeconomy policies and strategies at national and transnational level?

Research Methods

In this paper, an integrative research method has been adopted. An integrative research method used to analyse and blends the existing knowledge of a topic, from different perspectives (Cronin and George, 2023). This method is particularly effective in addressing complex, multifaceted issues which can't be easily understood by use of a single approach. Integrative perspective in the study can be used to provide a holistic view of the role of central public administration in implementing and monitoring CBe policies and strategies. We adopted this research method for this study since it offers a comprehensive and flexible approach to explore and address the research question.

Scoping literature review was conducted to map out and identify CBe strategies and policies on the academic literature. Then a bibliometric analysis was used to characterise, cluster, and map the evolution of the literature. Finally, pivotal table analysis used to extract data then analysed to understand the relationship between different variables. For example, the number of articles published, countries cited, and policy perspectives of the countries helped to shed light on emerging trends and evolution of CBe policies and strategies.

Scoping review

Scoping literature review was used to identify and map the broad academic literature in circular bioeconomy policies and strategies. Scoping review can be used in a study when the literature is broad and heterogeneous in nature (Peters et al., 2015), and since the academic literature for national and transnational CBe policies and strategies is broad and heterogeneous it was the best method in mapping out the literature. The method was applied to identify the academic literature with national or transnational CBe policies and strategies from the Web of Science and Scopus databases. The aim was to identify academic literature for further characterisation and analysis in understanding the role of public administration in transitioning towards a sustainable CBe.

Bibliometric analysis

Vosviewer tool was used in bibliometric analysis on the sampled data. Bibliometric analysis can be used to visualise the literature in terms of the emerging trends, characterisation of the literature, journal performance in the topic, and geographical mapping of the literature (Donthu et al., 2021). For this study, the aim was to analyse the emerging literature trends of national and transnational CBe policies and strategies using the key author's words, to characterise the clusters of the academic literature and to map the key countries cited in the academic literature.

The analysis of the author's key words, and their pattern was applied to shed light on how the topic has been evolving (Lu et al., 2020). Furthermore, the key authors' key words were used to cluster CBE policies and strategies academic literature perspectives. This was to aid in understanding the characteristics of CBe policies and strategies. Mapping of the cited countries in the academic literature was carried out to establish a relationship between the authors' country and the CBe policies and strategies. This was to understand further on the academic literature discourse perspectives, highlight the gaps in the literature and the geographical distribution. In understanding the discourse perspectives and geographical distribution of CBe academic literature, this helped to shed light on policy governance and understand the role of central public administration in implementing and monitoring the policies and strategies.

Pivot table analysis

Further analysis of data was done using a pivot table analysis tool which is used in organising, summarising and exploring data within academic publications to understand the relationship between various data variables. The tool is so flexible to use and can be used to summarise large quantities of data. The analysis was aimed at understanding the trend of articles published, and the authors interested in the topic. This was to aid the understanding of the evolution and patterns of CBe policies and strategies academic literature. The purpose of understanding the evolution and patterns of the academic literature was to expound the role of central public administration in promoting the transition to sustainable CBe.

Data collection

This study was limited to academic literature on CBe policies and strategies, so grey literature such as policy documents, reports, books, workshop papers and other relevant literature were not included. In addition, Web of science and Scopus data bases were used as the source of data. The two databases were selected because of being comprehensive and lead in article citation and journals coverage.

Prisma protocol was developed for data collection. When searching, a filter to include only English language documents was applied. Also, the search was filtered to include only articles and article reviews. The eligibility criteria used was that all articles and article reviews were eligible but with a limitation to English language to broaden the search within the language of analysis. The exclusion criteria applied was to exclude all articles which do not have an element of national or transnational CBe policies and strategies.

The search was carried out on 12th of April 2024, after several attempts of different search queries words. First the search was done by including all articles under topic of CBe broadly to include all relevant articles. Then to limit to specific search, the search query used the plural and singular of the words (Policy/strategy/plans/program) with limit to Key words or Titles. The following search query was used: *"Bioeconomy" OR "Bio-economy" OR "Bio economy") AND TITLE ("Circular Economy" OR " Circular*") AND TITLE ("Policy" OR "Policies" OR "Strategy" OR "strategies" OR "Plan" OR "Plans") OR ("Program " OR "Programme" OR "Programs " OR "Programmes))".*

The number of eligible articles found from Web of Science data base n=157, from Scopus database n=247 making a total of n=404. To clean the data, the number of duplicate articles deleted n=143. Total number of eligible articles which remained n=246. The exclusion strategy protocol used was to screen and exclude all articles which do not present an element of national or transnational circular bioeconomy policy or strategy after reading the abstracts of the articles. However, after screening only a sample of n=14 articles were found. The sample size was inadequate to analyse and for further characterisation. Therefore, there was a need to broaden the search limit to include all relevant literature from both databases.

A second search query was developed to ensure comprehensiveness, increase relevance, improve the sample size for a more precise analysis. In the second search, data was extracted from both Scopus and Web of Science databases on 19th of May 2024. The second search query was applied under Titles to broaden the search, with a filter limit to English language, articles and article review. Singular and plural of the search query words were applied to get precise results. The following search query was applied to both databases: *"Bioeconomy" OR "Bio-economy" OR "Bio economy" AND "Circular Economy" OR " Circular*" AND "Policy" OR "Policies" OR "Strategy" OR "strategies" OR "Plan" OR "Plans" OR "Program " OR "Programme" OR "Programs " OR "Programmes"*.

Articles found in Scopus database n= 736 and from the Web of science n=731, to a total number of n=1467 articles with a limitation to only English language. The sample of the literature was arrived at by screening the n=840 articles which were obtained after eliminating 627 duplicates. The total sample of literature found was n=40 articles after applying the exclusion strategy protocol. The exclusion strategy protocol used was to exclude all articles which do not present an element of national or transnational circular bioeconomy policy or strategy after reading the abstracts of the articles. This strategy aimed at including articles which present an element of national or transnational CBe policies and strategies. The analysis was done as shown in Figure 1 with a Prisma flow diagram.

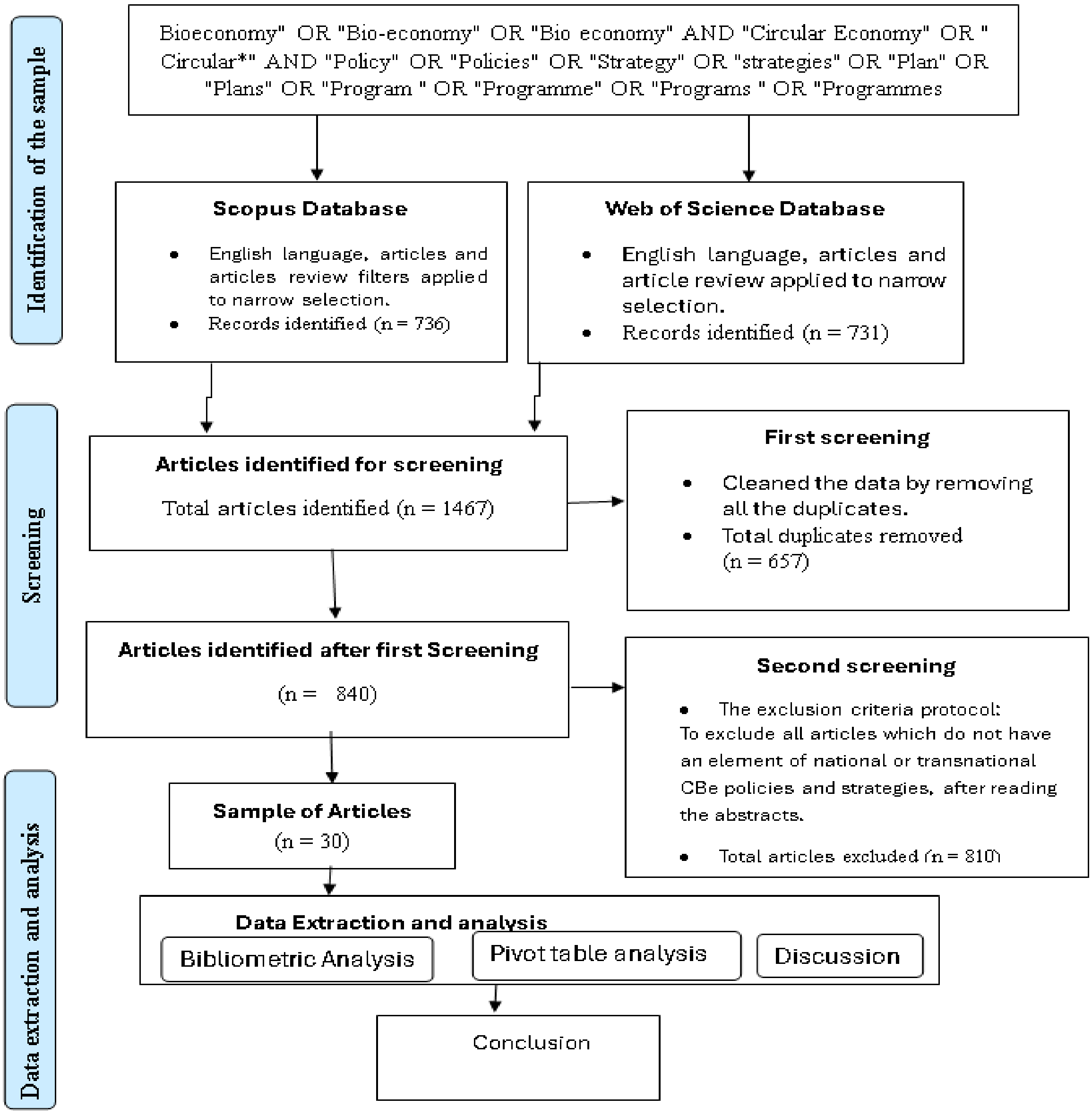

Figure 1. *Prisma Flow Diagram*

Results analysis and discussion

A bibliometric analysis of the author's key words was carried out to examine the frequency, distribution and patterns of the key words as used in CBe policies and strategies academic literature. The purpose of analysis was to get an insight of the research trends, the emerging characteristics of CBe policies and strategies, and the policy perspectives. The motivation in the analysis was to understand the academic literature evolution of the CBe policies and strategies in relation to the role of central public administration which is at the centre of policy implementation. Furthermore, the characterisation of the literature would shed light on the policy perspectives.

Figure 2 shows the occurrence of the author's key words as presented by VOS viewer tool. Some of the key words which were identified includes, governance, policy priorities, transition barriers, indicators, circular bioeconomy, bioeconomy, circular economy, blue bioeconomy, sustainability and innovations. Emerging and frequently used words such as circular economy and bioeconomy shows an increasing interconnection link between the concept of circular economy and bioeconomy in the academic literature. It can be noted that sustainability and circularity is at the heart of EU bioeconomy strategy (2018). While some of the emerging key words includes, animal feeds, bioenergy, policy priorities, innovations, bioeconomy guidelines, and social impact.

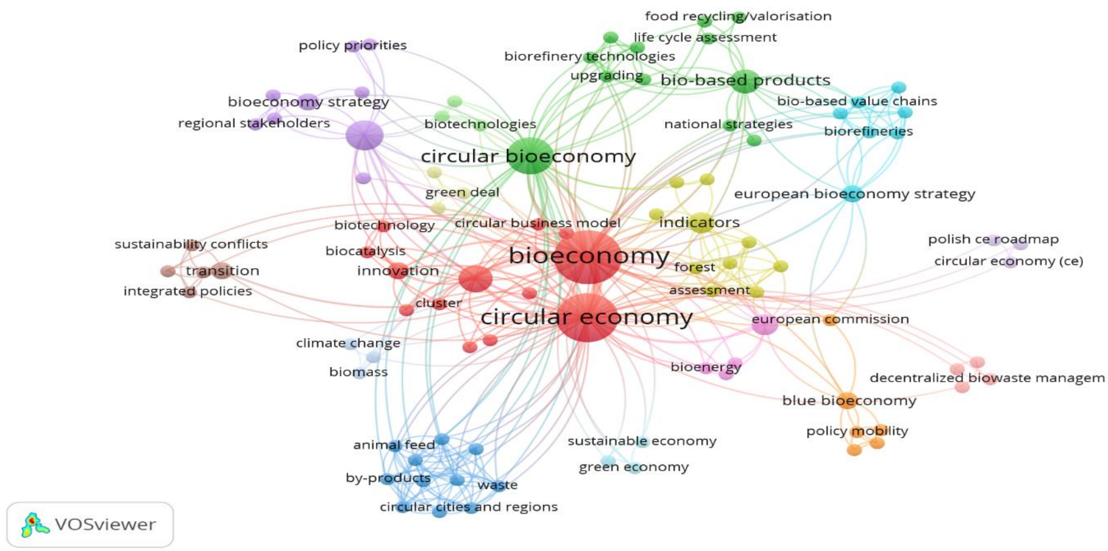

***Figure 2**. co-occurrence of the author's keywords. Adapted from Vos viewer.*

Patently, public administration does not appear among the author's key words. This would elude that the literature does not explicitly present the key roles of central public administration in the transition to a sustainable CBe. When assessing the transnational bodies responsible for the implementation of CBe policies, only the EU Commission is appearing among the key words. 22 of the articles sampled were indeed directly analysing EU region or one of the countries within Europe in CBe policies. This explains on why, the literature is European centred in terms of literature and policy perspectives where EU Commission has been pushing for adoption and implementation of national CBe policies and strategies. The European Commission is indeed leading in promoting, linking the key stakeholders, reviewing and supporting the implementation of the EU bioeconomy strategy (Bell et al., 2018). Therefore, many EU countries have adopted their national CBe policies and strategies from the EU bioeconomy strategy (2018).

The key words were also used in mapping the characterisation of the literature in CBe policies and strategies into different clusters. Grounding on the key words mapping, the academic literature on circular bioeconomy policies can be clustered as: circular bioeconomy, bio-based products, sustainability and sustainable development, assessment and indicators, EU bioeconomy strategy, and blue-bioeconomy. The characterisation identified is linked to the key sectors which CBe policies and strategies aim to address, and it shows an increasing number of clusters on CBe policies and strategies.

Blue bioeconomy cluster is one of the CBe policy cluster emerging with a policy perspective aiming at utilising marine and water resources such as fisheries, aquaculture, algae cultivation, blue biotechnology sector (de Grunt et al., 2021). For example, Finland and Norway are some of the countries where blue bioeconomy has emerged and is developing gradually despite technological and ecological challenges (Albrecht et al., 2020). The literature highlights that CBe policies and strategies can help countries to achieve sustainable development goals, however the transition needs to have a combined approach to promote coherent policy formulation and synergises (Gottinger et al., 2020).

From the analysis of the literature emerges that the role of public administration is not clearly presented in the articles, and this highlights an academic literature gap for further studies to better understand the key roles plays by public administration. Indeed, some scholars highlight the key roles of major stakeholders in the implementation of CBe. For example, governments through public authorities and institutions should facilitate the implementation of CBe policies and strategies through cooperation between public authorities and private sector, allocation of research and investment funds, promoting innovations through funding, coordination, monitoring and evaluation the policies (Konstantinis et al., 2018).
The analysis also mapping the countries cited in the academic literature, understanding the relationship between authors' geographical background and the cited countries and the academic literature evolution and geographical distribution. Cited countries can provide an insight into the study by identifying leading countries in the research topic and understanding the research collaborations and network by observing the patterns of network (Ferreira et al., 2022). In addition, the analysis can provide an overview of the hot spot countries in relation to CBe policies and strategies.

Table 1 shows a data extracted from the sampled articles on the countries cited, the number of articles cited, presence of CBe policy or strategy and a synthesis the policy perspectives. The table was constructed by extracting data by VOS viewer tool, and the articles sampled. From the result, EU countries such as Spain, Netherlands, Belgium, Italy and the United Kingdom (UK) are highly cited because of the increasing literature in CBe policies and strategies within the region which would be further linked to the increasing policy adoption within the region (Gould et al., 2023). In addition, EU has three policy frameworks and strategy priorities which are aimed in accelerating the transition. For instance, the EU Green Deal framework stresses the importance of bioeconomy as a key pillar of sustainable development (Fritsche et al., 2020), the updated Bioeconomy Strategy (2018) which provides a comprehensive framework for CBe policies (Barrett et al., 2021), and the Circular Economy Action Plan which focuses on efficient resource utilisation and sustainable production and consumption (D'amato and Korhonen, 2021).

Many EU countries have either developed national CBe policies and strategies for example the UK, Spain, Italy, Finland and among others, or they are in progress to developing a national CBe policy. In addition, EU has increased more funding research and innovations in CBe related sectors resulting to increased interests to the topic (Brandão et al., 2024) and thus more academic literature from the region.

The global south has a smaller number of countries cited from the articles analysed, which would be attributed to the low literature in CBe policies and strategies from the global south especially from the sub-Saharan region has no cited country. The literature highlights that CBe is not incorporated in the regulatory, institutional and policy frameworks of many African countries (Ncube et al., 2022). In addition, the CBe related policies are mainly founded on weak governance structures and with negative attitude towards target groups as explained in the article by Ncube (2022). Lack of enabling policy environment, low funding to research and innovations in CBe policies and strategies in the global south would be the contributing factors to less literature. However, further research would elude the challenges the literature in the global south on CBe policies and strategies.

***Table 1**. Circular bioeconomy (CBe) policy presence and policy perspective per Country in the sampled articles. Data extracted from the VOSviewer tool.*

Country	Number of Articles	Total citation frequency	CBe policy	Policy Perspective
Spain	7	336	Yes	Biotechnology, agriculture and forestry
United Kingdom	6	326	Yes	Comprehensive bioeconomy policy
Netherlands	5	631	Yes	Bio based with circular economy Principles
Poland	4	120	No	CBe policy is embedded in other relevant policies
Germany	4	246	Yes	Bioenergy, biofuel, and biological resources
Finland	4	244	Yes	Biobased, forestry, agriculture and Bio-blue economy
Belgium	4	281	No	Regional cross policies in bioeconomy
Portugal	3	118	No	CBe policy development in progress, with a blue bioeconomy road map
Italy	3	36	Yes	Agriculture, biobased and marine
Denmark	3	155	Yes	Agriculture, food production, biofuels
Switzerland	2	94	No	CBe framed within other policies
Slovakia	2	33	No	CBe policy development in progress
France	2	118	Yes	Comprehensive strategy with focus in agriculture, forestry and blue-bioeconomy
Czech Republic	2	153	No	However, bioeconomy is embedded in other relevant policies
Ukraine	1	2	No	CBe policy development in progress
Mexico	1	1	Yes	Agriculture based bioeconomy
Lithuania	1	4	No	CBe policy development in progress
Ireland	1	77	Yes	Forestry, agriculture and marine
Iceland	1	77	No	Fragmented in the existing policies
Hungary	1	2	Yes	Agriculture, forestry and renewable energy
Colombia	1	1	Yes	Agriculture, biotechnology, and food
Canada	1	77	yes	Forestry and agriculture biomass, bioenergy
Brazil	1	41	Yes	Bioenergy and biofuels
Austria	1	52	Yes	Comprehensive bioeconomy strategy, focus on biofuels, renewable biological resources
Australia	1	41	Yes	Bio-energy, forestry and blue-bioeconomy

In the analysis as shown in table 1, there are some common highlights and differences identified. For example, Italy, Ireland, Colombia, Denmark and some other countries have CBe policy interests in agriculture and bio-based perspectives. Poland, Czech Republic, and Iceland have fragmented policies in CBe which are embedded in other relevant policies, while UK and Australia have a comprehensive CBe policies with different perspectives. There are differences emerging in CBe policy and strategy framing according to the literature whereby some countries have CBe embedded in other policy frameworks while other countries have a specific policy framework for CBe. In addition, while some countries have established a comprehensive policy framework such as in UK, Australia, and France. Other countries such Canada, Finland Hungary and among others have established policies with special interests in bioeconomic sectors.

From the study, it can be noted that countries have different policy perspectives in CBe policies, with only few countries such as UK with a comprehensive CBe policy covering in all policy aspects of bioeconomy. Many countries have developed CBe policies and strategies with special focus on agricultural bioeconomy resources, forestry, biofuels, bioenergy and food sectors. Few countries have policies with special focus on blue bioeconomy, and animal feeds.

Nevertheless, there is need to do further studies to understand why the global south has less academic literature. One of the possible reasons would be lack of harmonisation of terms used in CBe policies and strategies, for instance the term biotechnology has been used in South Africa to refer to circular bioeconomy innovations and technologies in supporting the transition to a sustainable bioeconomy (Bambo and Pouris, 2020).

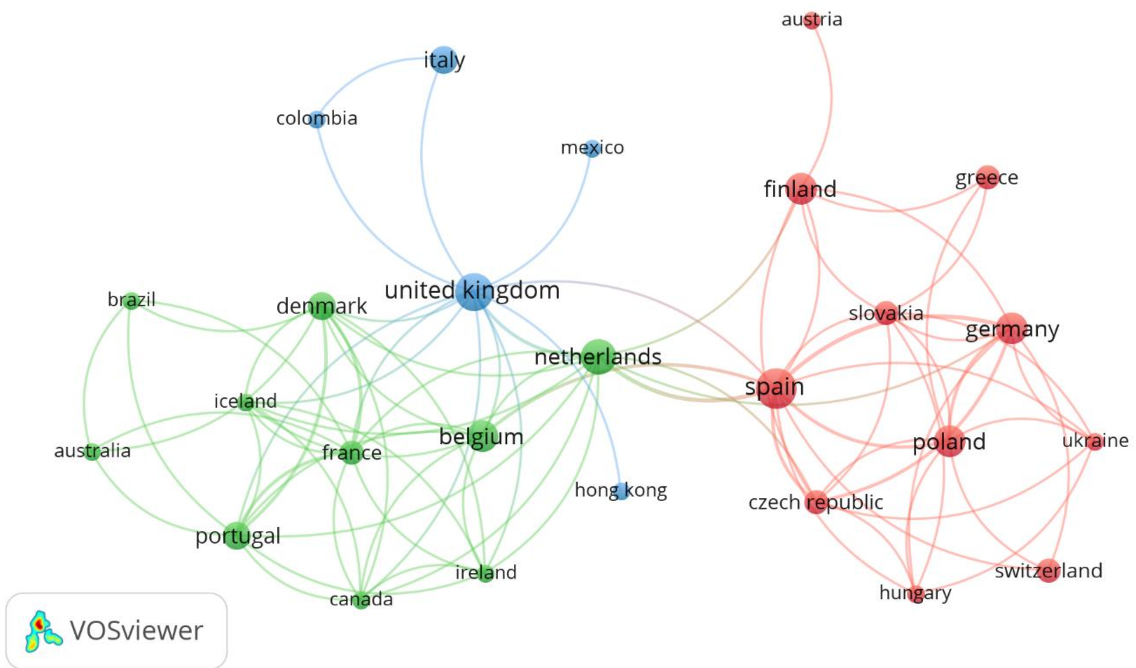

Figure 3. *Co-authorship country network visualisation. Adapted from Vosviewer*

Even within EU region, there is a disparity of academic literature and policy perspectives in CBe policies and strategies. Countries with CBe policies are likely to be highly cited in academic literature and especially if they have a comprehensive policy. The difference and similarity of policy perspectives is likely to create coauthor network of the scholars interested in the field. For example, we have 3 clusters of coauthor research network, the first one focuses on biotechnology, bioenergy and biofuels CBe policies with authors coming from Brazil, Netherlands, Irland among other countries. Second one focuses on forestry and biobased products CBe policies and strategies, mainly coming from Spain, Finland, Germany, Switzerland. And the third one focused on agricultural and biobased CBe policy perspectives coming from Italy, Mexico, UK, Colombia countries. It can also be noted that some countries like UK have comprehensive CBe policy interests therefore attracting different networking in research.

The analysis of the number of articles in CBe policies and strategies in the academic literature was to aid in understanding the evolution and development of academic literature. This was aimed at understanding the influencing factors and barriers to development of the academic literature in the field. Academic literature growth in CBe policies and strategies would be influenced by several factors such as presence of regulation and policy frameworks (Gottinger et al., 2020), emerging of new policy perspectives, research funding, technology, knowledge and networking (Dietz et al., 2023).

From the analysis, CBe policies and strategies literature has been increasing gradually since 2018 except in 2021 and 2022 where there was a decline which would be attributed to covid 19 impact as shown in figure 4. In year 2020, we had the highest number of articles published. However, it is very clear that the number of articles CBe policies and strategies is increasing gradually. Coincidentally, the number of authors per year, who are interested in the topic were few as shown in figure 5. Although CBe policies and strategies is a new but growing field (Gould et al., 2023), there is a need to do further research to understand on why the literature is growing gradually.

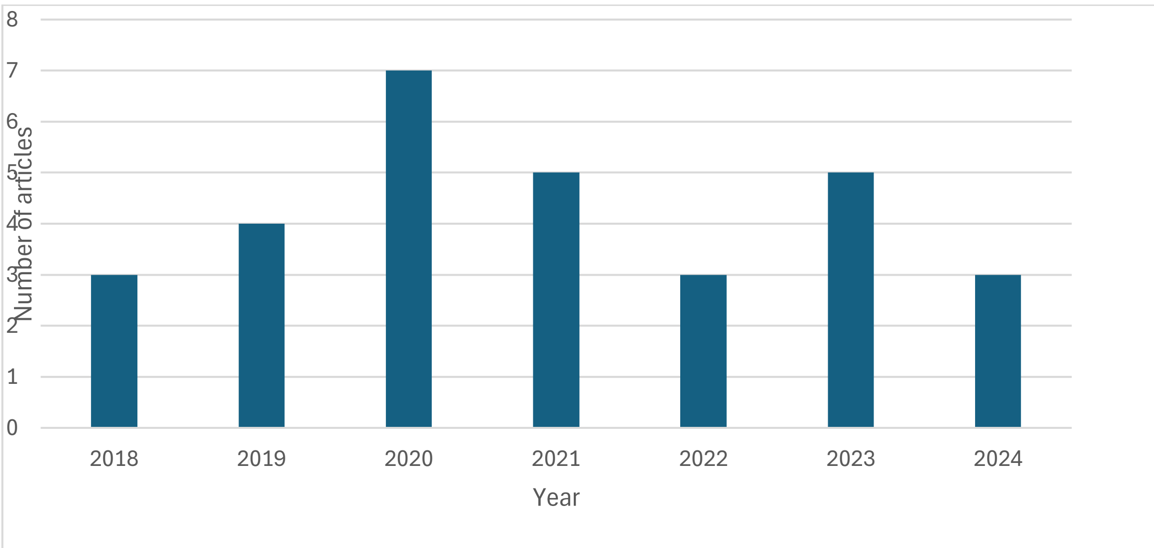

Figure 4. The number of articles published in CBe policies and strategies per year.

Conclusion

The study aimed at understanding the role of central public administration in transitioning towards a sustainable CBe at national and transnational level, as emerging form the academic literature. Even though the literature shows an increasing relationship between circular economy and bioeconomy under the strategies and policies, there is still lack of clear understanding of the role of public administration in the transition within the governance structure. The data analysed does not present the element of public administration among the key words. The academic literature does not clearly separate state authorities and the central public administration in their roles to promote the transition to a sustainable CBe. Although some scholars have tried to analyse the roles of stakeholders at the national and transnational level, there is need for further research to clearly understand the separate roles.

It is important to note that for efficient implementation of CBe policies and strategies, governments, through the national central public administration, should play a key role to promote policy mix, coordination, updating the policies and strategies, and monitoring the transition through relevant indictors and other roles (Birner, 2018). At the transnational level, the EU commission is key leading actor at EU level mandated to ensure adoption and implementation of the EU CBe policies and strategies at member state national level. Even though literature highlights the key role of the EU Commission, a further detailed study is needed to understand on the roles of other transnational bodies in relation to implementation of CBe policies and strategies.

Furthermore, from the study additional literature gaps were identified. For example, although there is a gradual increase of literature in CBe policies and strategies globally, the literature highlights limited number of countries and authors cited from the global south and especially from sub-Saharan Africa. The existing literature focuses more onto the EU perspective in CBe policies and strategies. Nevertheless, EU's lead in CBe policies and strategies literature which would be attributed to the existing transnational policy frameworks, regulations and strong institutions. Future studies would shed more light on why other regions like sub-Saharan Africa have low literature in CBe policies and strategies.

In addition, the academic literature highlights different perspectives of CBe policies and strategies which reflects different national policy interests. However, the literature does not highlight on the geographical representation of these sectors in CBe policies and strategies. More research through other research methodologies would explore on the geographical distribution of the different CBe policies and strategies in literature.

In conclusion, the study findings can be summarised in the following points:

- The academic literature does not clearly present the role of the national or transnational central public administration in the transition to a sustainable CBe. Public administration did not even appear in the key words. The is need for further studies using other methodologies.

- CBe policies and strategies is a gradual growing field with evolutionally emerging CBe policy hot spots. However, there is no clear characterisation of CBe policies and strategies even though there are different CBe clusters. More studies need to be done to characterise and cluster the policies.
- There is geographical disparity of the literature in CBe polies and strategies. EU seems to shape the growth of CBe policies and strategies academic literature. Further research can elude more on the factors influencing the disparity.

This study was the first step of a broad PhD research project which intends to understand the role of public administration in transitioning towards a sustainable circular bioeconomy. It intended to build a foundation for the entire research project by identifying the academic literature gaps within the topic. However, the study presents some limitations. First, the analysis was carried out on the academic literature only. In the next step of the research, more detailed analysis of the literature will be carried out by including grey literature such as policy documents to understand the role of central public administration in transitioning towards a sustainable CBe. Secondly, the academic literature was extracted from Web of Science and Scopus only. However, in future the study will include other relevant data sources to broaden the scope and a systematic literature review and content analysis research methods will be applied for a detailed analysis and characterisation of the literature.

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Social implications of Circular Economy in the wine supply chain: a literature review

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Abstract

Wine production is a relevant activity in many countries worldwide: in Italy, the wine industry generated 13.8 billion of euros, representing the 10% of the national agri-food sector turnover. Viticulture and wine making are ancient activities, which represent an important tradition in many cultures and have a fundamental bond with the territory. Indeed, vineyards are deeply affected by the environmental conditions and the characteristics of the territory in which they are located. On the other hand, scholars and policy makers have stressed their concern about the considerable environmental impacts caused by the wine supply chain, such as water consumption, waste generation, and chemical use. In parallel, the emerging debate on Circular Economy (CE) developed proposals for strategies to mitigate these impacts and make the wine industry more sustainable and profitable at the same time. In this regard, among the three pillars of sustainability, the social one has been basically underexplored. Despite this, a more holistic view is needed to assess whether circular business models are suitable to reach new levels of social sustainability. The present study aims to carry out a bibliometric analysis to explore the literature debate on social sustainability of CE in the wine industry by analysing the records' publication year, authors' affiliations, scientific journal, subject area, and conducting a network analysis of authors' keywords co-occurrence. The results provide a picture of the interest to date for this emerging but still overlooked topic, capturing the relationships standing among the concepts involved, and offer a baseline for further analysis.

Keywords: social sustainability, social impact, circular economy, wine, viticulture

Introduction

Wine production represents a highly competitive industry with tens of thousands of producers around the world (Golicic, 2022). The European Union (EU) – where France, Italy and Spain are the major producers – plays a key role at the global level, accounting for 61% of global wine production in 2023 (OIV, 2024). In 2023, the Italian wine industry generated 13.8 billion of euros, corresponding to the 10% of the national agri-food sector turnover (ISMEA, 2024). Moreover, the global wine industry is primarily constituted of small and medium enterprises (Gilinsky et al., 2016) which are commonly seen as the backbone of any healthy economy. Yet, this sector is challenged by some critical factors, such as burdensome environmental conditions, some of which are now being considered structural and not just conjunctural. In 2023 global wine production is characterized by a sharp contraction of production and a decrease in international trade (ISMEA, 2023). Italy, the world second-largest wine-producing country, experienced a drastic decrease in production level which accounted to

38.3 million of hectolitres, the smallest production since 1950 (OIV, 2024). On the other hand, wine production is responsible for significant environmental impacts (Christ and Burrit, 2013) related to land use, water use, energy use, chemical use, greenhouse gas emission, and waste generation and management (Baiano, 2021). Against this background, both scholars and policy makers have expressed their concerns and launched a call for a more sustainable viniculture. In this context, Circular Economy (CE) has been discussed as a solution model for a sustainable transition of the industry.

In order to enable a transition towards sustainability, a holistic approach to the environmental, social and economic impacts assessment of circular strategies is needed. Yet, authors argued that CE debate has clearly prioritised the environmental benefits and economic gains, whereas social impacts have been sporadically integrated into this concept (Geissdoerfer et al., 2017; Mies and Gold, 2021). Indeed, according to Kirchherr et al. (2017), in a sample of 114 CE definitions, social topics were included only in 18-20% of the definitions. A little increase in attention was registered in 2022 when social topics were identified in 24-27% of CE definitions (Kirchherr et al., 2023). This is because some authors have increasingly pointed out this gap in literature (Moreau et al., 2017; Scarpellini, 2021; Valencia et al., 2023), and this may have fostered the novel attention to the social implications of CE. Generally, scholars suggest that the underestimation of the social dimension may be linked to the difficulty of an objective measurement compared to environmental empirical phenomena, such as atmospheric CO_2 level (Desiderio et al., 2022). Social implications are, indeed, highly difficult to detect and quantify, especially in the context of globalized value chains. Moreover, Mies and Gold (2021) argued that the integration of social sustainability into the CE concept has been challenged by the blurred boundaries between the economic, environmental and social dimensions and the predominant instrumental approach to CE.

The underestimation of the social pillar is also confirmed by recent studies on CE applied in the agri-food sector (Scandurra et al., 2023) and emerges as a limitation in case studies assessing the sustainability performance of wine companies adopting circular business models (Mura et al., 2023).In this context, the main objective of this study was to conduct bibliometric and network analyses of the literature in order to answer to the following research question:

What is the state-of-the-art of the relations between social sustainability and Circular Economy in the wine industry?

The aim was to investigate and capture the relationships standing among CE and social sustainability in the wine supply chain to provide a baseline for future analyses addressing the social sustainability of circular business models in this industry. Within the agri-food sector, the wine industry is, indeed, deemed particularly important due to some of its intrinsic characteristics, such as: high competitiveness, transformation processes, worldwide distribution, and fundamental bond with the territory. After this short introductive section, this paper is structured as follows: Section 2 describes the methodology adopted to carry out the bibliometric and network analyses; Section 3 presents the results obtained and a critical discussion of the findings; Section 4 contains a summary of the study performed and its main implications.

Methods

In order to answer the research question and meet the aim of the study, bibliometric and network analyses were conducted. Bibliometric analysis is a popular method increasingly employed in business research (Donthu et al., 2021). Scholars use it for multiple reasons, among which are to explore new trends in the scientific literature or to investigate the conceptual framework in a specific field of the extant literature (Donthu et al., 2021; Banerjee et al., 2024). In the present study, the bibliometric analysis aimed to track down the annual publication trend, the geographical distribution of publications, the most influential scientific journals and the relevant subject areas. The aim was to trace the evolution of this search domain over time and space as well as the disciplinary perspective under which scholars have studied and discussed CE and social sustainability with regard to the wine industry. On the other hand, the network analysis explored authors' keywords co-occurrence to identify leading thematic areas in the research domains of CE and social sustainability in the wine supply chain. It was performed on VOSviewer Software version (1.6.20), using the normalization method Association Strength (van Eck & Waltman, 2010).

In accordance with the research question, the following key concepts were identified: social sustainability, Circular Economy, and wine. The search, conducted in April 2024 on the databases Scopus and Web of Science, was restricted to articles and reviews in English language, with no time or geographic limits. At first, the search used an all-inclusive query addressing all the three key concepts. Indeed, this query included the following combination of keywords within the Title, the Abstract, and the Author's keywords: "social sustainability" or "social impact*", "circular economy" – and alternative expressions such as "circularity", "circular strateg*" or "circular business model*" – "wine", "grape", "viticulture" and "viniculture", linked with Boolean operators "AND" and "OR". The search led to a total of four documents, therefore, it was decided to split the search query into two areas of investigation:

1. the first query (henceforth referred to as "query No. 1") seeks to analyse the literature debate on CE in the wine industry. It is intended to investigate which CE approaches or business models are discussed in relation to the wine production chain and whether social sustainability is contextually taken into account;
2. the second query (henceforth referred to as "query No. 2") investigates the current state of social sustainability discussion or assessment in the wine industry and, simultaneously, seeks to inspect whether any circular strategy emerges from the studies, despite the expression "Circular Economy" may not be explicitly included in the Title, Abstract or Authors' Keywords.

Since the four documents resulting from the all-inclusive query were found by query No. 1 and/or query No. 2, the all-inclusive query was excluded from the study. Concerning the eligibility criteria, the search intended to include all the scientific contributions examining the key concepts of this study; therefore, general exclusion criteria were developed and formulated as follows:

- for query No. 1, documents not addressing the CE in the wine industry are excluded;
- for query No. 2, documents not addressing the social sustainability in the wine industry are excluded;
- for both the queries, documents not analysing the wine industry are excluded.

In particular, and especially regarding the query No. 1, to provide the most comprehensive picture of the wine domain, the search strategy meant to collect contributions whose exclusive focus was on the wine industry as well as contributions assessing both wine industry and other industries, as long as significant information about the wine production were provided. This was particularly relevant for query No. 1, since a substantial portion of literature analysed the wine's by-products in parallel to other agri-food by-products.

In carrying out the bibliometric analysis, this study adopted a systematic approach based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009; Page et al., 2020). The PRISMA guidelines provide for a strict search methodology to help authors improve the reporting of systematic reviews and meta--analyses (Moher et al., 2009). Indeed, in the context of this study, the PRISMA approach supported the definition and description of the search strategy, as well as the selection of eligibility criteria and the screening processes. After selecting the limitations concerning the document type and language, the search query No. 1 produced a total of 466 publications (223 contributions from Scopus and 243 from Web of Science). From this result, 194 duplicates were excluded. Similarly, the search query No. 2 resulted in 121 publications (65 from Scopus and 56 from Web of Science). From this sample, 43 documents were excluded as duplicates between the two databases and other 4 documents were excluded because already found by query No. 1. Two more screening steps were conducted on the samples. Indeed, the abstract screening and the full-text screening were carried out to evaluate the publications against the eligibility criteria. Following the screening steps, the sample included 212 documents, 188 documents from query No. 1 and 24 from query No. 2. During the full-text screening, 8 relevant contributions (2 for query No. 1 and 6 for query No. 2) were identified to be added to this study using the snowballing technique (Wohlin, 2014). Thus, the final sample includes a total of 220 contributions. Details of the search strategy and the sample are presented in Figure 1 and Figure 2 respectively for query No. 1 and query No. 2.

With specific regard to the network analysis, a replacement of similar keywords was conducted using OpenRefine (Verborgh & De Wilde, 2013). This replacement consisted in the identification of keywords with equivalent meaning, using the cluster function, and allowed to reduce the number of authors' keywords from 718 to 552 in the field of CE, and from 131 to 113 in the field of social sustainability. Concerning the authors' keywords from query No. 1, it was chosen to include in the network analysis all the keywords whose minimum number of occurrence was equal to three. Instead, regarding the authors' keywords from query No. 2, the analysis was conducted on the largest set of co-occurring keywords.

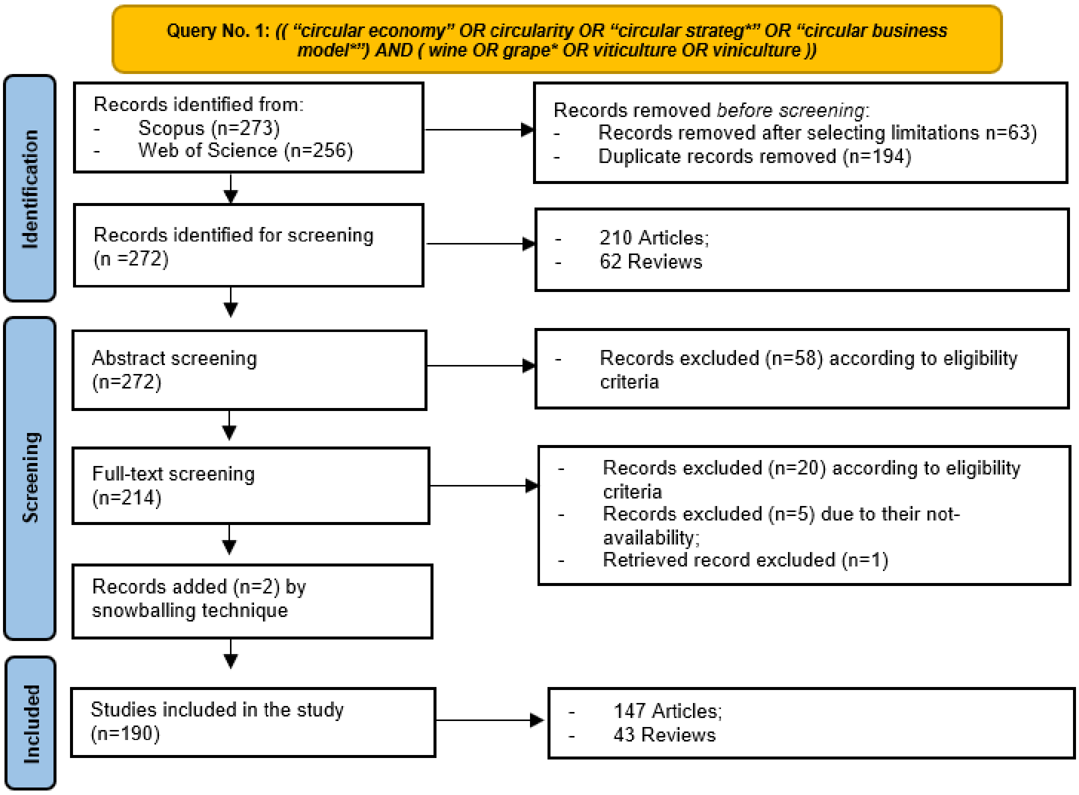

***Figure 1**. PRISMA-based flow diagram for search strategy of query No. 1.*

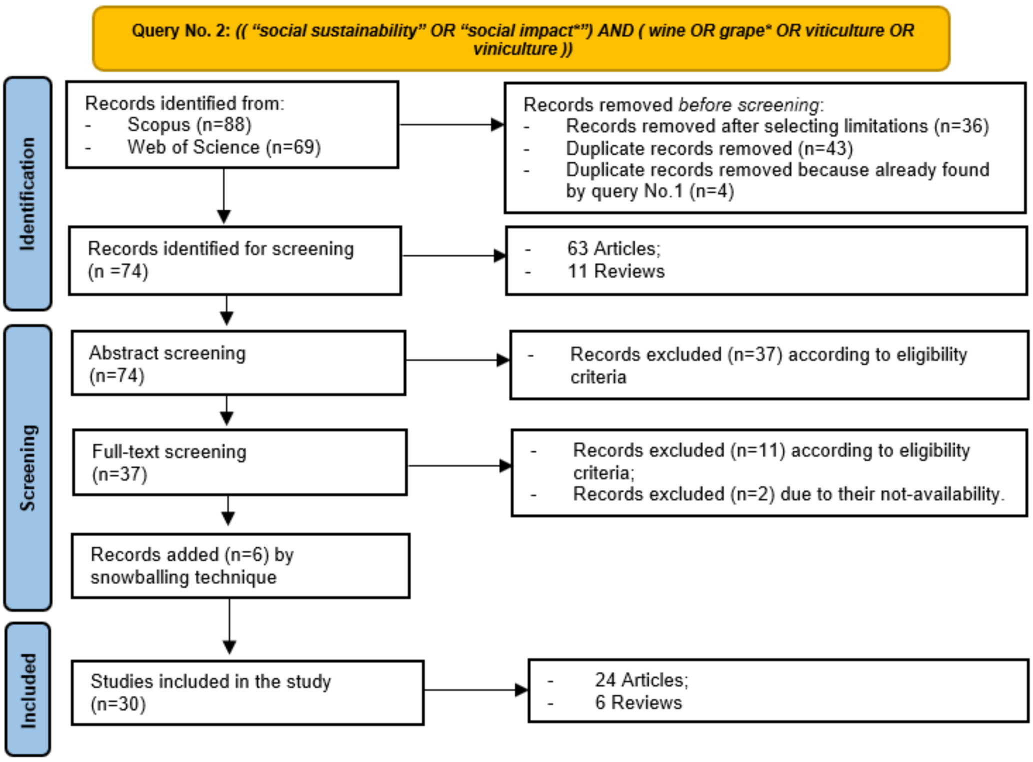

***Figure 2.** PRISMA-based flow diagram for search strategy of query No. 2*

Results and Discussion

This section describes the results obtained from the bibliometric and network analyses conducted on the 220 eligible papers. First, the yearly publication trend of literature on CE and social sustainability in the wine industry is reported, discussing the evolution of these search fields over time. Then, the geographical distribution of the samples according to authors' affiliations and the results of the analysis concerning the most influential scientific journals and the relative subject areas are discussed. Finally, the last section reports the results of the network analysis discussing the co-occurrence of authors' keywords.

Yearly publication trend

In the EU context, the interest on CE likely increased after the European Commission adopted, in December 2015, the first Circular Economy Action Plan. In the same year, the 17 Sustainable Development Goals (SDGs) were published and ratified by the United Nations as part of the 2030 Agenda. In particular, the 12th SDG, namely "responsible production and consumption", is the most relevant in terms of content for the area of CE (Širá et al., 2022) and probably fostered the research on circular strategies and business models. The CE is, indeed, considered by some authors (Corona et al., 2019) as the optimal pathway to sustainable development. According to the sample, in the wine industry CE has been addressed a little later, starting from 2018, as shown in Figure 3a which illustrates the records publication per year. Therefore, the sample suggests that CE analysis in the wine supply chain is a young field (query No. 1). This, however, does not automatically imply that any circular approach was studied earlier than 2018. Indeed, authors have explored reusing, recycling or recovering strategies in the wine supply chain even before 2018, without directly referring to the concept of "Circular Economy". For instance, the OIV Resolution CST 1/2008, which set the principles for sustainable vitiviniculture, already included provisions on the reduction, reuse and recycle of effluents and waste from winemaking in 2008 (OIV, 2008). Publication trend increased from 2020, presumably boosted by the introduction of the European Green Deal and the adoption of the new Circular Economy Action Plan by the European Commission. A peak in publications, equivalent to 32% of the sample, is registered in 2023. This may be also linked to the growing interest in functional foods in the period 2021-2024. Indeed, the potential link between the wine industry and functional foods lies in the fact that winemaking by-products provide valuable ingredients potentially employable in functional foods.

Figure 3b shows the annual publication trend of records from query No. 2. The sample indicates that literature started to address the social sustainability of the wine supply chain in 2010. Indeed, during the first decade of this century, the debate on social sustainability was probably induced and influenced by the strengthening of Corporate Social Responsibility (CSR) at the international and EU level. Actually, social sustainability has been framed in business management as corporate citizenship, corporate sustainability (CS) or corporate social responsibility (Missimer and Mesquita, 2022). Even some financial instruments have evolved in the same period: the first Social Impact Bond was announced in the UK on 18 March 2010 (Liang et al., 2014). In the same year, the International Organization for Standardization (ISO) published the ISO 26000, providing guidance for all companies to operate in a socially responsible way. Afterwards, the spread of sustainability actions and proposals has also affected the wine industry. In Italy, for instance, specific initiatives, such as the VIVA Sustainable Wine program (2011), have been developed to guide and support companies of the wine value chain in addressing all the three pillars of sustainability. The novel attention to the social dimension, witnessed by a moderate increase in publications between 2021 and 2023, may be linked to a more aware and better structured discussion of the concept of sustainability in recent years.

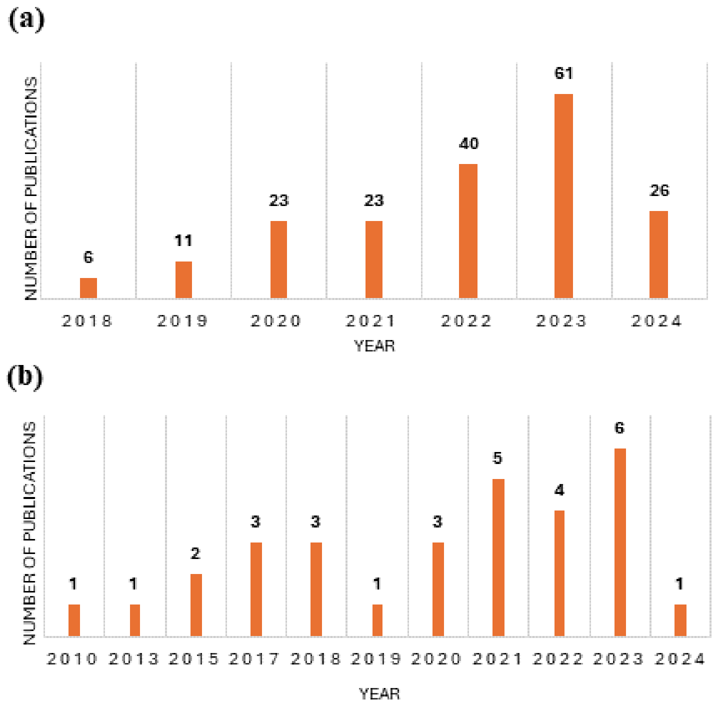

Figure 3. *Publications annual trend on the research area of Circular Economy (a) and social sustainability (b) in the wine industry.*

Geographical distribution of the publications

Figure 4a illustrates the geographical distribution of the publications based on authors' affiliations. In the research area of CE in the wine industry (figure 4a), the most active countries are Italy (26%), Spain (22%), and Portugal (15%). This result is consistent with the production levels of these countries: during the timespan 2018-2023, Italy, Spain and Portugal have been among the top 5 wine producers within the EU (European Commission, 2024). The high number of contributions from these countries is also in line with the publication trend per year since, as discussed above, publication peaks may have been linked to the development of European legislation on CE. It is interesting to note that countries such as the USA, Chile and South Africa appear slightly passive in this domain despite being among the world's major wine producers according to the OIV statistics (OIV, 2024). The same inertia is further surprising in the case of France that, although being the world largest wine producer and also subject to the EU legislation on CE, accounts only for 1% of contributions. In the study by Ngan et al. (2019), the United States, France and South Africa appeared among the top 10 countries in terms of literature production on CE, but accounted respectively for the 6.7%, 4.02%

and 3.94% of contributions, showing a slight interest in contributions on CE compared to other countries in the same list, such as China (33.78%), United Kingdom (13.76%) and Italy (10.64%). Chile is not even listed among the top 10 countries (Ngan et al., 2019), meaning that it has been less productive in publication on CE. Moreover, contrary to Italy, Spain and Portugal, in the context of wine production the United States, South Africa, and Chile belong to the so-called “New World” (Aylward, 2003; Banks & Overton, 2010). These countries are, indeed, relatively young in winemaking and this may affect their interest on CE in this industry.

Concerning the research area of social sustainability of the wine industry (figure 4b), again Italy (27%), Portugal (17%), and Spain (7%) appear among the most productive countries. The United States (12%), Australia (12%) and Brazil (7%) also resulted influential in this research field. Apparently, the interest on the social sustainability of the wine supply chain is widespread worldwide. This suggests that the attention to social impacts of wine production is not specifically linked to any regional context in terms of policy or legislation, but mostly reflects these countries’ wine production and consumption levels. Indeed, all the countries detected in the sample are among the major wine-producer or wine-consuming countries according to the OIV last report (OIV, 2024).

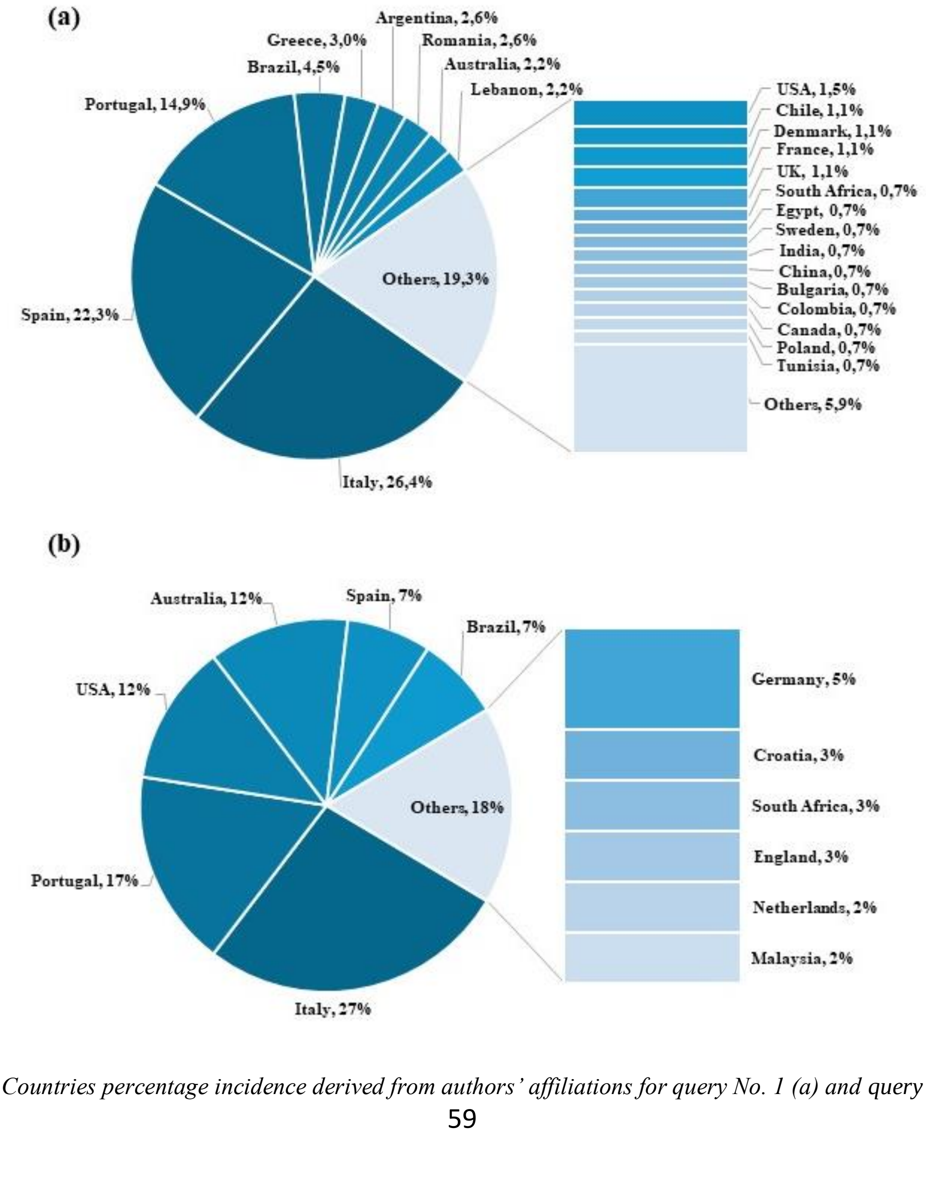

Figure 4. *Countries percentage incidence derived from authors’ affiliations for query No. 1 (a) and query No. 2 (b).*

Trend of journals and subject areas

The 190 documents addressing the CE in the wine industry (query No. 1) are published in 108 international scientific journals. This indicates that the research on the Circular Economy in the wine supply chain has interested a wide assortment of scientific journals. The most influential journals are listed in Figure 5a. *Sustainability* is the most recurrent journal and accounts for the 12.04% of contributions. It is followed by *Foods* (10.19%), *Science of the Total Environment* (7.41%) and *Molecules* (7.41%), *Applied Sciences (Switzerland)* (6.48%) and *Antioxidants* (6.48%) and, finally, *Journal of Cleaner Production* (5.56%). These journals share a primary interest in chemistry and biochemistry research. This is consistent with the sample since the research on valuable wine by-products presumably interested scholars related to these disciplinary sectors.

Figure 5b displays the full list of international scientific journals for the research area of social sustainability of the wine industry (query No. 2). The 30 articles are published in 23 journals, confirming that none of the journals is particularly recurrent. As shown in figure 5b, again *Sustainability*, is the most used journal with 5 publications, followed by *Journal of Cleaner Productio*n and *International Journal of Wine Business Research* which account for 3 and 2 contributions respectively. The remaining 20 documents were published in 20 different journals. The search fields typically addressed by these journals are very different one another. Some of the journals usually cover topics related to tourism, others primarily address environmental issues, and others cover aspects related to molecular neuroscience. This suggests that social sustainability has been studied as a trasversal topic from several disciplinary perspectives.

Figure 5. *Most influential journals and their occurrence for query No. 1 (a) and full list of journals and their occurrence for query No. 2 (b).*

Based on journal trends, figures 6 and 7 report the occurrence of subject areas and their intersection respectively in the research fields of query No. 1 and query No. 2. The results show that 'Environmental Science' is the most occurring subject area in the research domain of CE in the wine industry (figure 6). It is present in 73 documents out of 190: it appears alone in 16 cases, and in the remaining 57 cases, it is interconnected to other subject areas in 24 different combinations. The most common combination sees 'Environmental Science' linked with 'Energy', 'Social Sciences' and 'Computer Science', while the second most common combination sees it crossed with 'Energy', 'Engineering' and 'Business, Management and Accounting'. Among the top 5 subject areas, 'Agricultural and Biological Sciences' is the second most popular, followed by 'Energy', 'Chemistry' and 'Chemical Engineering'. Then, 'Biochemistry, Genetics and Molecular Biology', 'Social Sciences' and 'Engineering' appear respectively in 34, 30 and 28 publications. Moderately frequent are 'Medicine', 'Health Professions' and 'Pharmacology, Toxicology and Pharmaceutics'. Above all, particularly interesting is the intersections of 'Medicine' with 'Agricultural and Biological Sciences' and with

‘Environmental Sciences’. Indeed, while ‘Agricultural and Biological Sciences’ usually deal with food production and processing for human consumption, and ‘Environmental Sciences’ generally aim to provide solutions to environmental problems and ensure the sustainable provision of food, water, and energy, ‘Medicine’ covers many aspects of human health. Therefore, the link between these subject areas may be indicative of potential trade-offs between the environmental and social dimensions, at least in the domain of the social issue *human health*. The 5 less frequent subject areas are ‘Decision Sciences’, ‘Earth and Planetary Sciences’, ‘Arts and Humanities’, ‘Mathematics and Economics’, ‘Econometrics and Finance’ which account for only one contribution each. The prevalence of ‘Environmental Sciences’ suggests that a substantial part of scientific research has studied CE in the wine supply chain with an interdisciplinary approach to address environmental protection and resources consumption.

Concerning the domain of social sustainability in the wine industry, both similarities and differences emerge in comparison to the results of query No. 1. Figure 7 shows that ‘Environmental Science’ is the most frequent subject area also in this field. It occurs in 16 contributions out of 30: it appears alone in 4 publications and, in the other 12 cases, occurs in different combinations, the most common of which is with ‘Energy’, ‘Business, Management and Accounting’ and ‘Engineering’. Other frequent subject areas are ‘Social Sciences’, ‘Energy’, ‘Business, Management and Accounting’ and ‘Agricultural and Biological Sciences’. Apparently, the business management approach is much more influent in this sample than in the research field on CE. Contrary to the results of query No. 1, none of the publications relate to subject areas such as ‘Medicine’, ‘Nursing’ or ‘Health Professions’. The prevalence of subject areas such as ‘Environmental Science’ and ‘Energy’ indicates that the analysis of social sustainability in the wine supply chain has probably concerned the relationships between society and environment, while the frequent presence of ‘Business, Management and Accounting’ suggests that scholars have investigated the issues and challenges faced by organisations in this industry.

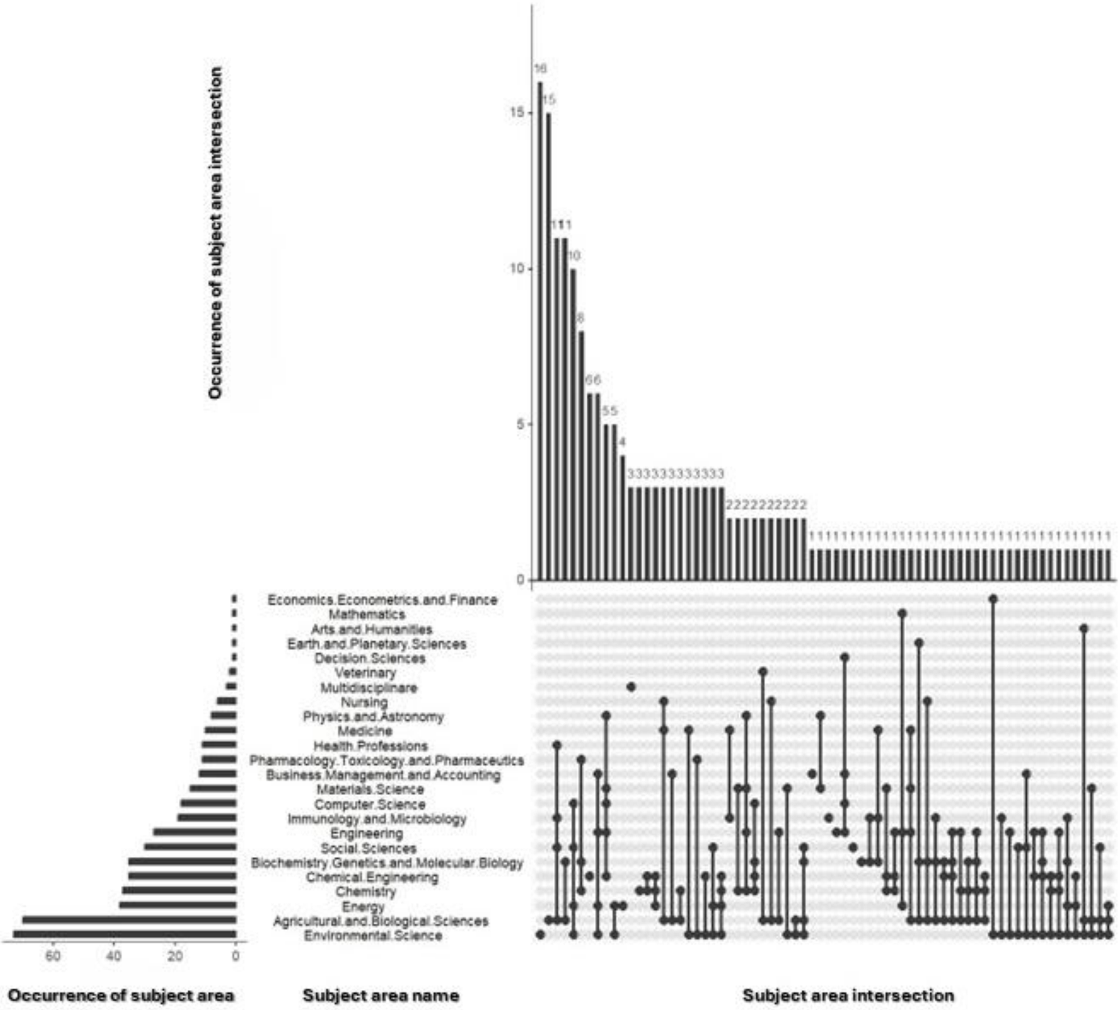

Figure 6. *Occurrence and intersection of subject areas in the research field of Circular Economy in the wine industry (query No. 1).*

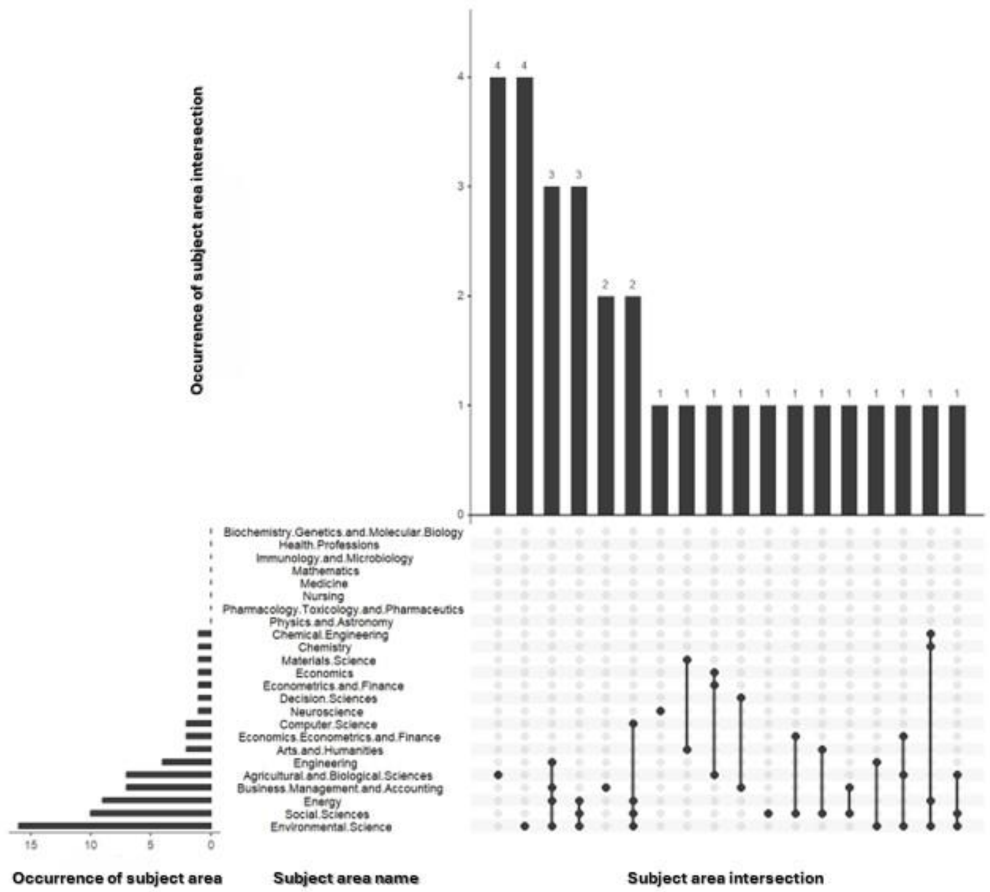

Figure 7. *Occurrence and intersection of subject areas in the research field of social sustainability in the wine industry (query No.2).*

Network analysis of authors' keywords co-occurrence

Figures 8 and 9 illustrate the network analysis' results respectively in the domains of CE (query No. 1) and social sustainability (query No. 2) in the wine supply chain. The analysis included 63 keywords from query No. 1 and 75 from query No. 2.

Regarding the query No. 1, results show that the "circular economy" is the most recurrent keyword, linked with all of the 8 identified clusters (figure 8). It is closely located to the red cluster and, especially, to "sustainability" which is also very frequent. Through "sustainability", "circular economy" is strongly connected to "grape pomace" that, due to its weight, seems to be the main wine by-product addressed in literature. The red cluster also includes keywords – such as "valorization,", "bioenergy", "biochar", "bio-waste" and "biomass" – referring to recovery strategies and particularly to energy recovery. Through "methane production" and "biomass", the red cluster connects with the other keywords of the blue cluster, namely "anaerobic treatment" and "biogas", which also relate to energy recovery, and then "sustainable development" and "climate change" implying that these energy recovery strategies are explored as solutions to contribute to sustainable development and reduce climate change. The keywords of the red cluster co-occur often also with "life cycle assessment", "biorefinery" and "bioeconomy". In the green cluster, the main keyword is represented by "phenolic compounds" which is related to "health" and keywords referring to extraction processes.

"Phenolic compounds" leads to the purple cluster where other references to wine by-products extracts are displayed, and mostly "antioxidants" turns out to be very frequent. "By-products" is another repeating keyword which drives to "sustainable wine sector". Finally, in the orange cluster, the recovery of winery waste is associated with other agri-food wastes and, particularly, to olive oil industry wastes. According to this analysis, the literature on CE in the wine industry mostly focused on downstream circular strategies, namely the energy recovery to address sustainable development and mitigate climate change and the recovery of compounds beneficial to health. Indeed, wine by-products turn out to be interesting for researchers mainly for bioenergy production and for the extraction of valuable compounds. In this regard, human health emerges as the only social impact detectable from authors' keywords. Furthermore, grape pomace is the main wine by-product examined in literature. Others are represented by wine lees, grape seeds, and vine shoots. Among the main extraction methods, the analysis shows that ultrasound-assisted extraction, the solid-liquid extraction and the microwave extraction are often discussed in literature.

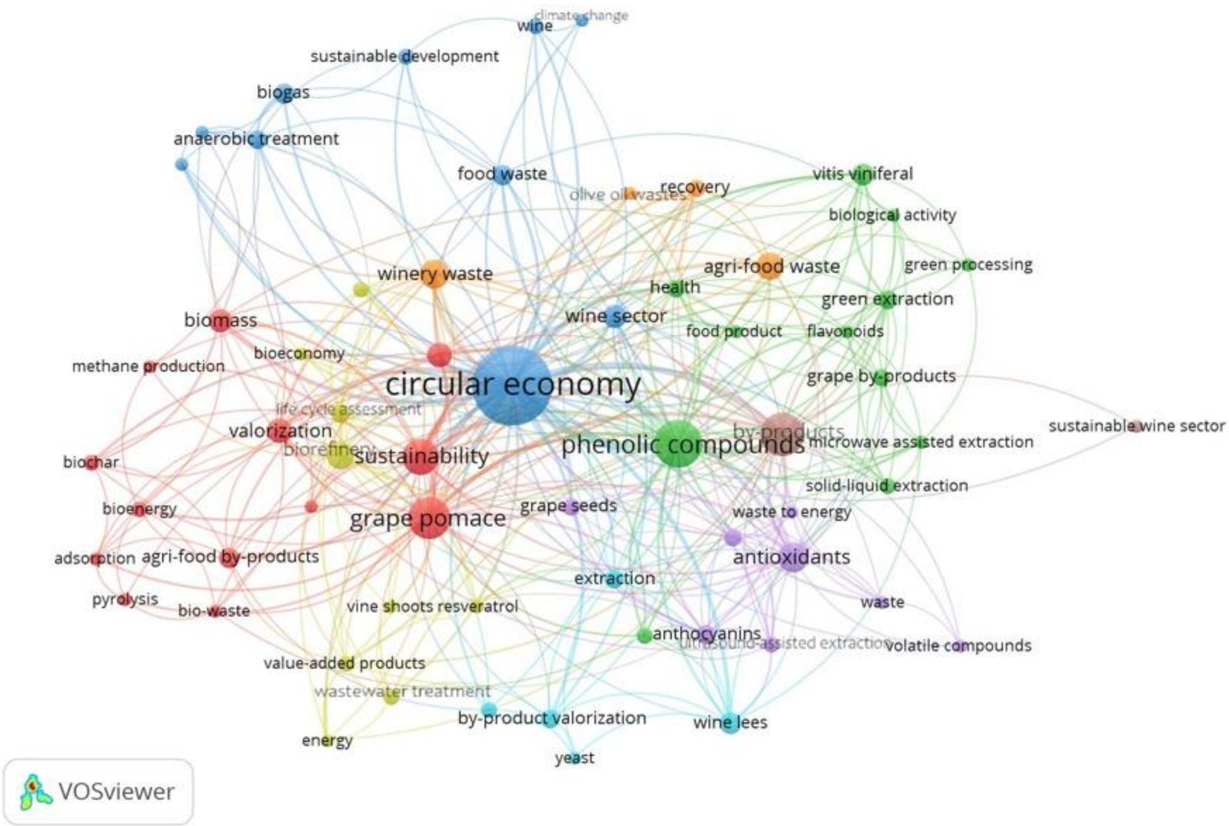

Figure 8. *Authors' keywords co-occurrence in the domain of Circular Economy in the wine industry (query No.1).*

Unlike the CE domain where clusters of keywords are highly interrelated, Figure 9 shows that authors' keywords in the domain of social sustainability are mainly clustered in sealed off compartments whose only link is with the epicentre represented by the keyword "sustainability". Indeed, "sustainability" is the most occurring keyword in the literature debate on social sustainability of the wine supply chain. On the contrary, the keyword 'social sustainability' is less adopted; indeed, only one article includes this term among the keywords (Floričić & Jurica, 2023). This may indicate that the primary focus of a great part of literature was not specifically on the social implications of wine supply chains but on the overall sustainability concept and social sustainability has been addressed as one of its three pillars. The keyword "sustainability" is most closely linked to "marketing strategies" and certifications such as "EMAS" and often co-occurs also with "social life cycle assessment" and "social organizational life cycle assessment", considered among the most important methods for assessing the potential social impacts of products or services and organisations. In the orange cluster, "wine sector" connects "sustainability" with "short-stay market" and "experience economy" suggesting that sustainable practices are studied in relation to the peculiar economic activities of the wine industry. Similarly, in the green cluster, "sustainability" co-occurs with "competitiveness", "tourism" and "food and wine experiences". This may indicate that sustainability is discussed as a competitive advantage for wine companies engaged in touristic activities. Then, "sustainability" is related to the brown cluster, grouping keywords such as "catch crops", "soil", and "land management". Finally, a reference to CE is detectable through the keyword "biomass gasification" which occurs together with "LCA", namely Life Cycle Assessment. The presence of "LCA" is comprehensible since it is one of the most adopted methods for assessing the potential environmental impacts throughout the whole life cycle of agri-food products (Notarnicola et al., 2017; Esposito et al., 2020).

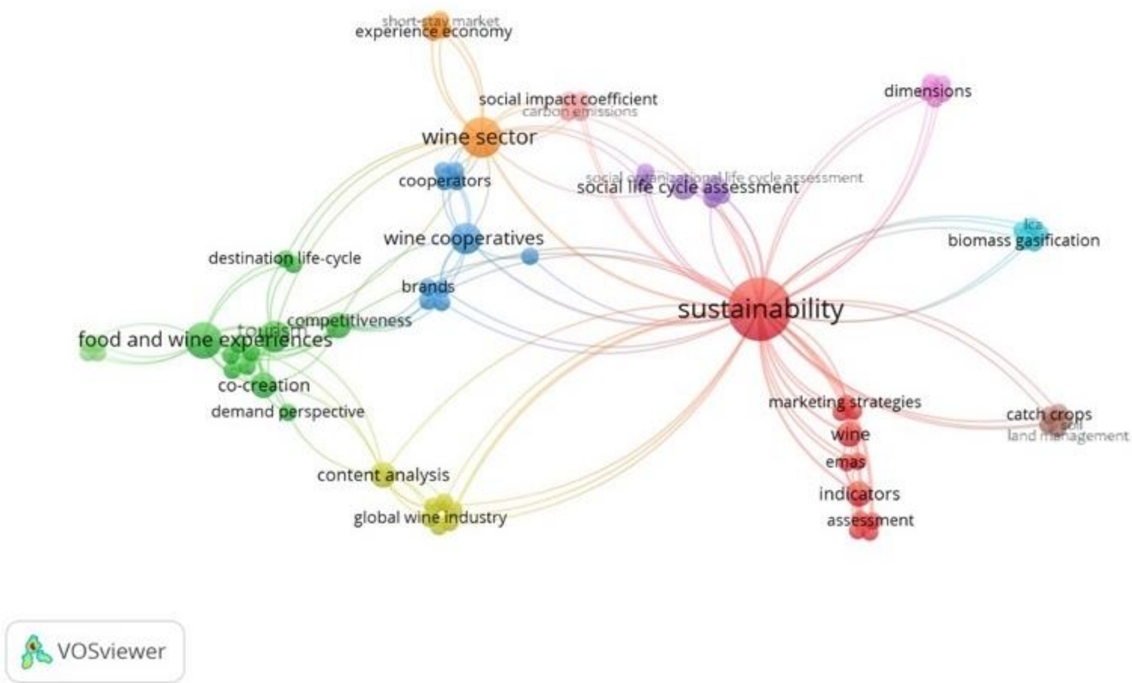

Figure 9. *Authors' keywords co-occurrence in the domain of social sustainability in the wine industry (query No. 2).*

Conclusions

This study aimed to provide first insights into the field of social implications of Circular Economy in the wine industry by conducting bibliometric and network analyses of the literature. The results suggest that the overall research area is relatively young and still underdeveloped, especially in the domain of social implications in the wine industry, where the sample only accounts for 30 contributions. Specifically, it seems that the two lines of investigations run different paths. In CE debate, it appears that researchers have mainly focused on winery waste management, analysing how winemaking by-products valorisation could lead to valuable beneficial compounds or energy sources. Within this framework, human health emerges as the most addressed social issue. The parallel focus on valuable extracts and human health indicates that the social benefit of CE in the wine supply chain is not recognised in the circular process but in the by-product's intrinsic characteristics, namely in the high phenolic content of wine by-products. This could be the reason why the only detectable social impact is human health, and no reference is made to other social impacts such as "job creation" or "training and education", which are usually associated to the circular transition (Luthin et al., 2023). On the other hand, the search on social sustainability in the wine industry allowed to assume that the literature has mainly addressed sustainability as a marketing strategy to boost the competitiveness of wine companies. Only a moderate portion of literature explicitly addresses methodological issues in social impact assessment.

Finally, the study allows to recognise that the social pillar is still overlooked in the wine supply chain and a holistic approach for the sustainability assessment of circular processes in this industry is still missing. It emerges the need for a systematic analysis on the social implications of circular wine production chains. Indeed, further studies should address this gap with the aim of fostering the social sustainability assessment of CE in one of the most important agri-food industries worldwide.

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A Study of Industrial Symbiosis Practices in the Bronte Pistachio Supply Chain: Challenges, Opportunities and Implications

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Abstract

Industrial symbiosis involves the exchange of materials, wastes, water and energy between different industries often located in the same area. These types of strategies appear to be crucial in mitigating crisis effects for individual companies as well as in supporting circular economy transition at meso level. This study aims at assessing the adoption level of circular economy and industrial symbiosis practices among six pistachio-producing organizations in the Bronte area. Through a questionnaire developed by ENEA and administered via the Symbiosis User Network (SUN) platform, the study evaluated the transfer and utilization of residual resources across the pistachio supply chain, spanning cultivation, harvesting, processing, and distribution stages. Findings indicate varying levels of engagement in industrial symbiosis, with motivations including resource efficiency, waste reduction, and economic benefits through collaborative exchanges. Challenges identified encompass logistical constraints, regulatory considerations, and the need for standardized tools to measure environmental and economic impacts. Despite these challenges, companies recognize the potential of industrial symbiosis for cost savings, environmental stewardship, and sustainability enhancement. The study underscores the importance of integrating technological innovations alongside traditional agricultural practices to improve efficiency and sustainability.

Keywords: Circular economy, Bronte pistachio, industrial symbiosis, sustainability, agri-food

Introduction

From the land to the fork

The Bronte Pistachio represents a significant economic resource for the Sicilian territory and for local producers who have recognized the true value of pistachio cultivation (Matarazzo A, et al., 2015).

Sicily is the only region in Italy where pistachios are produced, and the town of Bronte on the slopes of Mount Etna, with approximately 3,500 hectares in specialized cultivation, represents the main cultivation area (more than 80% of the regional surface), accounting for almost the entire Italian production (97-98%). The production of our country represents only 0.32% of the global production. The green pistachio from Bronte is sweet, delicate, aromatic, and above all unique, making it highly appreciated and in demand in European and Eastern markets (primarily Japanese) for its size and intense green colour. Among the various varieties cultivated in the Mediterranean and the Americas, it possesses colours and organoleptic qualities that make it unique worldwide, with a gentle flavour not found in fruits produced elsewhere. (Tomaino A. et al., 2010)

Bronte pistachio harvest is still carried out entirely by hand today due to the morphology of the volcanic terrain, which does not allow access to mechanized equipment. The harvest is done by dropping the fruits into containers carried on the shoulder or by shaking the branches to collect the fruits on sheets spread at the foot of the plants. After the harvest, through mechanical rubbing, the fruit is separated from the hull or the covering that encloses it, and dried in the sun for 3/4 days, thus obtaining the in-shell pistachio called “Tignosella”. At this point, the major processing steps begins with drying. This is done by exposing the pistachios to direct sunlight, manually turning them every 2 hours to ensure even drying and to prevent mold formation. The drying process lasts about 72 hours, a very long time that requires extensive labour. Once the product is considered "dry," it is placed in storage to undergo selection and sorting, an extremely important phase as the pistachios undergo a careful quality check.

Next is the shelling, the removal of the woody shell that encloses the pistachio seed. The subsequent step is peeling, which is not used by everyone as it alters the integrity and fullness of the flavour.

To achieve the perfect balance in terms of taste, a fundamental process is roasting, which, depending on the temperature and duration, characterizes the pistachios and, consequently, the finished products. After roasting, the pistachios are collected on a "giostra" that keeps the product continuously stirred under a suction system to speed up cooling. Finally, before packaging, there is an additional pass through a metal detector for a final check to ensure no foreign objects are present (https://www.pistacchiodibronte.it/).

Consequent to the production and partial transformation stage, there are integrated companies which distribute pistachio through supermarket chain or Hotel, Restaurant and Cafè (HORECA) channels. Other organizations sell their product to other manufacturing companies which furtherly transform it to obtain sweet or sour products for high-spending niches.

The expansion into international markets, which appreciate the regional specialties of our country, is on a steady growth path (Wilson J., et al., 2018). The countries with which business relationships are particularly maintained include: France, Germany, Switzerland, Belgium, Luxembourg, Kuwait, and Korea. In the biennium 2014/2015, particular attention was given to Arab countries (important exclusives were granted in the UAE and Kuwait) and South Korea (Matarazzo A, et al., 2015). In Italy, the price of pistachios varies depending on the product: for Tignosella, it is 10-11 €/kg, for shelled pistachios, it is 30-33 €/kg, and for peeled pistachios, it is 38-40 €/kg (www.pistacchiodibronte.it/).

According to 2017 ISTAT data, about 3,400 tons of Bronte DOP green pistachios are produced in Bronte, while the national production, as mentioned above, is 3,884.6 tons.

The growth rate in recent years of the worldwide spread of Bronte pistachios is impressive. In 2015, it did not reach 12 million euros, and since then, the balance has been steadily increasing, culminating in a significant leap in 2019 when sales increased by 35% compared to the years 2015/2016.

DOP regulations and Voluntary Standards

In order to protect and enhance a product that has unique characteristics due exclusively or essentially to its geographic origin, Bronte producers have advanced a proposal aimed at recognizing and safeguarding the Bronte Green Pistachio and the Bronte area. The process of the proposal for the production specifications of the "Bronte Green Pistachio" lasted about ten years. The proposal was approved by the Ministry of Agricultural and Forestry Policies (MIPAF) and published in the Official Gazette on October 8, 2001. Only after three years, in March 2004, was the Decree of the Ministry of Agricultural and Forestry Policies published with the "Temporary protection granted at the national level to the denomination 'Pistacchio Verde di Bronte'" (Official Gazette No. 76 of March 31, 2004, Decree of March 4, 2004). On November 3, 2004, 30 producers established the "Consortium for Protection" based in Bronte, with the aim of defending, safeguarding, and promoting the area's flagship product, unique in its kind. On June 9, 2009, the official regulations were published in the Official Gazette, granting the "Pistacchio Verde di Bronte" Protected Designation of Origin status (2009/C 130/09).

The production specifications attached to EC Regulation No. 21/2010 establish:

- The cultivation area of the plants, which includes the municipalities of Bronte, Adrano, and Biancavilla.
- The harvesting techniques, which are carried out manually by beating the branches over nets or by hand-picking using baskets.
- The rules for labeling the product at the time of commercialization. The "Pistacchio Verde di Bronte" can only be placed on the market with the Protected Designation of Origin (PDO) logo appearing on every commercial package.
- The product characteristics, which at the time of commercialization must comply not only with common quality standards but also with specific physical and organoleptic features.

On top of that, the Bronte Green Pistachio owes its importance and distinction, both locally and globally, to the numerous certifications obtained over the years by its producers. The international certifications obtained over the years include UNI EN ISO 9001 (quality management systems), UNI EN ISO 14001 (environmental management systems), UNI EN ISO 45001 (occupational health and safety management systems), HALAL (Certification Body and Islamic Authority), IFS (International Food Starndard), and BRC (British Retail

Consortium). These certifications protect the selection of raw materials, product design, production, control, and customer support for the use of the finished product (Bowler K., et al., (2017).

Innovation and circular economy good practices

Technological innovation has been revolutionizing agriculture, leading to significant advancements in productivity, sustainability, and profitability (Mahdi J. et al., 2018). From precision farming techniques to the use of robotics and artificial intelligence, technology is reshaping the way crops are grown, harvested, and managed (Giunta F. et al., 2018). Some of the most common investments in the pistachio production are:

- Introduction of precision agriculture techniques, such as GPS-guided tractors and drones, for more efficient and targeted application of resources in pistachio cultivation.
- Implementation of sensor technology for real-time monitoring of soil moisture, temperature, and nutrient levels, allowing for optimized irrigation and fertilization schedules.
- Adoption of remote sensing technology, including satellite imagery and aerial photography, for early detection of pests, diseases, and nutrient deficiencies in pistachio orchards.
- Integration of automated harvesting machinery and robotic systems for improved efficiency and labour savings in pistachio harvesting operations.
- Implementation of blockchain technology for traceability and transparency in the pistachio supply chain, enabling consumers to verify the origin and quality of pistachio products.
- Integration of data analytics and machine learning algorithms for predictive modelling of pistachio yield, pest outbreaks, and crop health, enabling growers to make informed decisions and optimize management practices.
- Development of innovative post-harvest technologies, such as cold storage and modified atmosphere packaging, to extend the shelf life and preserve the quality of pistachio products during storage and transportation.

In addition, with the entry into force of the "Rural Development Plan (RDP) for Sicily 2014-2020," talk began about an innovative project for Bronte Pistachios, which involves implementing innovations in pistachio crops to combat fungal diseases recently identified in the Bronte area. The "Clean Pistachio" project, financed by sub-measure 16.1 of the RDP for Sicily 2014-2020, aims to enhance both pistachio crops (organic, conventional, and PDO) and processed products. To achieve this goal, the 9 project partners (Department of Di3A at the University of Catania, lead entity "Cooperative of Smeraldo Bronte Pistachio Producers", 6 Sicilian agricultural companies, Benedetto Radice Secondary School - Bronte) take place within the project. Employing innovative technologies is crucial to reduce environmental impact over the course of three years to make crop management ecologically compatible and sustainable, thereby achieving a high-quality end product (Ghanei, A.R., et al., 2014).

The ultimate goal of the Rural Development Plan (RDP) is sustainable development. In line with this objective, agri-food companies might exploit circular economy logics, industrial ecology, industrial symbiosis and industrial metabolism.

Several agri-food sector organizations are experimenting innovative circular economy good practices (GPs) to implement within different business areas (Nobili C. & Cappellaro F., 2021)

The National Agency for New Technologies, Energy, and Sustainable Economic Development (ENEA) established the Italian Circular Economy Stakeholder Platform (ICESP) to gather and promote innovative good practices. To date, ICESP has compiled approximately 240 GPs from various sectors and business areas to measure their environmental, social, and economic impacts and to assess their replicability, thereby encouraging their adoption by other companies. Despite 44 of these GPs originating from agri-food organizations, their shareability is often restricted due to the unique characteristics of the sector (e.g., the use of another company's waste in food production processes is frequently debatable).

Additionally, ENEA has promoted the formation of Italy's first industrial symbiosis network, the "Symbiosis Users Network" (SUN). This network currently unites 39 partners, including universities, political institutions, research organizations, private companies, technology networks, and local authorities. The SUN network aims to be the Italian reference point for operators seeking to implement industrial symbiosis at the industrial, research, and territorial levels. Industrial symbiosis involves the exchange of materials, water and energy between different industries, which are usually separated one from another but they are usually located in the same area. In this view, by-products andwaste generated by a production process become resources for another one (Oliveri L.M., 2022). Through a physical exchange of materials, energy, water and by products, separate industries can reach competitive advantages by collaborating with each other, thanks to the synergy created by geographic proximity and cooperation. ENEA since 2010 with the Ecoinnovation Sicily project has developed and tested a methodology for IS implementation at regional level (Cutaia et al., 2015; Luciano et al., 2016) and several IS projects all over Italy.

This study, in collaboration with ENEA structured and administered a questionnaire, developed by ENEA within the Symbiosis Users Network (SUN), to some pistachio companies to gauge their genuine interest on implementing circular economy and industrial symbiosis, to assess their degree of knowledge of these approaches and understand their level of readiness to these economic models.

Thus, in the following paragraphs, specific features of the questionnaire and details of organizations under analysis are reported, providing some crucial preliminary results.

Methods

To evaluate the current level of circular economy and industrial symbiosis in the Bronte pistachio it has been developed a specific questionnaire to administer to organizations along the supply chain. The purpose is aimed at studying the production and recycling techniques of companies involved. The administering of this questionnaire was carried out in collaboration with ENEA (Department of Sustainability of Productive and Territorial Systems and Joint Research Structure in Catania) to six pistachio organizations in the Bronte area, Sicily, to gauge their transfer and/or sharing of residual resources, whether they be material, energy, water, services, or capacity, among companies, in such a way that the residual outputs of one company can be used as inputs by another.

The questions that were posed to the producers are as follows:

1. Have you ever tried to implement an Industrial Symbiosis process in your company?
2. Motivation
3. Description of the residual resource and its use through the classification of the resource and the type of symbiosis, whether input or output
4. Additional details about the resource
5. Sector of origin of the residual resource with indication of the production activity code and quantities
6. Sector of destination of the residual resource with indication of the production activity code and quantities
7. Indication of the number of entities involved to whom the resource is destined or from whom it is received
8. Analyze the results by describing the impacts/benefits/effects
9. Indicate if tools are used for measuring industrial symbiosis and/or standards for measuring environmental aspects
10. Analyze the results by quantifying the impacts/benefits/effects
11. The economic value attributed to Symbiosis
12. The legal status of the good at the time of exchange, indicating the start date and end date (if applicable)
13. List the facilitating elements that allow the application of Industrial Symbiosis
14. List the barriers/critical issues/limits to the application of the Industrial Symbiosis process
15. Indicate whether it is a consolidated practice or an innovative activity, indicating conditions for replicability or expansion.

The questionnaire was administered digitally to the six pistachio-producing companies through the SUN (Symbiosis User Network) platform, all located in the Bronte area, which are involved in the cultivation, harvesting, processing and distribution of Bronte pistachio.
The sampling plan used was not randomly chosen, consisting of selecting companies based on their size, date of establishment and position along the supply chain to allow for comparison.

***Table 1**. Sample organizations from the Bronte pistachio supply chain*

Respondent	Location	Incorporation	Emploees	Revenue	Main business
Firm 1	Bronte	2006	150/200	4,000,000.00	Distribution
Firm 2	Bronte	2007	10	200,000.00	Production
Firm 3	Bronte	2018	10/15	80,000.00	Production
Firm 4	Bronte	1930	5	1,000,000.00	Transformation
Firm 5	Bronte	2001	85/130	55,000,000.00	Transformation
Firm 6	Bronte	2012	50	38,000.00	Distribution

These companies employ a significant number of workers, divided into specialized workers for the cultivation and pruning of the plants; workers responsible for harvesting, shelling, and drying the raw material; qualified workers for the processing and transformation of the raw material into semi-finished and finished products; and employees responsible for the sale and marketing of the product. All the companies result from decades of work that has been passed down from father to son over the years, witnessing an ever-growing production and sale of products thanks to an increasingly quality-conscious and natural food market. The work carried out in the fields is hard and still entirely manual, but the great passion for agriculture shared by the Bronte producers drives them to continue cultivating pistachios as tradition demands, always striving to maintain the quality of the raw material while innovating technologically.

Results and Discussion

From the study it emerges that six pistachio processing companies, it was found that half of them engage in industrial symbiosis by selling their waste or byproducts to other companies, thereby creating a closed-loop system that enhances sustainability and reduces waste. These three companies have successfully identified value in what would otherwise be discarded, transforming it into a resource for other industries. However, the other three companies do not participate in industrial symbiosis. In particular, firm 1, firm 3 and firm 6 do implement industrial symbiosis while the other ignore this possibility.

The primary reason for this is their perception that they do not produce any waste or byproducts suitable for such exchanges. This highlights a potential gap in awareness or understanding of the full spectrum of byproducts generated and their possible applications in other industrial processes. Addressing this knowledge gap could further enhance resource efficiency and sustainability across the pistachio processing sector.

In response to the inquiry regarding the implementation of industrial symbiosis, there was a notable divergence among the six pistachio processing companies surveyed. Three of the companies reported that they do not participate in industrial symbiosis, explaining that they do not have any waste or byproducts to offer to other industries. This response reflects a perception that their production processes are either waste-free or that any byproducts generated are not suitable for further use.

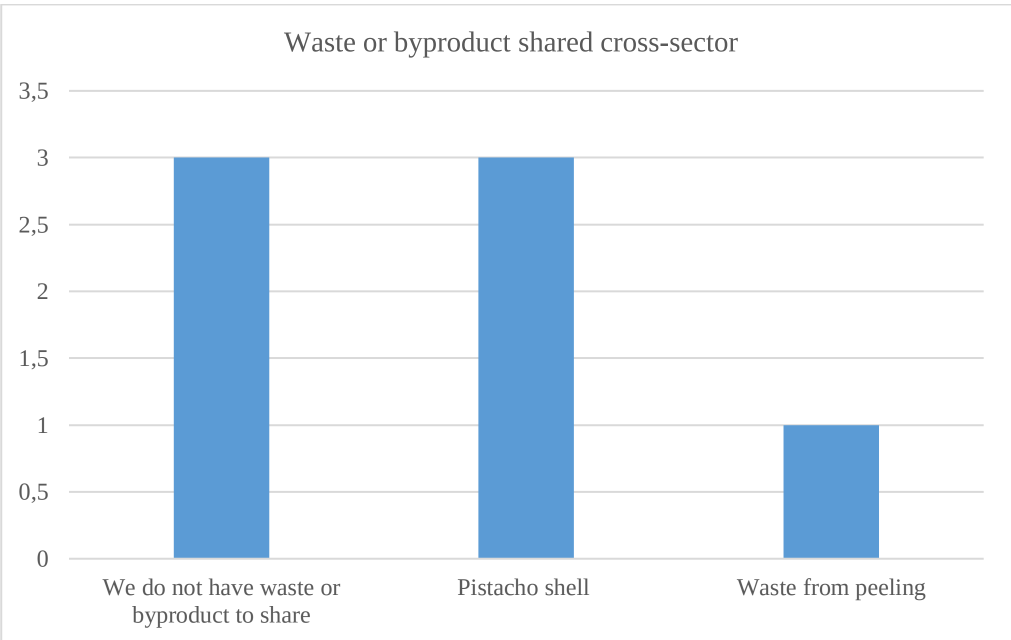
Conversely, the remaining three companies, referred to as Firm 1, Firm 3, and Firm 6, acknowledged that they do generate waste or byproducts and have effectively implemented industrial symbiosis. These companies specifically identified pistachio shells and waste from the peeling process as significant byproducts. By recognizing the value in these materials, they have established systems to sell them to other companies, thereby creating a closed-loop system that enhances sustainability and reduces overall waste. (Ellen MacArthur Foundation, 2015).

This disparity in responses underscores a critical gap in awareness and understanding within the pistachio processing industry regarding the types and potential uses of byproducts. Firms that do not currently engage in industrial symbiosis might benefit from increased education and information on how byproducts like pistachio shells and peeling waste can be repurposed. These byproducts can be utilized in various ways, such as in the production of biofuels, animal feed, or even as raw materials for other manufacturing processes (Benítez, A., et al., 2020).

Furthermore, the implementation of industrial symbiosis by Firms 1, 3, and 6 serves as a model of best practices within the industry. Their success demonstrates the environmental and economic benefits of such initiatives, including waste reduction, cost savings, and the creation of new revenue streams. Encouraging other companies to adopt similar practices could significantly enhance the overall sustainability of the pistachio processing sector (Oliveri L.M., et al., 2022).

While half of the surveyed companies have yet to recognize or capitalize on the potential of their byproducts, the experiences of the other half illustrate the tangible benefits of industrial symbiosis. Bridging this knowledge gap through targeted education and outreach could foster greater industry-wide adoption of sustainable practices, ultimately leading to a more efficient and environmentally friendly pistachio processing industry.

Figure 2. *Waste or byproduct produced by Pistachio companies and provided to other cross-sector companies*



In delving into the origins of waste and byproducts within the pistachio processing sector, insights gleaned from survey responses underscore a diverse array of contributing factors.

Companies highlighted several pivotal areas that contribute to their waste streams, notably the cultivation of pome fruits, various fruit trees, and the generation of a complex mixture involving water, fruit waste, and other substances. This multifaceted distribution indicates that waste generation spans across different stages and processes of production. (Voukkali I., et al., 2023).

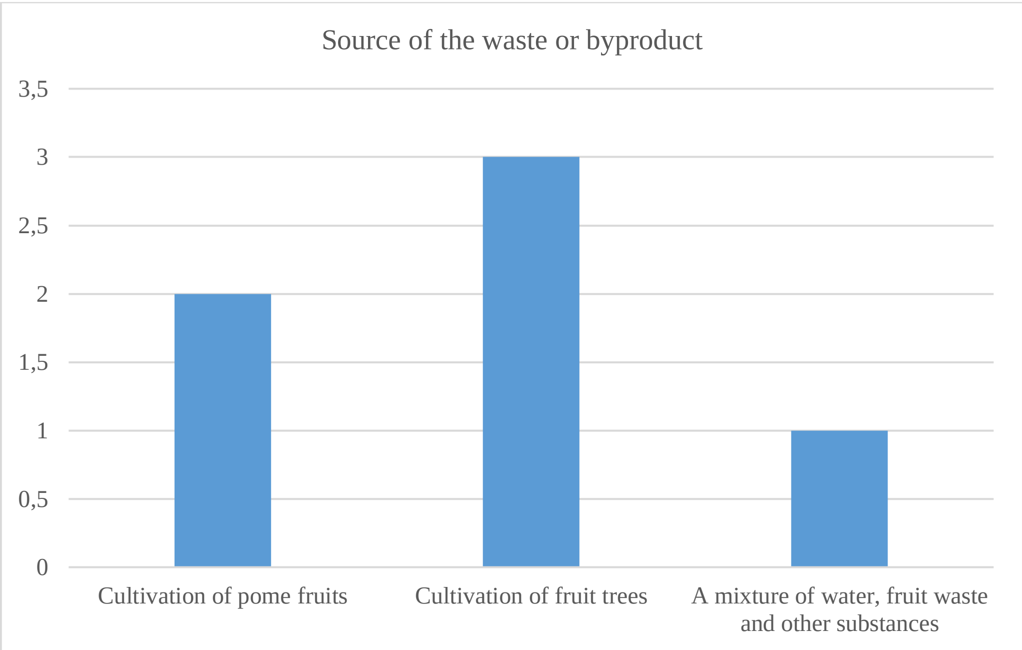
The cultivation practices of pome fruits and other fruit trees involve intensive activities such as pruning, harvesting, and processing, all of which yield significant quantities of organic waste. Moreover, the handling and processing of fruits entail the creation of residual mixtures comprising water, fruit waste, and additional substances, thereby further augmenting the overall waste stream.

Recognizing and comprehending these diverse sources of waste is pivotal for devising targeted strategies aimed at fostering industrial symbiosis.

By understanding these dynamics, companies can identify specific byproducts suitable for reuse and develop symbiotic relationships that enhance sustainability and operational efficiency within the sector. Such initiatives not only mitigate waste but also optimize resource utilization, thereby advancing environmental stewardship and economic viability in pistachio processing.

By focusing on these goals, pistachio producers can enhance the sustainability of their operations, contributing to the long-term viability of the industry and the health of the environment and communities they depend on.

Figure 3. *Source of waste or byproduct produced by Pistachio companies*

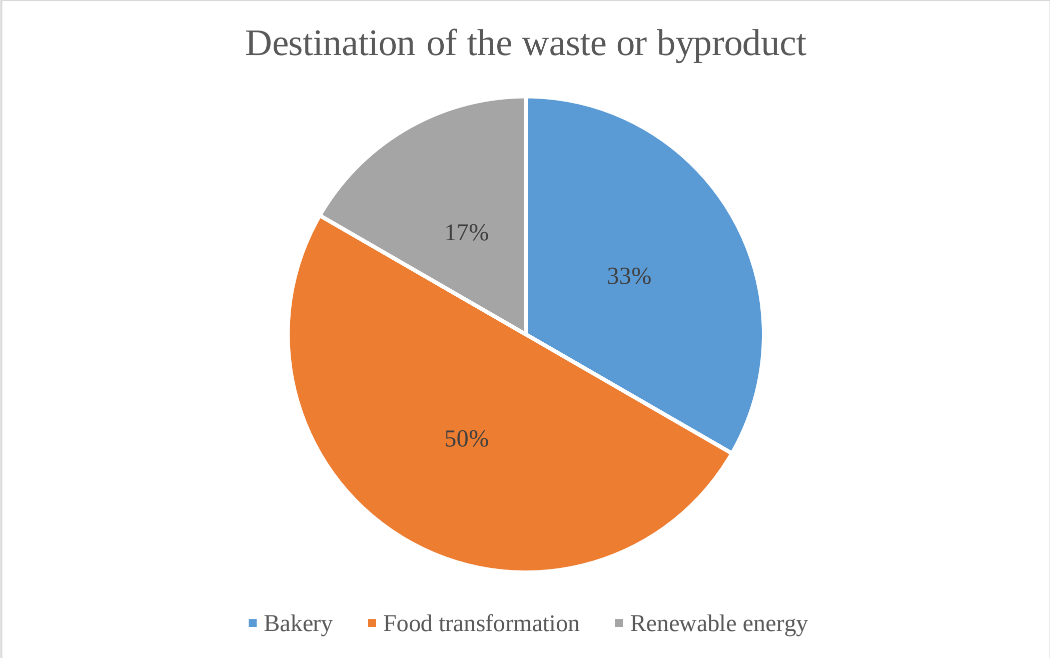


In the exploration of waste and byproduct management in the pistachio industry, interviews with various pistachio companies have revealed a nuanced distribution of destinations for these materials. The primary recipients identified by these companies include the bakery sector, food transformation factories, and industries focused on renewable energies. Interestingly, food transformation factories emerged unanimously as the predominant buyer of pistachio waste or byproducts among all interviewed companies. These factories specialize in processing agricultural residues and byproducts into ingredients or additives for food products, thereby providing a crucial outlet for the pistachio industry's waste streams (Mohsin, M., et al., 2022). The collaboration between pistachio processors and food transformation factories exemplifies a robust form of industrial symbiosis, where one industry's waste becomes another's valuable resource, contributing to overall resource efficiency and sustainability (Xu, S. et al., 2018).

Despite the predominant role of food transformation factories, pistachio companies also indicated marginal involvement with other sectors. Some byproducts find their way into industries focused on renewable energies, where biomass derived from agricultural waste can be utilized for bioenergy production (Elanthamilan, E., et al., 2020). While less prominent, these secondary channels signify efforts to diversify the utilization of pistachio waste beyond traditional food applications, contributing to broader sustainability objectives (Benítez, A., et al., 2020).

The strategic preference for food transformation factories reflects not only the economic feasibility but also the technological compatibility of repurposing pistachio waste into value-added products within the food industry. This symbiotic relationship not only reduces waste disposal costs and environmental impact but also fosters innovation in product development and process optimization (Matarazzo A. et al., 2018). Moving forward, enhancing collaboration with renewable energy sectors and exploring additional avenues for byproduct utilization could further strengthen the pistachio industry's sustainability framework and contribute to a more circular economy approach in agricultural production.

Figure 4. *Destination of waste or byproduct produced by Pistachio companies*



Conclusions

The study explored the unique cultivation and processing methods of Bronte pistachios, highlighting the stringent adherence to traditional practices dictated by the volcanic terrain's morphology. Despite technological innovations transforming agriculture globally, Bronte pistachio harvest remains entirely manual due to terrain constraints, ensuring meticulous quality control from cultivation to packaging. The subsequent processing stages, including drying, shelling, and roasting, are meticulously executed to preserve the pistachios' distinctive flavour and quality characteristics, crucial for maintaining the product's reputation in international markets (Tomaino A. et al., 2010).

It is assessed the adoption of circular economy and industrial symbiosis practices among six pistachio-producing organizations in the Bronte area through a detailed questionnaire administered via the Symbiosis User Network (SUN) platform. This initiative aimed to evaluate the transfer and utilization of residual resources across the pistachio supply chain, encompassing cultivation, harvesting, processing, and distribution stages.

Challenges and barriers identified include logistical constraints, regulatory considerations, and the need for standardized tools to measure environmental impacts and economic values associated with symbiotic exchanges. Despite these challenges, companies recognize the potential benefits of industrial symbiosis in terms of cost savings, environmental stewardship, and sustainability enhancement.

Moving forward, fostering a culture of innovation and collaboration, supported by initiatives like the SUN platform, will be crucial for advancing circular economy principles within the Bronte pistachio sector. Continued research and development efforts should focus on overcoming barriers, promoting knowledge-sharing, and establishing frameworks that facilitate symbiotic exchanges to maximize resource efficiency and sustainability in pistachio production.

Overall, the study provides valuable insights into the current landscape of industrial symbiosis within the Bronte pistachio supply chain, laying the groundwork for future advancements towards a more sustainable and economically resilient agricultural sector.

The study investigated the implementation of industrial symbiosis among six pistachio processing companies, revealing a notable disparity in their engagement with sustainable practices. Three companies successfully participate in industrial symbiosis by repurposing waste and byproducts, particularly pistachio shells and peeling waste, as resources for other industries. This practice highlights their commitment to a closed-loop system that enhances sustainability by reducing waste and creating new revenue streams (Ellen MacArthur Foundation, 2015).

In contrast, the remaining companies perceive their production processes as either waste-free or unsuitable for industrial symbiosis, indicating a significant gap in awareness regarding potential byproducts and their applications.

The findings underscore the critical importance of bridging this knowledge gap within the pistachio processing sector. Educating companies about the diverse sources and potential uses of byproducts, such as biofuels and animal feed, could facilitate broader adoption of sustainable practices (Benítez, A., et al., 2020).

Moreover, the successful examples set by firms engaging in industrial symbiosis demonstrate tangible benefits, including waste reduction and cost savings, which could inspire industry-wide improvements in resource efficiency.

Future efforts should focus on enhancing collaboration between pistachio processors and various sectors, such as food transformation factories and renewable energy industries, to maximize the utilization of byproducts. This approach not only reduces environmental impact but also fosters innovation in agricultural production and supports the transition towards a more circular economy model (Foley J.A., ET AL., 2011). Overall, addressing these challenges and promoting awareness of sustainable practices within the pistachio processing industry has the potential to significantly enhance its environmental sustainability and economic viability in the long term.

Acknowledgements

"This study was funded under the National Recovery and Resilience Plan (NRRP), Mission 4 Component 2 Investment 1.3—Call for proposals No. 341 of 15 March 2022 of Italian Ministry of University and Research funded by the European Union—NextGenerationEU, Award Number: Project code PE00000003, Concession Decree No. 1550 of 11 October 2022 adopted by the Italian Ministry of University and Research, CUP E63C22002060006, Project title "ON Foods—Research and innovation network on food and nutrition Sustainability, Safety and Security—Working ON Foods".

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Track 2: Healthcare

The Reconditioning of Medical Devices: Consumer Perspectives

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Abstract

Sustainability in the healthcare system has become an increasingly important issue in the modern era. The sector now faces the need to ensure medical care while also preserving the environment, promoting equity in access to services, and responsibly managing resources. Medical devices (MDs) are essential for the diagnosis, treatment, and monitoring of health conditions. Single-use MDs negatively impact the sustainability of the sector. Currently, their reconditioning is prohibited by Italian regulations, but adopting a circular model could help reduce these impacts. The importance of responsible consumption and production is also highlighted by Goal 12 of the 2030 Agenda. Consumer attitudes and behaviours regarding sustainability play a crucial role in shaping business practices. The aim of this study is to investigate consumer perspectives on the importance of the MDs sustainability and highlight elements affecting the propensity to accept reprocessed MDs. To achieve the research objective, an empirical investigation was conducted using a quantitative approach and a structured questionnaire was administrated to a sample of 308 consumers. The collected data were analysed using descriptive and multivariate statistical techniques. The results show that respondents' predisposition towards the reconditioning of MDs is determined by three factors: social acceptance of reconditioned MDs and reliability of the process, willingness to purchase sustainable medical devices and finally perception of the importance of sustainability. This research has contributed to the existing knowledge by investigating the consumer's perspectives on an increasingly important topic, namely the refurbishment of MDs.

Keywords: medical device, medical device reconditioning, SGD 12, sustainability, healthcare

Relevant Topic: Circular Economy and sustainability

Introduction

Sustainability has become a topic of vital importance in the modern era, encompassing all aspects of human life and sectors, including healthcare. The industry now faces the necessity of ensuring medical assistance while preserving the environment, promoting equity in access to services, and responsibly managing resources. In the literature, various definitions of sustainable healthcare are found. According to Mohrman and Shani (2011), a sustainable healthcare system focuses on the effectiveness of preventing and reducing the impact of diseases, not only through the care provided within healthcare facilities but also through the improvement of the overall community's health. Fruitman (2004) highlights the need for a sustainable healthcare system to balance cost control and the provision of high- quality healthcare.

Medical devices represent an important niche in the healthcare industry and contribute to improving health levels by developing innovative solutions for diagnosis, prevention, treatment, and rehabilitation (Ministry of Health, 2023). In the European context, the medical device sector is of rising importance. At the same time, in Italy, it represents a large part of the market—€17.3 billion (export and domestic market). The sector is composed of 4,449 companies, mostly small and medium-sized enterprises, and public spending on medical devices and services is about 7% of the total healthcare expenditure (Confindustria Dispositivi Medici, 2023). Medical devices are defined as "Any instrument, apparatus, implant, substance or other product, whether used alone or in combination (including computer software used for its proper functioning) and intended by the manufacturer to be used in human beings for diagnosis, prevention, control, therapy or alleviation of a disease; diagnosis, control, therapy, alleviation or compensation for an injury or handicap; study, replacement or modification of the anatomy or of a physiological process; intervention in conception, the product of which does not exert its principal action, in or on the human body, for which it is intended, by pharmacological or immunological means or by metabolic process but whose function may be assisted by such means" (Regulation 2017/745/EU). Additionally, medical devices are categorised into classes based on the degree of risk associated with their use. This classification considers various factors, including the device's intended use, duration of use, degree of invasiveness, mode of operation, and the organ in which the device performs its function (Ministry of Health, 2023). The following fall under the category of medical devices: medical devices, governed by Regulation (EU) 2017/745, and in vitro diagnostic medical devices, governed by Regulation (EU) 2017/746.

Single-use medical devices also contribute to the healthcare sector's unsustainability (i.e., resource depletion, waste generation, and greenhouse gases) (MacNeill et al., 2020; Benedettini, 2022). Investigating how to apply principles of circularity while maintaining the stringent quality standards required could help reduce the negative impacts of healthcare systems (Moultrie et al., 2015; Kane et al., 2018; Benedettini, 2022). These themes are also linked to two Goals of the 2030 Agenda: Goal 12, related to responsible and sustainable consumption and production, and Goal 3, related to health and well-being.

The circular economy has become an increasingly studied and important approach both in literature and for the institutional actors. In recent years, Europe has issued the "New Circular Economy Action Plan" with the objective of increasing the spread of this approach and achieving climate neutrality by 2050. The circular economy represents an innovative economic paradigm whose primary purpose is to minimise waste and maximise the use of resources (Awan and Sroufe, 2022). The aspect of reuse and reconditioning in healthcare is complex and multifaceted. The design of medical devices represents a high-risk area because they are directly connected to people's health and well-being and thus require high safety and quality standards. Specifically, their reconditioning is provided for by European regulations, but each member state is free to make a final decision, and in Italy, it has been prohibited (Ministry of Health, 2023).

The perspective and behaviours of consumers regarding sustainability play a crucial role in shaping commercial practices. In a context where globalisation has made supply chains increasingly complex, access to information, facilitated by the spread of social networks and new technologies, becomes essential for consumers to guide their purchasing decisions and help them evaluate not only the quality and price of a product but also its social, environmental, and economic impact (Parmiggiani, 2009). As highlighted by Renzi et al. (2022), several factors positively influence the development of sustainable consumer behaviour, particularly social factors, knowledge, habits, and values, while the cost of products has a negative impact. *Sustainable consumer behaviour* can be defined as behaviour based on awareness of long-term effects on the natural and social environment (Epstein, 2018). The emergence of climate changes (i.e., floods, fires, rising temperatures) has contributed to increasing awareness and profoundly impacts consumer perceptions and attitudes. These events serve as catalysts, attracting public attention and increasing focus on environmental challenges (Del Gobbo, 2020). A survey conducted by the Nielsen Global Survey of Corporate Social Responsibility and Sustainability, involving 30,000 individuals in 60 countries, found that in Europe, 51% of consumers are inclined to financially support brands characterised by sustainable practices (Cicerchia, 2006). The growing demand for sustainable products pushes companies to integrate eco-friendly practices into their philosophy (Cagliano et al., 2011). This transformation embraces every sector, including healthcare, and paves the way for a more sustainable approach to the design and use of medical devices. Researchers have generally called for more studies to identify predictors of sustainable consumer behaviour (White and Simpson, 2013; Renzi et al., 2022).

Against the above backdrops, the present research aims to evaluate consumers' perspectives regarding the importance of sustainability in the medical device sector and verify the elements that influence their willingness to accept reconditioned devices. To achieve the research goal, an empirical investigation was conducted using a quantitative approach. A structured questionnaire was administered to a sample of 308 consumers. The collected data were analysed using descriptive and multivariate statistical techniques. The originality of the research lies in studying consumers' perspectives on a topic that is gaining increasing importance, namely the possibility of using reconditioned medical devices. The remainder of the article is organised as follows: after this introduction, the methodology is presented, followed by the description and discussion of the results, and finally, the conclusions are highlighted along with possible research implications, limitations, and future research directions.

Methods

To achieve the study's objective and analyse users' points of view about the importance of medical device sustainability and their propensity to accept reconditioned medical devices, an empirical survey was developed in Italy through a quantitative approach. In particular, a structured questionnaire was administered between October and November 2023. It was developed considering the scales present and already validated in the literature and the research objective. Precisely, the instrument consists of five main sections and includes 21 questions (multiple-choice, scales, and open-ended questions): i) Perceptions of the importance of environmental, social, and economic sustainability in the healthcare system and medical device sector; ii) Reconditioning of medical devices; iii) Packaging and choice of materials; iv) Waste management; v) Profiling of respondents.

Scale questions use a 5-point Likert scale, where one indicates that they totally disagree and five indicate that they totally agree with the statement. The questionnaire was administered via social networks (such as Facebook and LinkedIn) and via e-mail. The sample was selected using the snowball approach (Guido, 1999; Mugion et al., 2018). Specifically, it is composed of consumers in general, considering that all populations enter into contact with the healthcare system and use medical devices at some point in their lives. At the end of the process, 308 fully completed questionnaires were collected. Data were analysed using SPSS IBM 17.0 statistical software (Muthen & Muthen, 2017). Specifically, descriptive analyses were used to highlight the sociodemographic characteristics of the sample, and bivariate analyses were developed to analyse the interactions between variables using Cronbach alpha, factor analysis, and linear regression analysis. The results are presented through the support of tables and graphs.

Results and Discussion

Analysis of the sample

The total number of respondents is 308 and the sample consists of approximately 58% females and 42% males (see Figure 1).

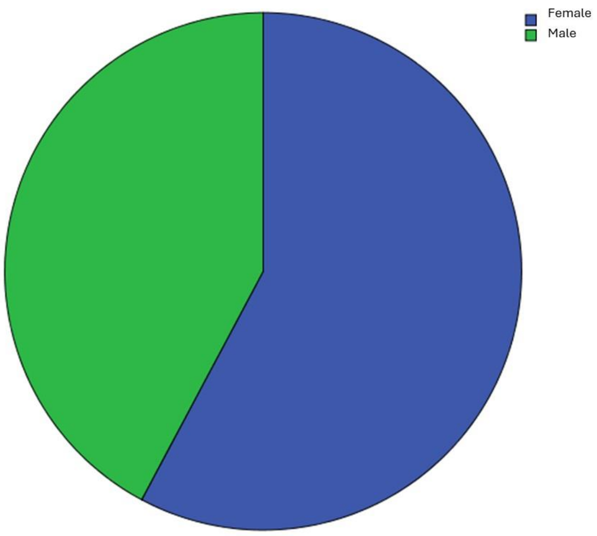

***Figure 1**. Gender.*

The sample consists of individuals aged between 18 and 79 years. Specifically, 73 respondents belong to the 18-28 age group, 101 respondents fall into the 29-39 category, 59 individuals are between 40 and 50 years old, 47 respondents are between 51 and 61 years old, and 28 individuals are over 62 years old. Approximately 34% of respondents hold a master's degree, about 32% have a high school diploma, 16% have a bachelor's degree, 9% have a master's certificate, and only 1% possess a doctoral or post- graduate degree (Figure 2).

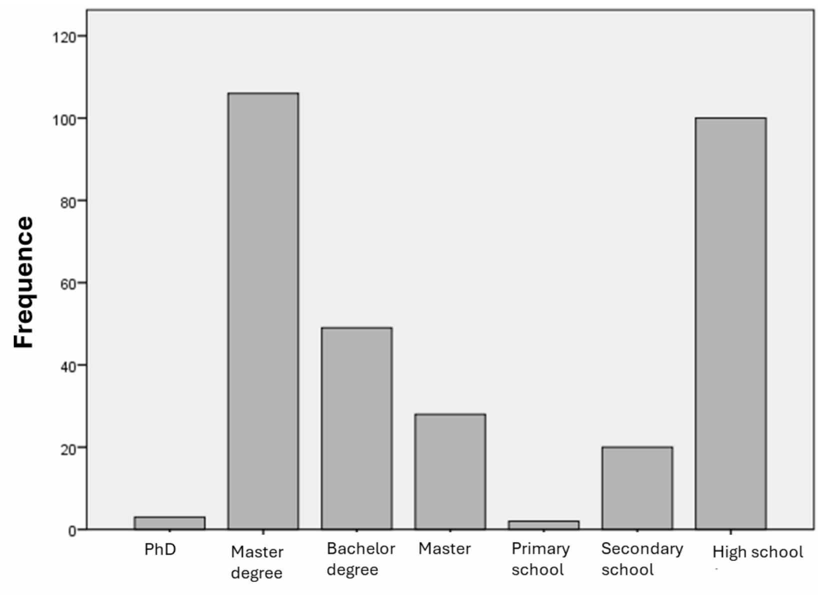

***Figure 2**. Level of education.*

The majority of the sample, 54%, are employed as office workers, 19% are self-employed, 11% are still studying, 8% work as homemakers, 5% are retired, and 2% are seeking employment (see Figure 3).

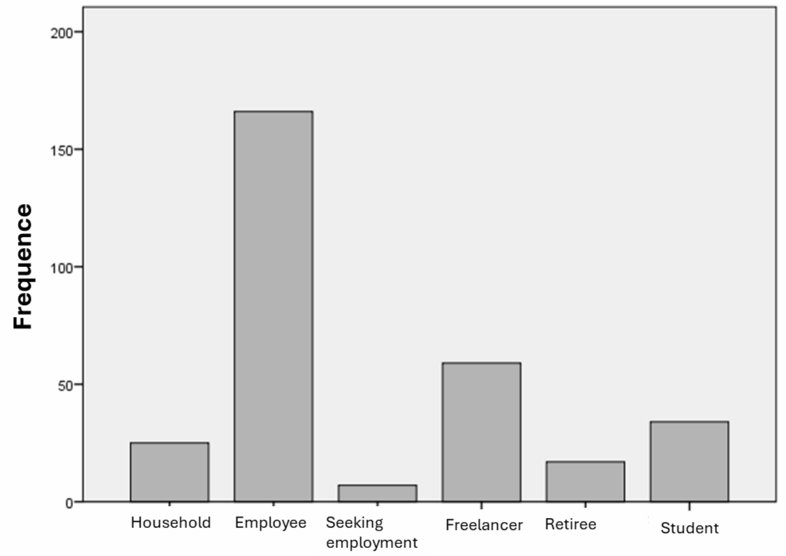

***Figure 3**. Profession.*

Cronbach Alpha

The Cronbach's Alpha value of 0.932 obtained from the questionnaire analysis using SPSS software indicates a high reliability of the scale employed (see Table 1). A Cronbach's Alpha exceeding 0.7 is generally regarded as a strong indicator of internal consistency, suggesting that the items on the scale are highly correlated and consistently measure the phenomenon under investigation. This high level of reliability warrants the continuation of subsequent analyses, specifically bivariate statistical analyses, factor analysis, and multiple linear regression.

***Table 1.** Cronbach Alpha.*

Cronbach Alpha	N. of elements
,932	21

Factor analysis

Factor analysis is a technique that allows for the reduction and synthesis of information by studying the interrelationships among variables. The aim of this analysis is to create a reduced number of latent variables derived from linear combinations of the original variables. In this instance, an exploratory analysis was first conducted to determine the number of factors to select, using the Principal Component Analysis method without rotation. This approach is helpful in identifying the smallest number of factors that explain the maximum variance. Once this step was completed and the factors identified, a confirmatory analysis was performed using the Maximum Likelihood method and VARIMAX rotation to achieve a clear separation of factors, ensuring that a single variable tends to correlate only with one factor. Subsequently, the factors were named based on the variables from which they were composed.

The first verification to be performed is to examine whether there is a correlation among the factors, using

Bartlett's Test of Sphericity and the Kaiser-Meyer-Olkin (KMO) Test. For factor analysis to be conducted, it is necessary for Bartlett's Test to yield a high value and a P-value < 0.5. In this case, a P- value of 0 was obtained, which is acceptable. Additionally, the KMO Test must provide a value greater than 0.7; otherwise, the correlation between pairs of variables could not be explained by other factors, and factor analysis could not be conducted. In this case, the KMO Test returns a value of 0.922, indicating that it is possible to proceed with the subsequent analyses, data are summarized in Table 2.

Table 2. *Test Bartlett and KMO.*

Measure of Sampling Adequacy (MSA) by Kaiser-Meyer-Olkin (KMO)		,922
Bartlett's test of sphericity	Chi-square	4739,841
	gl.	210
	Sign.	,000

The next step involves analysing the communality table, which provides information on the amount of variance explained by the common factors. It is necessary that all values exceed 0.4. In this case, the communalities of the variables are all above the specified value.

The subsequent step is to analyse the Total Variance Explained and the Scree Plot (see Figure 4) to determine the correct number of factors to extract. Factors with an Eigenvalue greater than one are considered. Moreover, the number of factors should explain at least 60% of the total variance. By examining the table of SPSS and the graph it appears appropriate to extract four factors.

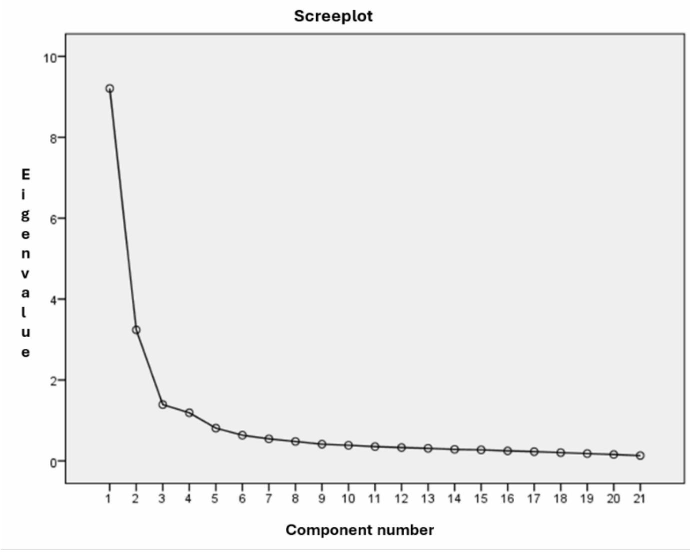

Figure 4. *Scree Plot, source SPSS.*

Once the four factors have been identified, it is necessary to repeat the analysis using the Maximum Likelihood method and Varimax rotation to observe the value of each factor loading, ensuring that none are below 0.4 or that an item is correlated with only one factor. The factors are composed as follows:

- Factor 1: social acceptance of reconditioned medical devices, positive attitude towards reconditioned medical devices, approval of reconditioned medical devices by important individuals, perception of the reliability of reconditioned medical devices, need for familiarity with the reconditioning process to accept the medical devices, development of trust in the reconditioning process to influence its use, and ability to control the use of reconditioned medical devices.

- Factor 2: possession of information to choose a sustainable medical devices, knowledge of technologies to produce medical devices, participation in training initiatives regarding the sustainability of the healthcare system and medical devices, and knowledge of healthcare waste disposal policies.

- Factor 3: importance of environmental, social, and economic sustainability in the production and marketing of medical devices.

- Factor 4: influence of packaging sustainability on purchasing decisions of medical devices, preference for packaging with sustainable materials, willingness to pay a higher price for sustainable medical devices, and awareness that individual behaviour can influence sustainability management practices of medical devices.

Finally, the factors are named based on the items they comprise:

- Factor 1: Social acceptance of reconditioned medical devices and reliability of the process.

- Factor 2: Training on sustainability in healthcare.

- Factor 3: Perception of the importance of sustainability.

- Factor 4: Willingness to purchase sustainable medical devices.

Multiple linear regression

The multiple regression analysis conducted using the Stepwise method was applied to investigate the potential relationship between the propensity to recondition medical devices rather than discard them (the dependent variable y of the model) and the four factors extracted from the factor analysis (the independent variables x). The Stepwise technique begins with an empty model (without predictors), and, at each step of the analysis, variables are added or removed based on their significant contribution to explaining the variability of y. The Alpha values used are those assigned by default in SPSS. In the first step, the variable "Factor 1" is entered; in the second step, the variable "Factor 4" is added; and finally, in the third step, the variable "Factor 3" is included. Factor 2 is never included in the model, and all the variables considered are never removed.

The adjusted R-squared value (which accounts for the complexity of the model) in the final step of the procedure is 60.8%, indicating that approximately 61% of the variability in the propensity to recondition medical devices rather than discard them is explained by the linear relationship with the variables in the model. The ANOVA table tests whether the explanatory variables have any statistically significant effect on y. In this case, a P-value approximated to zero is obtained for the F-test statistic, leading to the conclusion that at least one x is associated with the dependent variable. Additionally, it is necessary to verify that multicollinearity does not exist through the Variance Inflation Factor (VIF). The VIF must be less than 5, and in this analysis, the VIF is equal to one for all variables, indicating no multicollinearity and the regression analysis can proceed. Finally, SPSS performs a test for each regression coefficient and returns the corresponding t-test statistic and associated P-value. In this case, all P-values are significant, being less than $\alpha=0.05$. Therefore, it can be concluded that the identified factors (F1, F3, and F4) seem to positively influence the propensity to recondition medical devices rather than discard them. The factor with the most significant impact is Factor 1, "Social acceptance of reconditioned MDs and reliability of the process," with a beta of 0.673, followed by F4, "Willingness to purchase sustainable medical devices," with a beta of 0.259, and finally, F3, "Perception of the importance of sustainability," with a beta of 0.191. Figure 5 shows the graphical representation of these findings.

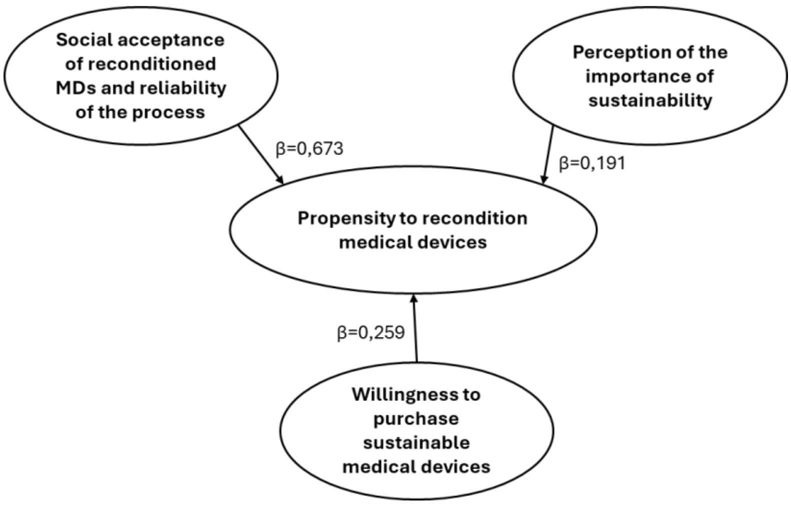

Figure 5. *Graphical representation of linear regression model.*

Conclusions

Sustainability emerges as an increasingly important element in the healthcare sector and as a criterion in consumer purchasing decisions. This, in turn, influences companies and their operational and management models. As in all fields, healthcare organizations and medical device companies are invited to carefully consider their activities' implications and orient their strategies towards sustainability and greater responsibility. The study reveals that sustainability in the healthcare sector requires an integrated approach and the involvement of all system actors (including policymakers, companies, consumers, and suppliers). The transition to a circular economy can represent an innovative economic paradigm that offers significant advantages in terms of efficient use of raw materials and resources and reducing negative impacts in this field as well.

The objective of the present research is to evaluate consumers' perspectives on the sustainability of medical devices and the factors that influence the acceptance of reconditioned devices. To achieve this goal, a questionnaire was administered to a sample of 308 respondents. The data were analysed using univariate and multivariate statistical techniques. Through the application of factor analysis, the variables were synthesized into four factors: factor 1 - Social acceptance of reconditioned medical devices and reliability of the process; factor 2 - Training on sustainability in healthcare; factor 3 - Perception of the importance of sustainability; factor 4 - Willingness to purchase sustainable medical devices. Subsequently, multiple linear regression analysis was conducted to verify how these factors impacted the propensity to recondition medical devices rather than discard them. The study revealed that three of the four factors positively impact this propensity. Specifically, F1 - Social acceptance of reconditioned medical devices and reliability of the process has the most significant impact, followed by F4 - Willingness to purchase sustainable medical devices, and F3 - Perception of the importance of sustainability.

Based on the findings, it can be affirmed that regulators are called upon to identify new ways to ensure the sustainability of the medical sector and understand how to apply circularity principles to the use and production of medical devices while continuing to guarantee the required quality levels, adequate hygienic conditions, and correct functionality of the products. The analyses highlight the importance of increasing society's trust in reconditioned medical devices, as social acceptance seems to have a statistically significant impact on the propensity to recondition rather than discard the product. It is important that all necessary information regarding the reconditioning methods and processes, the technologies used, how to use the devices, and the positive sustainable impacts that can be achieved are shared with users. In general, it is evident that informed and aware people are more inclined to recondition medical devices, which is why it is important for companies and governments to activate training initiatives aimed at citizens to explain the phenomenon. It is also noted that increasing citizens' awareness of the importance of sustainability and the need to reduce resource use can have positive effects on the propensity to reuse medical devices.

Sector leaders must increase their training and information efforts, both internally among healthcare professionals and externally among end-users, to promote a greater understanding and adoption of sustainable practices. Staff training becomes a fundamental element, along with the ability to develop reusable products that meet the most stringent regulatory requirements and the ability to communicate correctly with users/consumers, identifying effective communication channels to inform consumers and healthcare operators promoting a culture of sustainability.

At the same time, companies can commit to using fewer resources from clean and sustainable sources, optimizing production processes to reduce waste, and promoting the reconditioning of medical devices in dialogue with institutions. Transparency in business practices becomes a fundamental element in this context to increase the trust of regulators and citizens. Sustainability must become part of business models and corporate culture. Collaboration with environmental organizations, research institutes, and other stakeholders is essential to promote sustainable practices and develop common standards.

Moreover, new technologies such as 3D printers and additive manufacturing can become essential elements in the design phases of products with the goal of making them more circular. Companies must continue to explore innovative solutions that align technological progress with sustainability and invest in research and development activities.

Existing policies and regulations play a crucial role in supporting the sustainability of the medical device sector. It is essential that these regulations are continuously updated to reflect technological advancements and encourage the adoption of sustainable standards.

As with all studies, the present research has limitations that can be overcome by developing future analyses. Specifically, this research involved only one country, Italy, whereas future studies could extend the analyses to other geographical areas and contexts to understand if consumer views change depending on the social context. Additionally, the sample could be further expanded. The present study adopts a quantitative approach, and future research could also develop qualitative analysis to investigate the emotions and impressions of the respondents more deeply. Finally, future analyses could consider the perspectives of other system actors such as doctors, nurses, professionals, manufacturing companies, accreditation bodies, and institutions (hospitals and governments/regions).

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Acknowledgements

ECS Project 0000024 Rome Technopole, - CUP [F83B22000040006], PNRR Mission 4 Component 2 Investment 1.5, funded by the European Union - NextGenerationEU

A food provision method using action cards for hospitalized patients during a disaster

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Abstract

Purpose: During disasters such as earthquakes, continuing to provide medical services is essential. Meal provision is one such medical service that sustains life and can also function as a part of medical treatment. It is essential, then, to continue to provide meals to hospitalized patients during disasters. This study, therefore, used Hospital A as a case study to establish a method using action cards that can help medical staff provide meals smoothly during a disaster.

Design/methodology/approach: We extracted 90 necessary actions during a disaster for each of the four steps of meal provision (situation assessment, preparation, transportation, food provision, and waste collection and storage). After clarifying the general requirements for an action card, we created 22 action cards describing these actions. A disaster drill was conducted at Hospital A to verify the method's effectiveness.

Findings: We identified six areas where the action cards needed improvement and improved them accordingly. A questionnaire survey of 12 staff members at Hospital A confirmed the validity of the improved action cards.

Originality: While studies have assessed disaster resilience in hospitals and examined actual stocking situations, no study has established a systematic, concrete method for continuing to provide food to patients during a disaster. By establishing such a method, our study fills this gap in the literature.

Keywords: Disaster medical care, Disaster resilience, Healthcare quality, Disaster drill, Hospital food

Introduction

In Japan, where natural disasters such as earthquakes and tsunamis are common, ensuring the continuity of healthcare services in the event of a disaster is essential for the safe and security of society. Disaster resilience is defined as "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions" (United Nations Office for Disaster Risk Reduction, 2009). Traditionally, research has focused on areas such as the earthquake resistance of infrastructure, equipment, machinery, and buildings. In recent years, however, there has been an increasing focus on the importance of considering the human activity aspect of disasters, that is, how to continue activities after a disaster strikes and how to quickly return to normal conditions (Hayashi, 2016). While some studies have specifically assessed disaster resilience in hospitals (Cimellaro *et al.*, 2009; Ikeuchi, 2009), they trend to deal with hard aspects such as infrastructure and earthquake resistance and do not consider aspects of human activity during a disaster. Although there is recognized need for research to consider disaster resilience more broadly, concrete, systematic methods for doing so have yet to be established.

Among the various medical services, the provision of meals to hospitalized patients is not only for the intake of energy and nutrients essential for life, but also a part of medical treatment and therapy, such as the provision of special therapeutic meals. Therefore, meal provision plays an extremely important role in early healing and avoiding the deterioration of medical conditions; this remains the case even in the event of a disaster. For example, during the 2011 Great East Japan Earthquake and 2016 Kumamoto earthquakes, food reserves were maintained for a number of hospitalized patients, but owing to various obstacles in cooking, transportation and disposal, the food provision could not be sufficiently continued. This resulted in the deterioration of the nutritional status and medical conditions of the hospitalized patients. Therefore, continuous food provision for hospitalized patients in the event of a disaster will improve the disaster resilience of hospitals and contribute to ensuring a safe and secure society.

The Centers for Disease Control and Prevention in the US has addressed disaster food security, but not specifically for people with medical needs, such as hospital patients. In Japan, meanwhile, the Ministry of Health, Labour and Welfare mandated hospitals to develop business continuity plans in 2017. In this regard, the Tokyo Metropolitan Government's Bureau of Social Welfare and Public Health's Guidelines for Developing BCPs for Base Hospitals for Disaster Management noted that the need to store and provide disaster food for inpatients; however, it did not provide specific methods. In addition, many of the previous studies have reported individual hospital cases or examined actual stocking situations (Matsuzaki *et al.*, 2014). No studies, however, has concretely clarified how to continue providing food to hospital inpatients in the event of a disaster.

This study, therefore, investigated how to ensure the continuity of food provision to inpatients during a disaster as a way of improving the disaster resilience of hospitals. Taking Hospital A as a case study, we aimed to develop a method to enable medical staff to smoothly provide meals during a disaster using action cards which are explained in the next section.

How food can be provided in disaster situations

What is an action card?

The use of action cards is recommended for hospital response to disasters (Advanced Life Support Group, 2018). Therefore, this study used action cards to clarify the process of food provision during a disaster. Action cards are advanced instructions that can guide rapid, appropriate decision-making and encourage taking required actions in emergency situations such as disasters. Action cards clearly and concisely indicate what each staff member should do in the event of a disaster so that the person in charge of a given role can read the action cards and quickly take effective action. Different from the standard operational procedures or manuals used under normal circumstances, action cards must be prepared such that, in an emergency, they can be easily understood by those who do not have sufficient knowledge of the task or unfamiliar with it.

Visualization of the entire food provision process during a disaster

To examine specific provisioning methods, we established an overall picture of the disaster food provision process, as shown in Figure 1.

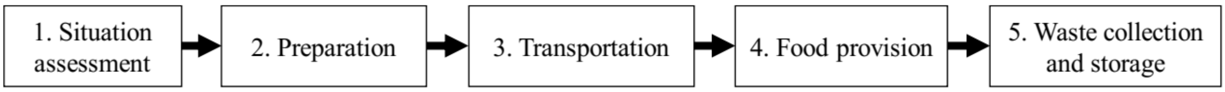

Figure. 1 *Overview of food provision processes during a disaster in a hospital*

As shown in Figure 1, five processes are involved in food provision. On that basis, we extracted the tasks required for each process in detail and identified the necessary actions.

We made the following assumptions:

a. Hospitals are affected by disasters, but the situation is not such that medical treatment must be stopped; rather, medical services must be continued.

b. No external supplies are available for three days after the disaster.

c. Essential services such as water, gas and electricity have been cut off.

d. Hospitalized patients receive two meals per day, six meals in total during three days. Patients receiving tube feeding are excluded.

Tasks and actions for "1. Situation assessment"

The purpose of this process was to gather information to determine how to provide food in the event of a disaster. The leader of the day is responsible for this process, as instructions are given to each staff once the information has been gathered.

The method for providing emergency food is determined before a disaster occurs but will need to be changed according to the situation after the disaster. Therefore, in addition to confirming the disaster situation, the number of hospitalized patients, and transport routes, we identified seven specific tasks that need to be carried out, such as securing the medical staff needed to transport and provide meals. In total, we identified 20 specific actions that are necessary for performing each task.

Tasks and actions for "2. Preparation"

The purpose of this process is to decide how food can be served and to prepare for it, based on the situation identified in "1. Situation assessment." It is necessary to transport food and prepare the necessary items to serve it. These tasks are carried out by administrative staff in the hospital. The hospital nutritionist is responsible for deciding the content of the meals and the schedule for serving them to patients, as this requires knowledge of the patient's nutritional status. The staff members performing each of these tasks must be assigned, and informed and must report to the manager. Based on the above, we identified five necessary tasks and specified 16 actions required for each task.

Tasks and actions for "3. Transportation"

The purpose of "3. Transportation" is to ensure that administrative staff transport the necessary food items according to the schedule determined in "2. Preparation."

More specifically, food is transported from the warehouse to the wards where the patients are hospitalized and to handed over to the nurses in the wards. The transportation method are based on the use of trolleys and lifts, as lifts can be temporarily used based on private power generation, even if the power is cut off in hospital A. Based on the above, we identified the four tasks required for this process, resulting in a total of 24 required actions.

Tasks and actions for "4. Food provision"

The aim of this process is to provide transported emergency food to hospitalized patients. Nurses are responsible for this process as they provide meals to patients under normal circumstances. Here, the nurses must prepare meals to be served to all inpatients in the ward, serve meals to individual inpatients and, if necessary, help patients with their meals. We identified four tasks for this process, resulting in 18 required actions.

Results of "5. Waste collection and storage"

This process ensures that post-food waste is properly collected and stored to prevent post-food nosocomial infections. Under normal circumstances, medical waste from hospitals is transported to dedicated medical waste stores, which are temporarily replenished and then removed by contractors. Medical waste stores are usually located in the basements of hospitals or at a distance from the wards where patients are hospitalized. This increases the person-hours required to transport waste to medical waste stores. As it might not be possible to provide sufficient workforce in the event of a disaster, a room with a lockable door can be set up as a temporary storage area close to the ward where the waste is stored.

Therefore, the main task is to collect the waste after inpatient meals and transfer it to the temporary storage area. Four tasks are required with 12 actions for each task.

Overall results of the food provision process

Table 1 presents the results of identifying the tasks and actions required for all processes involved in providing food to hospitalized patients during a disaster. Table 1 shows that actors involved in the food provision are a leader, administrative staff, dieticians, and nurses. In total, we identified 24 tasks and 90 actions for implementing the processes.

For example, in "1. Situation assessment," the leader must carry out the following seven tasks: confirm the total number of tasks required in the process and the working time (1-0), make sure they are a leader (1-1), Obtaining the workforce needed to complete these tasks (1-2), check damage to the food stores (1-3), check transport routes (1-4), check the number of inpatients served meals (1-5), and check that the meal is already cooked and ready to use (1-6). We found that 20 actions were needed to perform these seven tasks in "1. Situation assessment."

Table 1. *Results for food provision processes, tasks, and actions*

No.	Task			Person in charge	Number of actions	List of figures (photos) and tables used in action cards	Number of action cards
1	Situation assessment	1-0	Perform all situaliton assesment tasks and the working times.	Leader	3		6
		1-1	Make sure you are a leader.		1		
		1-2	Get the workforce to perform these tasks.		3		
		1-3	Check the damage to food stockpile warehouses.		4	Photographs of four stockpile depots.	
		1-4	Check the transport routes.		6	Hospital floorplan and transport route map.	
		1-5	Check the number of inpatients served meals.		2	Calculation tables to count inpatient admissions for each ward.	
		1-6	Check that the meal is already cooked and that it can be used.		1		
2	Preparation	2-0	Confirm all preparetion tasks and working times.	Administrative staff and nutritionists	2		2
		2-1	Prepare some action cards to give to each member of staff.		3		
		2-2	Establish a schedule for the transport and provision of food and communicate this to therelevant staff.		3	Three-day food menu list (with photos)	
		2-3	Prepare the necessary equipment for transportation.		7	Clear indication of where goods are stored.	
		2-4	Report when transport is ready to the leader.		1		
3	Transportation	3-0	Confirm all trasportation tasks and working times.	Administrative staff	6		8
		3-1	Gather the information needed for transport.		8	a. Hospital floorplan and transport route map. b. List of foodstuffs to be transported (every first to sixth meal).	
		3-2	Transport food to the various wards.		7	a. Place of storage in the stockyard (with photograph) b. Method of loading with trolleys (with photographs) c. Table of food storage box sizes/cart loading capacity d. Method of loading by lift (with photograph)	
		3-3	Give necessary food to the charge nurse on each ward.		3		
4	Food provision	4-0	Confirm all food provision tasks and working times.	Nurse	5		4
		4-1	Prepare the food for distribution to hospital ized patients.		6	a. 3-day menu (with photos) b. Photograph of the storage area (ward day room) for the first meal. c. Photograph of the trolley used to serve the meals.	
		4-2	Serve the food.		5		
		4-3	Help patients with meals if necessary.		2		
5	Waste collection and storage	5-0	Confirm all waste collection and storage tasks and working times.	Nurse	4		2
		5-1	Clean up meals and dishes.		4		
		5-2	Transport collected waste to temporary storage.		3	Photos of temporary storage areas.	
		5-3	Report completion of food provision to the leader.		1		
				Total	90	Total	22

Creating action cards

Requirements for action cards and how to achieve them

Based on the tasks and actions required for food provision identified in the previous section, we clarified the requirements that we need to consider when developing action cards and how each requirement was realized. The results are presented in Table 2. We assumed that the users of the action cards are people who were performing the tasks and actions more or less for the first time in an emergency situation.

Table 2 shows the three requirements: ease of understanding the task content, ease of use, and ease of management. For example, regarding the ease of understanding the task content, the following four points must be considered: clarification of the position of the task, clear indication of the task procedure and task location through the use of charts and diagrams, clear indication of who should perform the task, and readability.

Regarding how these requirements were implemented in this study, for example, for the abovementioned clarification of the position of the task, it was necessary to clarify the overall picture of the necessary tasks at the beginning and clarify the position of the specific task in the overall task at the beginning.

The right-hand side of Table 1 shows that the action cards created from the correspondence shown in Table 2. As a result, we identified 90 actions comprising 22 action cards for the five food provision processes shown in Figure 1.

Table 2. *Requirements for action cards and how to achieve them*

Requirement for action cards	How to achieve the requirement	
Ease of understanding the task content	Clarification of the position of the task	Clarify the overall picture of the necessary tasks at the beginning
		Clarify the position of the specific task in the overall task at the beginning
	Clear indication of the task procedure and task location through the use of charts and diagrams	The way of performing a task is given in the form of "Do XXX" - one action, one sentence.
		Task locations and transport routes should be clearly indicated on the floor plan drawings.
		The work object is presented in the form of actual photographs and a list of names.
	Clear indication of who should perform the task	Indicate the person in charge (type of job profession) or change the color of the action card for each job profession.
		Prepare a number of sets of action cards and decide who is going to do the action by passing (holding) the cards.
	Readability	The font size of the text on the action card should not be too small.
		Use as few words as possible and make extensive use of figures and tables.
		Action cards should be printed in color, not black and white.
Ease of use	Ease of carrying	The action cards should be portable and worn around the neck on a cord so that workers do not have to hold them in their hands.
		Make the action card small enough to hold in one hand.
	Ease of flipping	Bind several action cards together with a ring .
		Ensure that the carrying strap and the action card can be separated.
	Ease of understanding the progress of the task	Place a tick in front of "Do XXX" for each action so the operator knows what action they have completed.
		A column is provided for the operator to record the information obtained and decisions made.
Ease of management	Ease of storage and durability	Laminate the action cards to prevent them from being soiled or damaged.
		Pre-designate and prepare the pens for use on the activity cards.

Examples of the created action cards

Figure 2 and 3 shows some of the action cards created for Hospital A based on Table 2. Figure 2 shows the three action cards for “1. Situation assessment.” The one on the left is the front cover showing

all the tasks in Figure 1, with the task to be performed circled in red to clarify the position of the task among all tasks.

The action card in the center of Figure 2 is an example of a photograph showing the name and location of a stockpile. The use of photographs makes the cards easier to understand than would be the case with textual explanations.

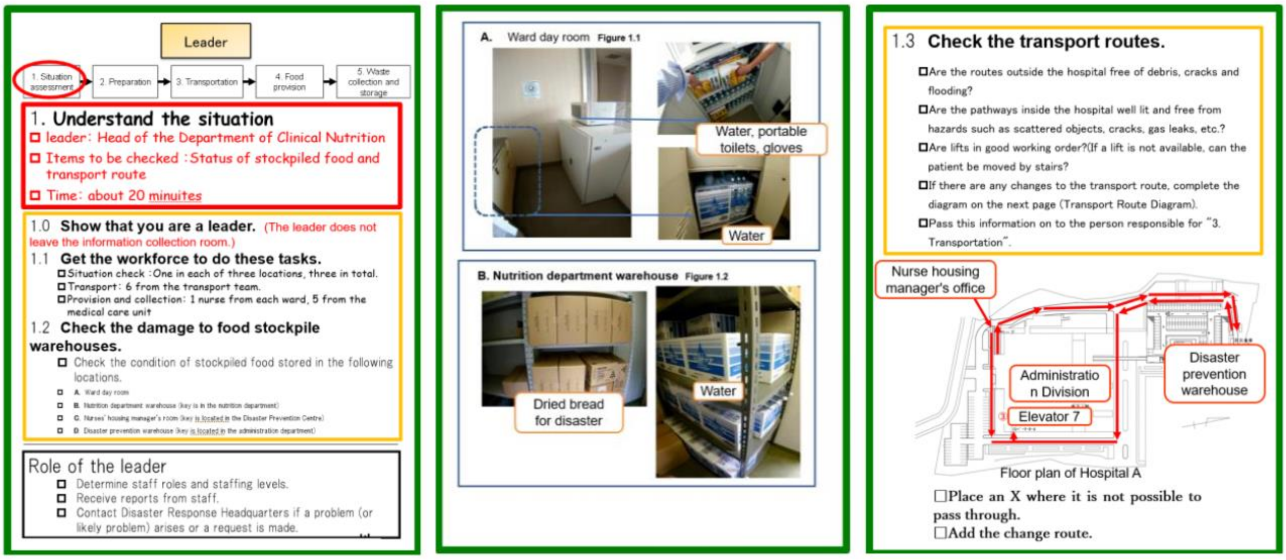

***Figure. 2** Examples of the action cards created for Hospital A*

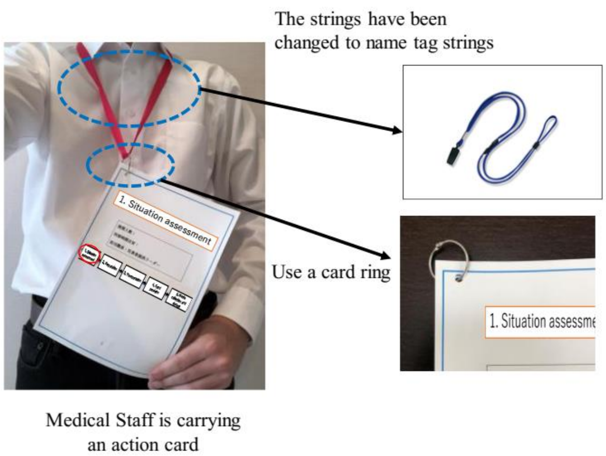

Figure. 3 Photo of medical staff carrying action cards

Similarly, the action card on the right side of the diagram provides an explanation of the transport method, along with a map of the transport route. The red arrows in the diagram show the predetermined transport route. If the route needs to be changed based on the actual disaster situation, the medical staff is instructed to write down the changed transport route.

As with all action cards, the content to be checked or acted upon was expressed in a commanding tone in the form of single action and single sentence, such as "Do XXX". At the beginning of each sentence, there was a tick box to prevent omissions and make it easier to check the progress of the task. The action cards were not monochromatic but were produced in a range of colors so they would be visually easy to read, and the font sizes, pictures, and tables were also designed to be readable by the medical staff.

Figure 3 shows how the medical staff carry the action cards. Based on the disaster drill described in next section, the strings have been changed to name tag strings so they would not interfere with the action cards when they were turned over.

Verification through disaster drills using action cards

We conducted the disaster drill at Hospital A, a major disaster center hospital in Saitama Prefecture, Japan. Twelve members of Hospital A's Disaster Management Committee participated in the study. Two were from the nursing department, one from the pharmacy department, one from the laboratory department, one from the clinical engineering department, one from the clinical nutrition department, one from the rehabilitation department, one from the diagnostic imaging center, one from the radiology department, one from the hospital administration department, one from the administration department, and one from the general consultation office. Additionally, three individuals, including the lead author, participated as radiographers. The twelve participants were divided into three teams and trained to transport food from three stores simultaneously.

All participants in the disaster drill were given the data for all the action cards in advance so they could understand the content. On the day of the drill, each participant received a set of action cards. Participants were asked to write directly on the action cards their opinions that emerged during the preliminary reading of the contents, as well as opinions that formed during the disaster drill. After the disaster drill, these opinions were collected on the action cards.

Table 3 shows the schedule for the day of the disaster drill; Figure 4 presents a snapshot of the disaster drill at Hospital A.

Table 3. *Time schedule of the disaster drill conducted at Hospital A*

Time		Program
Start	End	
15:00	15:10	Opening (explanation of disaster drill content)
15:10	16:20	Implementation of the disaster drill
16:20	16:30	Break
16:30	17:00	Exchange of opinions about the disaster drills
17:00	17:10	Closing

Figure. 4 Photo of disaster drill at Hospital A.

Table 4 shows the opinions (1) - (6) received from the participating staff of Hospital A after the disaster drill. Opinions (1) - (3) pertain to the content of the meals provided while opinions (4) - (6) are related to the action cards. Opinion (3) is beyond the scope of this study. We took opinions (1) - (6) except for (3) into consideration to make improvement to the created action cards in Hospital A. For example, in response to opinion (1), we changed the meal menu to reduce the amount of water used for cooking as much as possible. In response to opinion (4), the keys for opening each storage room and the location of the vehicles used for transport were specified and clearly indicated on the action cards. We then administered a questionnaire to the 12 medical staff members regarding the improved action cards based on Table 4. As a result, it was found that the improved action cards was easier to handle and that almost no points were difficult to understand.

Following the investigation, the action cards developed and improved upon for this study were officially adopted as a disaster preparedness manual for Hospital A at a management meeting and were approved for use as a standard for meal provision behaviour during a disaster.

Table 4. *Opinions received from Hospital staff participants and corresponding improvements made to action cards*

No.	Participant opinions and feedback	Improvements to action cards
1	Difficulty transporting water.	The menu was changed, and water used for cooking was reduced as much as possible.
2	Some disaster food requires tableware.	Disposable tableware was used in the hospital.
3	Food for general staff should also be transported.	The purpose of this study was to provide meals to inpatients; the provision of meals to hospital staff is beyond the scope of this study.
4	Need to clearly indicate where equipment will be stored.	The keys to open each store and the location of the vehicles used for transport were recorded and clearly indicated on the action cards.
5	The size of the action cards is too large.	The font size of the text on the action cards was slightly reduced.
6	The string gets in the way when turning the pages of the action cards.	The strings were changed to nameplate strings.

Conclusion

The continuity of medical services during a disaster contributes to the social safety. This study focused on the provision of food to inpatients as a medical service in the disaster context. We clarified the requirements for the action cards used in this study and the points to be considered when creating them. We verified the effectiveness of the action cards by using them for a disaster drill at Hospital A. We can assume that the requirements for the action cards and how to achieve them are applicable not only to food provision but also to other medical services. However, this has yet to be verified. Future work should also verify our proposed food method in other hospitals.

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Moving hospital care to the patient's home. Implications for value co-creation and its actors

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Abstract

Facing challenges of higher healthcare demands, an aging population, budget constraints, and scarcity of healthcare staff, new ways of organising healthcare are needed. One example is hospitals at home (HaH), where in-patient care services are delivered in patients' homes instead of hospitals. HaH is often supported by digital technology such as self or distance monitoring, as well as around-the-clock support from the hospital. However, it is critical to operationalise the organisation of HaH to ensure envisioned efficiency gains and impacts on value-creation. This paper explores how different enrolment strategies affect value-creation and patients' acceptance of HaH programmes. A qualitative case study approach was employed, utilising semi-structured interviews with diverse healthcare professionals and key informants. The study suggests that ESD (early supported discharge) may realize more value, while AA (admission avoidance) may have higher acceptability due to differing patient interactions and expectations. Effective expectation management and early information are crucial for improving acceptance of HaH programmes. These findings imply that tailored strategies are needed to balance value-creation and patient acceptance in HaH programmes.

Keywords: value-creation, transformation, Hospitals at Home, healthcare services, digitalisation

Introduction

Facing challenges of higher healthcare demands, an aging population, budget constraints and scarcity of healthcare staff, new ways of organising healthcare are needed (Denecke, May, Borycki, & Kushniruk, 2023). One example of a rather recent way of organising healthcare is *Hospital at Home* (HaH). HaH is an emerging type of acute care where treatment and monitoring of patients are carried out in the home instead of in the hospital (Brody et al., 2019). HaH as an approach can, among other things, alleviate pressure on ordinary health care services during surges in hospitalisations such as during pandemics (Pandit, Pawelek, Leff, & Topol, 2024), it can lower patient risks for hospital related infections and other adverse events (Hecimovic, Matijasevic, & Frost, 2020), and it can decrease risk for institutionalisation among older adults (Goodwin, Howrey, Zhang, & Kuo, 2011). Many sources state that it is also more cost efficient than regular health care, though those results are still being debated (De Sousa Vale, Franco, Oliveira, Araújo, & Sousa, 2020).

As HaH is a recent phenomenon, many different care models have been described as HaH (Denecke et al., 2023; Lai et al., 2021; Leff et al., 2022), leading to controversy over the model's efficacy and definition. The definition used here is that of Leff & Montalto (2004) which emphasises that HaH is a complete substitute for inpatient admission (with 24-hour level access to hospital-level care). HaH should provide an intensity of care similar to that provided in the hospital, and the care it provides cannot be provided by usual community-based home care services. Denecke et al. (2023) found five types of services that are typically included in HaH programmes: *diagnostics-related services* such as blood testing or tele-ultrasound; *monitoring-related services* such as phone or video appointments with hospital staff, telemonitoring of vitals, or nurses visiting in the home; *treatment-related services* such as administration of medications, rehabilitation, palliative care support, or therapists visiting in the home; *accompanying services* such as visits from social workers or patient education; and *emergency handling*, i.e. a 24/7 telephone hotline for emergencies. Some of these services can only be carried out in person, but quite a few can be carried out remotely – depending on the particular HaH programme and the individual patient.

There are mainly two ways in which patients are enrolled in HaH programmes. Most common is having the hospital's emergency department (ED) triaging and directing patients to HaH without admitting them to the hospital, referred to as *admission avoidance* (AA). Patients can also be enrolled in HaH programmes after triage through phone, though that is rarer. The other alternative is to discharge hospitalised patients before their treatment is finished, continuing their treatment at home –*early supported discharge* (ESD) (Denecke et al., 2023) Research has shown that AA may be more beneficial than ESD in terms of clinical outcome and cost, but these results are preliminary (Leong, Lim, & Lai, 2021). In this paper, AA and ESD will be referred to as *enrolment strategies*. Irrespective of enrolment strategy, patients are evaluated on medical and social criteria, and if their condition and circumstances are not deemed stable enough, they will be kept at – or admitted to – the hospital.

The setup of treatment and included services may influence acceptance of HaH as an alternative to hospitalisation (Lai et al., 2021). It is probable, therefore, that also the choice of enrolment strategy may influence patients' acceptability of being included in the HaH programme. However, prior research on patients' and caregivers' reasons for accepting or declining enrolment in HaH programmes is limited, but Saenger et al. (2020) identified key reasons for acceptance and refusal of HaH programmes. The main reasons for acceptance include being more comfortable at home (78.2%), having family around (40.7%), and avoiding exposure to other sick people (22.7%). Conversely, common reasons for refusal include preferring hospital care (15.0%) and concerns about HaH meeting care needs (12.9%).

Unclarity exists regarding how enrolment strategies (Leong et al., 2021) and included services (Denecke et al., 2023) might influence patients' acceptance of HaH as an alternative to hospitalisation and also how the service value-creation is influenced. The purpose of this paper is to explore how different enrolment strategies may affect the subsequent value-creation in, and patients' acceptance of, HaH. The purpose is operationalised into two research questions:

- How is value-creation in HaH programmes affected by enrolment strategy?
- How are patients' acceptance of HaH programmes affected by enrolment strategy?

Relating to the first research question, the view on value-creation in this paper draws on Grönroos & Voima (2013) in that value is seen as created by customers in their own sphere. In this context, "customer" refers to those for whom the organisation creates value – patients as well as others, such as next of kin. In the provider sphere, providers can support customers' value-creation by generating or combining resources. Traditionally, work to enhance value by quality improvement initiatives have focused on the provider's sphere (Martin, Elg, & Gremyr, 2019; Wen, Sun, & Yan, 2022). For services however, which are based on interaction, it is critical to focus on the joint sphere in which customers and providers interact (Grönroos & Voima, 2013). In healthcare services, both technical processes (what is delivered) and interpersonal processes (how it is delivered) (Donabedian, 1988) occur in the joint sphere, shaping the perception of both technical and functional quality (Grönroos, 2011).

In relation to the second research question, customers' perceived quality is shaped by their expectations as well as their experiences of a service (Grönroos, 2011). This applies to enrolment strategies in that an already hospitalised patient (i.e. enrolment through ESD) will have different expectations and experiences as compared to a patient without previous hospitalisation (i.e. enrolment through AA). Thus, the enrolment strategy will affect the patient's perception of service quality. In this paper, we argue that the same framework can be used to discuss patients' acceptance of enrolment. This is an important area of HaH research since patients who willingly accept healthcare services are encouraged to more actively participate in their own care, thus positively impacting their health outcomes (Abrahamsen Grøndahl, Karlsson, Hall-Lord, Appelgren, & Wilde-Larsson, 2011; Gallan, Jarvis, Brown, & Bitner, 2013).

Methods

As HaH is a contemporary issue that is studied in its natural setting, a qualitative research approach (Meredith, 1998) with a case study design is deemed suitable (Voss, Tsikriktsis, & Frohlich, 2002). The empirical case category (Dumez, 2015) is enrolment strategies to a HaH programme, whereas the theoretical case category (Dumez, 2015) is value-creation and patients' acceptance of HaH.

The data collection is based on semi-structured interviews (Kvale & Brinkmann, 2009) from a single-case setting at a clinic about to launch a HaH programme. To capture a range of perspectives the interviewees were chosen to represent physicians, nurses, improvement specialists, and managers. In total seven individual interviews were conducted (see Table 1), each lasting 60-90 minutes, recorded and transcribed verbatim. Interviews were conducted in Swedish. Quotes have been translated to English. To ensure anonymity, pseudonyms are used when referring to the interviewees.

In addition to the case study, two key informant interviews (Patton, 2015) were conducted with three individuals each having over a decade of experience in HaH. The first interview was exploratory, discussing overall HaH experiences, while the second, conducted after initial case analysis, focused on enrolment strategies' impact on value-creation and acceptance of HaH. The second interview served both to gather data and validate initial findings. Both lasted 60 minutes and were conducted in English.

Table 1. *Overview of respondents*

Type of interview	Pseudonym	Role
Case interviews	Eivor Robertsson	Nurse
	Isabella Sörensen	Manager
	Laila Adolfsson	Nurse
	Ulrica Ljungborg	Nurse
	Vivian Gerhardsson	Physician
	Gunnel Lundquist	Improvement specialist
	Emelie Wallin	Physician
Key informant interview 1	Maureen Cunningham	HaH Assistant Director
	Bridget Ormond	HaH Head of Service
Key informant interview 2	Bridget Ormond	HaH Head of Service
	Erin Keeley	HaH Team Manager

Interview data were analysed using QSR NVivo. Analysis involved initial open reading of transcripts followed by iterative coding integrating deductive and inductive approaches. This abductive method involved continuous refinement between empirical data and existing literature (Dubois & Gadde, 2002). Deductive coding focused on enrolment strategies (Denecke et al., 2023), while inductive coding addressed staff concerns about HaH programmes. To ensure rigor, one co-author, not involved in data collection, provided additional perspectives (Eisenhardt, 1989).

Results

This chapter presents three tables detailing how different enrolment strategies impact HaH services and patient acceptance, illustrated and discussed using interview data.

Impact of HaH enrolment strategy on the value created for patients

Table 2 maps HaH service categories from (Denecke et al., 2023) to enrolment strategies, excluding "Treatment-related services" due to dependency on diagnosis and monitoring, and "Emergency handling" which commences post-enrolment and remains unaffected by the enrolment method.

Table 2. *Mapping of HaH services to enrolment strategies*

Services (Denecke et al., 2023)	**ESD**	**AA via ED**	**AA via phone**
Diagnosis-related services	Diagnosis and decision to enrol patient in HaH programme is made in inpatient ward after extended observation and tests.	Diagnosis and decision to enrol patient in HaH programme is envisioned to be made in the emergency department after observation and tests.	Diagnosis and decision to enrol patient in HaH programme is made over phone based on information relayed in the phone call and other remotely accessible information.
Monitoring-related services	By the time of enrolment in a HaH programme, patient has already spent time, and built relationships with, inpatient staff. Staff, in turn, have had time to gain an understanding of patient's life and circumstances.	When enrolled in a HaH programme, patient has not spent any significant time with inpatient staff.	Same as AA via ED.
Accompanying services	Between the point of enrolment in a HaH programme and actually leaving the hospital, staff can provide the patient with in-person education and training, even allowing the patient a trial period to test equipment and get accustomed it.	After enrolment in a HaH programme, patient needs to be educated and trained either during appointments or remotely.	Same as AA via ED.

Table 2 outlines how the enrolment strategy impacts key aspects of the HaH service: diagnosis and enrolment decisions based on inclusion criteria; relationship building between patient and inpatient staff (non-explicit part of the service offering); and patient education. These three areas are described below.

Diagnosis and enrolment decision based on inclusion criteria

With AA the time for inpatient staff to observe patients and run tests is decreased. As noted by physician Emelie Wallin, this is not necessarily a bad thing, since this may decrease the number of unnecessary interventions and tests that are done:

“We poke and prod on things on the patient all the time, so there is a risk of us doing unnecessary interventions. Some things would have resolved themselves if only one had waited.”

On the other hand, and observed by the same physician, decreased time with the patient may lead to physicians feeling pressured to *not* make necessary tests and to make decisions based on too little information, causing increased margins of error.

HaH Team Manager Erin Keeley was not concerned. She explained that GPs, care homes, ambulance staff, and other accepted referrers provide information for HaH specialists to triage within ten minutes by phone. Head of Service Bridget Ormond added that families and patients cannot self-refer: *“It has to be a clinical referral.”* A new evaluation is conducted when the mobile team reaches the patient's home to ensure the phone decision is correct. Keeley noted their enrolment strategy reduces patient wait time for treatment.

“We have a two-hour "referral to treatment" time, so our service needs to be out in that patient's home within a two-hour time frame. And the chances are, if that patient was put in an ambulance and brought to one of our hospitals, they would be still sitting outside the hospital in an ambulance waiting on triage at the hospital at ED. Within two hours, they wouldn't have gone through triage at the ED. So we're definitely a quicker service and we, as I say, we've got two hours to get out there and start treating the patient.”

Thus, the decreased time for diagnosis in AA, as compared to ESD, can have mixed effects on the value created for patients, largely dependent on the setup of the HaH programme. An interesting point made by the key informant interviewees was that it is more natural for hospitals to have an ‘ESD mindset’, whereas community based services naturally have more of an ‘AA mindset’.

“That's why you are potentially focusing a bit more on early supported discharge, because it is linked to the patients that you have in front of you in the hospital, whereas that is the opposite of what we are. We're out in the community and go to the hospital as and when [needed]*. So it nearly is the flip of that.”*

– Bridget Ormond, HaH Head of Service

Relationship building between patient and inpatient staff

Developing relationships between patients and staff was mentioned as important in some cases for communication to be effective.

“Some patients don’t seem to care [who they talk to]*. But for example, if I have someone with both type 2 diabetes and bipolar disorder, then I know that a follow-up call will never be ‘just a follow-up’. In those cases, it’s good to have the same nurse who knows the patient. So, it will depend on their history and what type of patient they are.”*

– Laila Adolfsson, nurse

As pointed out by improvement specialist Gunnel Lundquist, it can also be an important factor in making patients feel safe:

"Patients feel very safe when it's very few different people who meet with them or who answer the phone. It's very good. It's more difficult for large clinics to have that type of continuity which patients expect, but it is possible when [some members of staff] *work in smaller groups with the same thing. But it cannot be too few people either, because then it becomes vulnerable."*

Continuity in the relationship can also increase a more holistic treatment of patients by knowing what is and is not normal for that individual.

"You don't have this contact with the patient and the same sense of responsibility as if you meet them here [in the hospital] *and promise them that 'I will personally follow up your lab results'.* […] *If those lab results end up with someone else, they might think that they are normal* [and not tell the patient]*."*

– Isabella Sörensen, manager

Building trust and relationships, though not explicitly part of the HaH service, can significantly impact the value created, as discussed earlier. Strong relationships may increase patients' likelihood of sharing sensitive information crucial for determining HaH eligibility, such as living in unsafe conditions. In AA scenarios, where time for trust-building is limited compared to ESD, there's a risk that important information could be missed, which might have been detected if the patient were hospitalised. This risk can be minimised through rigorous admission procedures and strategic use of physical visits and home calls.

"We get to see how everything works in the patient's home environment and we get another picture when we step through their door. When the patients come to the hospital, we only see them here. We get a broader picture [through house calls]*."*

– Vivian Gerhardsson, physician

Because, as pointed out by manager Isabella Sörensen, digital meetings cannot completely make up for not meeting in person:

"The digital visits do not have the same presence and it is more difficult to understand who you are talking to, for example if they squirm when asked about drug abuse. You lose the sense, maybe a feeling in your stomach, of who the person in front of you are."

Patient education

Time is also a factor when educating and training patients in the usage of equipment. Multiple interviewees mentioned that patients are, for example, encouraged to check their own temperature while in the ward and report it to the nurses. In the same way, patients could be allowed to borrow and practice using equipment in the ward for several days overseen by staff before being discharged. Such prolonged training sessions are only possible with ESD and may in some cases lead to better outcomes, as compared to AA.

Impact of enrolment strategy on patients' acceptance of HaH

Tables 3 and 4 map reasons for accepting or refusing enrolment in HaH programmes from Saenger et al. (2020) to enrolment strategies. Reasons not specifically related to enrolment strategies are excluded from the tables and analysis, such as concerns about visitors at home, inconvenience of HaH, perceived social support at home, physician persuasion, and concerns about family illness. Additionally, the reason "patient being discharged imminently" is excluded as it does not allow for comparison between ESD and AA for already admitted patients.

Table 3. *Mapping of reasons for patients' acceptance of HaH to enrolment strategies*

#	Reasons for acceptance of HaH (Saenger et al., 2020)	ESD	AA via ED	AA via phone
A	**More comfortable at home**	Patient is not at home before enrolment in HaH programme.	Patient visits the ED for enrolment process but can return home the same day.	Patient stays at home during enrolment process.
B	**Like having family around**	Family restricted to visiting hours prior to enrolment in HaH programme.	Brief parting from family during visit to the ED.	Can have family around continuously.
C	**Able to do things around the home**	Not able to do things around the home before enrolment in HaH programme.	Able to do things around the home except during visit to the ED for enrolment process.	Able to do things around the home with no interruption.
D	**Away from other sick people**	Exposed to other sick people before enrolment in HaH programme.	Brief exposure to other sick people during visit to the ED.	No exposure to other sick people.
E	**Bad previous hospital experience**	Patient may have or relive a bad experience during hospitalisation.	Brief period during visit to the ED where patient may be having or reliving a bad experience.	No physical exposure to hospital environment.
F	**Fear of not returning home from hospital**	Patient already hospitalised – fear already fulfilled.	Patient avoids hospitalisation – fear avoided.	Patient avoids hospitalisation – fear avoided.

__Table 4.__ Mapping of reasons for patients' refusal of HaH to enrolment strategies

#	Reasons for refusal of HaH (Saenger et al., 2020)	ESD	AA via ED	AA via phone
G	**Prefer to receive care in the hospital**	Patient receives care in hospital and is then given the option to enrol in HaH programme.	Patient may receive some in-hospital care in the ED but is not hospitalised before enrolment.	Patient receives no in-hospital care before enrolment.
H	**Concern that HaH would be insufficient to meet care needs**	An extended period exists when inpatient staff may try to address patient's concerns through information.	The period for addressing patient concerns is short.	Same as AA via ED.
I	**Caregiver needs respite**	Some respite for caregiver while patient is hospitalised.	No respite for caregiver.	Same as AA via ED.
J	**Concern that home environment is unsafe**	An extended period exists when family members may be able to address the concerns.	No time to address the concerns.	Same as AA via ED.
K	**Need to consult with PCP before agreeing to HaH**	An extended period exists where patient can consult with PCP.	Limited possibility to consult with PCP before enrolment decision.	Same as AA via ED.

Table 3 and table 4 show how enrolment strategies address different reasons in different ways. In the tables, three categories of patient wants and needs can be identified: wanting things that are not possible in hospital (reasons A, B, and C); wanting to minimise risks or address concerns (reasons D, F, H, I, J, and K); and personal preference for or against being hospitalised (reasons E and G). These three areas are described below.

Wanting things that are not possible in hospital

For patients who want things that are not possible to do or have in hospital (A, B and C), AA has clear benefit over ESD since it minimises the time patients spend in hospital.

In the case of risk minimisation, however, AA and ESD demonstrate different strengths. AA is superior in addressing the risk of not returning home after hospitalisation (F), as well as the risk of exposure to hospital related illness (D).

> *"If you're staying in the hospital, there is an increased risk that you will be infected by something."*

– Eivor Robertsson, nurse

AA does not, however, allow much time for patients and caregivers to address different types of concerns. Of course, some concerns cannot be addressed no matter the amount of time available – for those the enrolment strategy will not matter.

"Not all patients want [HaH]*, because they think that it's better to stay in the hospital. It's not like just because we think that 'if you get to be with your family, you will want this'. Instead, they might think that 'no, it's much safer to stay in the hospital'."*

– Gunnel Lundquist, improvement specialist

Wanting to minimise risks or address concerns

For concerns that require a matter of days or weeks to be resolved, ESD may be an alternative. While the patient is hospitalised, worries about the sufficiency of HaH can be addressed (H), a PCP can be consulted (K), family members may be able to remedy a problematic home environment (J), and a tired caregiver may have time to recover (I). In other words, patients that refuse enrolment by AA should not be written off as candidates for HaH; they may come around to being accepting of ESD if the time spent in hospital is used to address their concerns.

"We had a patient who had been with us in the hospital for three weeks already. I told her that: 'everything looks good, we can discharge you with continued policlinical support'. At first, she thought it wasn't a good idea, so we said: 'think about it and you can decide tomorrow'. And then she started to digest the idea and […] *she went home and could be at home for several weeks.* […] *I met with her afterwards and she thought that it was very good that she had been able to go home, even though it felt a bit scary."*

– Vivian Gerhardsson, physician

However, as pointed out by Ormond and Keeley, giving caregivers' a respite by hospitalising a patient may not only make them lose confidence in their own ability to care for their family member, but may even cause prolonged time for the patient in hospital.

Personal preference for or against being hospitalised

When it comes to personal preferences for or against being hospitalised, AA may be optimal for patients who want to avoid hospitalisation (E), and ESD may in some cases work as a compromise for patients who initially wanted to be hospitalised (G). For as nurse Ulrica Ljungborg said:

"It can be really boring to stay in the hospital if you don't have any major ailments or care needs. Perhaps you're only receiving a few short controls per day, but you still have to stay in the hospital all the time."

On the other hand, from the experience of HaH Assistant Director Maureen Cunningham, it is often difficult to enrol patients in HaH programmes once they have been hospitalised, because once the family and patient are in the hospital, they develop a preference for hospitalisation; they want to stay and 'get it done'.

Cunningham noted that not only do patients and families develop such a preference, but doctors often have it as well. As a consequence of this, it is much easier to turn someone around in the ED, because once a patient has a bed, it is difficult to make the doctors let go. This sentiment was echoed by improvement specialist Gunnel Lundquist:

"There will be some doctor saying: 'No, that patient should not go home', despite the patient qualifying for it. But a doctor who doesn't have that experience, they will think that it is safest for the patient to stay in the hospital. We are all so very different when it comes to thinking about safety."

Erin Keeley described how their HaH programme work to counteract this phenomenon:

"*We have* […] *specialist nurses. And they will attend ED each morning to look at who's in ED. They'll consult with ED staff. They'll look at the* […] *lists. They'll look at nursing home admissions throughout the night, and they will go and case find either in ED or up on the baseline wards to try and take that patient out again."*

Bridget Ormond noted that this happens in collaboration with doctors on the ward and that it must typically happen within a set time frame:

"*By day three, day four, they're not sick enough to come on to acute care at home, at that stage the window has gone. If it's going to happen that somebody comes out through acute care at home, really, you're talking within the first 24 up to 36 hours that we would be wanting to catch those people. Much beyond that they're towards that point where they're just being monitored or they're continuing on a type of a treatment."*

Discussion

Our findings suggest that the enrolment strategy for HaH programmes influences both the services provided and patient acceptance. This chapter explores its impact on value-creation and patient acceptance in HaH, discussing each in turn.

More time for joint value-creation in ESD than in AA

For staff to correctly diagnose a patient or evaluate them for enrolment in HaH programmes, information must flow from patient to staff. For patients to correctly understand their condition and follow instructions, information must flow from staff to patient through educational efforts. There is no predetermined minimum amount of time needed for all parties to absorb information, nor for the time required to build the trust needed in some cases. In AA the period spent gathering information is however, by design, significantly smaller than in ESD. Additionally, the results highlighted multiple situations where that decreased period can potentially negatively impact patient outcome, with only one example where decreased time can potentially have a positive effect (fewer unnecessary tests and interventions).

This decreased period for information exchange can be interpreted as AA having fewer activities in the joint sphere (Grönroos and Voima, 2013) than ESD, and thus also less room for interpersonal processes

(Donabedian, 1988). Drawing on Grönroos and Voima's (2013) model of value-creation, it can also be argued that the customer sphere – where the customer independently creates value facilitated by the provider – contains similar activities irrespective of enrolment strategy. However, the possibility for the provider to facilitate such independent value-creation can differ depending on enrolment strategy. As less time is spent on building relationships for patients that were enrolled using AA it is more difficult for inpatient staff to act as facilitators for value-creation. This means that, on the whole, there is a risk that less value is realised in AA than in ESD. Hospitals that offer both ESD and AA must create new ways of exchanging rich information and building trust with patients, otherwise there is a risk of less value being created for their AA patients than for their ESD patients. Mobile teams carrying out regular house calls could be an interesting venue to explore in this regard.

Although this analysis seems to point towards ESD as the superior enrolment strategy, there are complicating factors. The time patients spend in hospital in ESD may affect value-creation positively but by taking part in the ESD, patients may also be exposed to hospital related injury and illness, a risk that would have been diminished through AA strategies. More research, specifically statistical analysis of large patient volumes, is needed to show whether the risks of ESD outweigh its positive effects on value-creation, as compared to AA. Other complicating factors are those of patient expectations and experiences that may influence which enrolment strategy is the most effective.

ESD patients more difficult to enrol in HaH than AA patients

Patients offered enrolment in HaH programmes will have different frames of reference informing their decision to accept or refuse. Using the terminology of Grönroos (2011), they will have different *expectations* of what HaH entails depending on what has been communicated to them, and they will have had different *experiences* leading up to the moment of enrolment, both of which will affect their perceived quality of the HaH programme and their acceptance of it.

In ESD, patients are initially admitted to a hospital ward where staff inform them about the upcoming HaH care, including its purpose and duration. This communication shapes patient expectations about their hospital care. Introducing HaH later as an option conflicting with initial communications can lead to low patient acceptance, as it may not align with their expectations and could make them feel prematurely discharged. To enrol hospitalised patients in HaH programmes successfully, healthcare providers should manage expectations from admission, assess eligibility early, and provide information about HaH as a potential option. This proactive approach addresses patient concerns early, increasing the likelihood of acceptance if HaH becomes feasible.

Aside from expectations based on what is communicated, ESD patients will also get to experience in hospital care, i.e. receiving multiple check-ups each day, having direct access to staff at all hours, and in some cases building relationships with members of staff. Experiencing these (using the terminology of Donabedian (1988)) technical and functional processes will inform patient's perception of 'what healthcare entails' and how they should assess quality of care. It may also cause them to develop a preference for or against being hospitalised. Depending on their experiences, ESD patients may develop a fear of HaH not being sufficient to meet their care needs, since the impression they get on the ward is that the presence of staff and their continuous check-ups are either necessary for their safety or in some way preferable to being left to one's own devices at home. Information regarding the efficacy and benefits of HaH as well as the risks of hospitalisation (expectations management) may not be enough to convince patients that have had certain experiences (good or bad) in hospital. Consequently, healthcare providers need not only manage expectations from the moment of admittance, but also design the patient experience in a way that is conducive to a positive perception of HaH. Allowing patients to test monitoring themselves using HaH equipment, while still in the hospital, is one example of how patients can be given such experiences.

In contrast, patients enrolled in HaH programmes through AA have not spent time in hospital directly before enrolment. This means that AA patients, unlike ESD patients, do not have experiences that can be used to directly compare in hospital care with HaH care. This in turn means that experience plays a smaller role in AA patients' acceptance of HaH than it does for ESD patients. For example, an AA patient who has not experienced nurses physically checking in on them multiple times per day will not find it jarring to only check in once every morning with their nurse via video call, because they 'do not know what they are missing'.

Due to limited experience with technical processes, AA patients' acceptance is heavily influenced by their expectations, informed by comparable services and information about HaH. To increase acceptance, healthcare providers must manage expectations through early and accurate information. A challenge is the small window to influence expectations, often only during an ED visit or phone call.

Limitations and future research

The interviews in this paper only cover staff perspectives, which is a limitation. Future research should include patient perspectives, increase the number of interviewees, and diversify the types of care and enrolment strategies to validate the conceptual framework. Additionally, the theoretical framework needs strengthening for a more robust analysis.

Three areas for future research are suggested. First, an expanded theoretical framework and additional interviews could analyse role and relationship differences caused by enrolment strategies (Leff et al., 2022), such as the role of caregivers. Second, examining how different enrolment strategies are implemented from an organisational standpoint would enhance understanding of handling organisational challenges in HaH programmes. Third, exploring the effects of various HaH setups on value-creation and patient acceptance could reveal if differences in setups can counter those caused by different enrolment strategies, ensuring equal care levels.

Conclusions

The results in this paper suggest that the strategy used when enrolling patients in HaH programmes affects both the value created for patients and patients' acceptance of being enrolled. It was found that both enrolment strategies carry with them different types of risks for patients and that these need to be quantified further in future research. It was however also found that less value might be realised in AA (admission avoidance) than in ESD (early supported discharge) due to a decreased period of time available for joint staff-patient activities in AA. It was concluded that hospitals must therefore find ways to make up for the loss of these activities, e.g. by creating new ways of exchanging rich information and building interpersonal relationships without being dependent on patients having an extended stay in hospital.

Even though AA was found to possibly limit the realisation of value, ESD was not found to necessarily be the superior enrolment strategy from an acceptance point of view. ESD patients will have had their expectations shaped by their experiences as patients in hospital, which may make it difficult for them to accept an alternative way of receiving care. It was concluded that proactive expectations management and staff informing patients about HaH programmes early on might be one way to mitigate that risk.

In summary, ESD may realise more value, but AA may have increased acceptability. If patients do not accept enrolment, no value can be realised through HaH, despite it being a comparable (and sometimes superior) healthcare option. Further research is needed to quantify and compare the different strategies' efficacy depending on other factors, such as the setup of the HaH programme and its access to advanced monitoring equipment.

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Track 3: Sustainability in Tourism

Sustainable Practices in Small and Medium-sized Hotels. An Approach to the Case of the Basque Country

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Abstract

Tourism plays an important role due to its economic and occupation potential, especially in Europe where this sector employs 10.9 million people, constituting a substantial portion of the non-financial business economy. However, the exponential growth of the tourism industry has raised environmental concerns, prompting a demand for more sustainable travel options. The impact of tourism on the environment is highlighted, especially through energy use, wastewater, and solid waste production in accommodations. The hospitality industry has responded to these concerns by adopting green practices, with a focus on eco-friendly concepts like "eco hotels". Hotels are increasingly going green for various reasons, including cost savings, and responding to rising consumer awareness of environmental issues. Sustainability efforts are often expressed through green labels on websites to reassure eco-conscious tourists. The research aims to determine the state of art on sustainability in tourist accommodations, emphasizing small and medium-sized enterprises (SMEs). Furthermore, an analysis on the websites of small and medium-sized hotels located in the Basque Country was conducted to assess their incorporation of ecolabels and communication regarding sustainable practices. Also, the emergence of a new group of tourists, termed "sustainable", "responsible", or "eco-conscious" is driving hoteliers to adapt their supply to meet this demand. However, challenges in translating tourist attitudes into behavior and implementing sustainable practices without compromising guest satisfaction are acknowledged. The study concludes by emphasizing the critical role of SMEs, calling for further research into practical strategies for overcoming identified barriers and fostering for more sustainable future for the hospitality sector

Keywords: Sustainability, Tourism, Ecolabels, Customer satisfaction, Certification

Relevant Topic: Fostering sustainable transition

Introduction

Tourism plays an important role due to its economic and occupation potential, especially in Europe. Some of the key influencers on travel and tourism in recent years have been globalization, digitalization and sustainability. Ease of mobility, increased awareness of new destinations, and the internet as a source of information and commerce have caused this market to grow exponentially. Yet with this growth has also come increasing public concern about the industry's impact on the environment, resulting in consumer demand for more sustainable travel options (Statista, 2023).

Tourism is a complex industry connected with various activities and value chains, causing 8% of the global carbon emissions in 2013 (Toshima et al., 2021). The human activities and behaviors of tourists more strongly affect the environment when compared with those of resident people (Li et al., 2023). A European tourist consumes approximately 300 L d-1 of water whilst a normal resident 100-200 L d-1. Moreover, the total waste generation average is 1.98 kg (6 L) per guest per night (Gössling et al., 2011).

Tourism demand has changed significantly with the advent of the Fourth Industrial Revolution. The most notable is the demand for green, environmentally friendly products and services (Chang, 2011). There is a need for a business's engage in green innovation to produce green products and services that meet the needs of consumers, promoting green consumption (Xuan Dam et al., 2023).

The debate on sustainable tourism is not new; the term sustainable tourism emerged in the late 1980s (Tiago et al., 2021). The World Tourism Organization (UNWTO) defined sustainable tourism, also known as ecotourism or green tourism, as "a form of tourism that attempts to take responsibility for its current and future economic, social and environmental impacts, by looking at the needs of visitors, the industry, the environment, and host communities" (UNWTO, 2023b).

In recent decades, a growing body of scientific literature has addressed the grave sustainability problems related to tourism activity and economy. Scholars have looked critically at the immense CO_2 emissions stemming from the increasing number of air travelers as well as the excessive consumption and waste of water, energy, food, and other resources due to unsustainable practices and technologies in the hospitality and catering sectors (Gössling et al., 2012; Manniche et al., 2021). Research regarding sustainability issues is becoming an increasingly vital area in this service-driven tourism sector (Islam et al., 2020). Recently, researchers have advocated that the demand for sustainable tourism services is on the rise. Thus, to meet increasing demand, tourism firms are changing the behavior and are increasingly looking into sustainable strategies and offering eco-friendly services (Islam et al., 2020). The United Nations Sustainable Development Goals (SDGs) further highlight the importance and responsibility of the tourism and hospitality sector to engage, contribute and make a difference to sustainable development (Shereni et al., 2023).

The accommodation sector plays a crucial role in driving local economies and generating employment opportunities. In March 2022, conscious travelers worldwide were asked what challenges they faced when trying to travel in a sustainable and socially conscious manner. 48 percent of travelers said the hardest part about travelling sustainably was choosing sustainable accommodation (Statista, 2023a). This underscores the critical importance of focusing on sustainability within the hospitality sector.

Tourist accommodation is a complex subsector of tourism that contains, amongst others, hotels, resorts, serviced apartments, lodges, guest houses, holiday homes, cottages, and shared accommodation (Warren & Becken, 2017). With the extraordinary growth of the hotel industry over the years, hotels are also facing pressure to be environmentally responsible, take due care and adopt environmentally friendly activities that do not harm the environment (Nisar et al., 2021). Since they are directly responsible for environmental issues such as water, energy and waste, the pressure to be environmentally friendly is stronger in hotels (Kizanlikli et al., 2023).

The hotel sector is one of the tourism industry's largest drivers of employment and economic revenue as mentioned before but at the same time it is one of the most energy-intensive. In fact, hotels and other types of accommodation account for 2% of the 5% global CO2 emitted by the tourism sector (UNWTO, 2023a). Accommodation is the third highest energy-consuming item (after travel and transport) in tourism due to the high energy consumption for heating or air conditioning (up to 50% in some cases), hot water and cooking (Beccali et al., 2009). The hotel sector is responsible for a large share of the environmental impacts of tourism because of its high energy and water consumption and waste generation (Razumova et al., 2015). Tourist accommodations should focus on decreasing the consumption of energy and water as well as increasing waste management, recycling and green purchasing, thereby shifting from a linear to a circular model (Li et al., 2023).

Hospitality industry has focused more on a wide variety of green hospitality practices to mitigate its negative impact on the environment and meet the growing environmental concerns of consumers (Merli et al., 2019). Together with the development of an understanding of sustainability in tourism, the "eco hotel" concept has gradually become more and more important. Eco hotels are those that conserve water and energy, reduce solid wastes, use recycling and reuse programs, and generate sustainable environmental planning and economic solutions (Kizanlikli et al., 2023). Today, due to the problems arising from the relationship of tourism and environment, most hotels have had to adopt environmentally friendly practices in order to minimize their harm to the environment and attain a greater market share (Kizanlikli et al., 2023).

Eco-friendly hotels are defined as "nature-oriented, environmentally focused and environment friendly in use of energy, water, and materials that do not exacerbate impacts on the earth and environment" (Sadiq et al., 2022). Eco-hotels (also known as green hotels) are environmentally friendly rest areas which follow sustainability principles and adopt ecological practices in their operations in order to help to protect the world. Terms such as "green hotel" and "green hospitality" are keywords that have attracted many recent studies in the literature. Evaluation of the green performance of units is a key task to achieve sustainable development (Wang & Nguyen, 2022).

Hotels go green for a variety of reasons, including cost savings, public funding, staff commitment, public scrutiny, investor relations, and general societal good. However, one of the primary motivations for hotels to go green is to respond to rising consumer awareness of environmental issues (Kizanlikli et al., 2023).

One of the strategies used by hotels to promote their sustainability is expressed through the green labels displayed on their websites, which allow the "eco-conscious" tourists to be reassured when booking online. This label is defined as a "management tool that can visually inform customers of new green features of a product” (Yildiz et al., 2023). According to the source, as of February 2022, 78 percent of travelers are intending to stay at least once in an eco-friendly or green accommodation when looking at the year ahead (Statista, 2022b).

The research was motivated by two key questions pertaining to sustainability within the tourism accommodation sector:

Research question 1: How is sustainability manifested in the operations and practices of tourism accommodations?

To address this research question, we have delved into existing literature related to sustainability practices within tourism accommodations. This exploration aims to determine the current state of the art and identify any existing gaps in this field.

Research question 2: What factors hinder or facilitate the implementation of sustainable practices in the hospitality industry?

The purpose is to drivers influencing the adoption of sustainability strategies in hotels.

Methods

A comprehensive literature review on sustainability in tourist accommodations was conducted. The literature review was conducted following the guidelines of the PRISMA protocol (preferred reporting items for systematic review and meta-analysis) proposed by Moher et al., (2009). Data collection encompassed a comprehensive search strategy, which not only included established scientific databases such as Scopus and Web of Science (WoS) but also extended to the exploration of grey literature sources, including UNWTO, Eurostat and Statista. This approach aimed to capture a broad spectrum of information and insights relevant to the research objectives.

The search was based on the following formula: TITLE-ABSTRACT-KEYWORDS (("Sustainable touris*" OR "Circular touris*" OR ecotouris*) AND (sustainability OR "circular economy") AND (Hotel* OR accommodation* OR "hospitality sector")).

A descriptive analysis was conducted using bibliometric analysis to explore and identify the impact on the field of sustainability assessment in tourist accommodations. In this section, 87 articles were assessed. The study employed a qualitative content analysis approach to examine the relationships between established concepts and the text using the software MAXQDA.

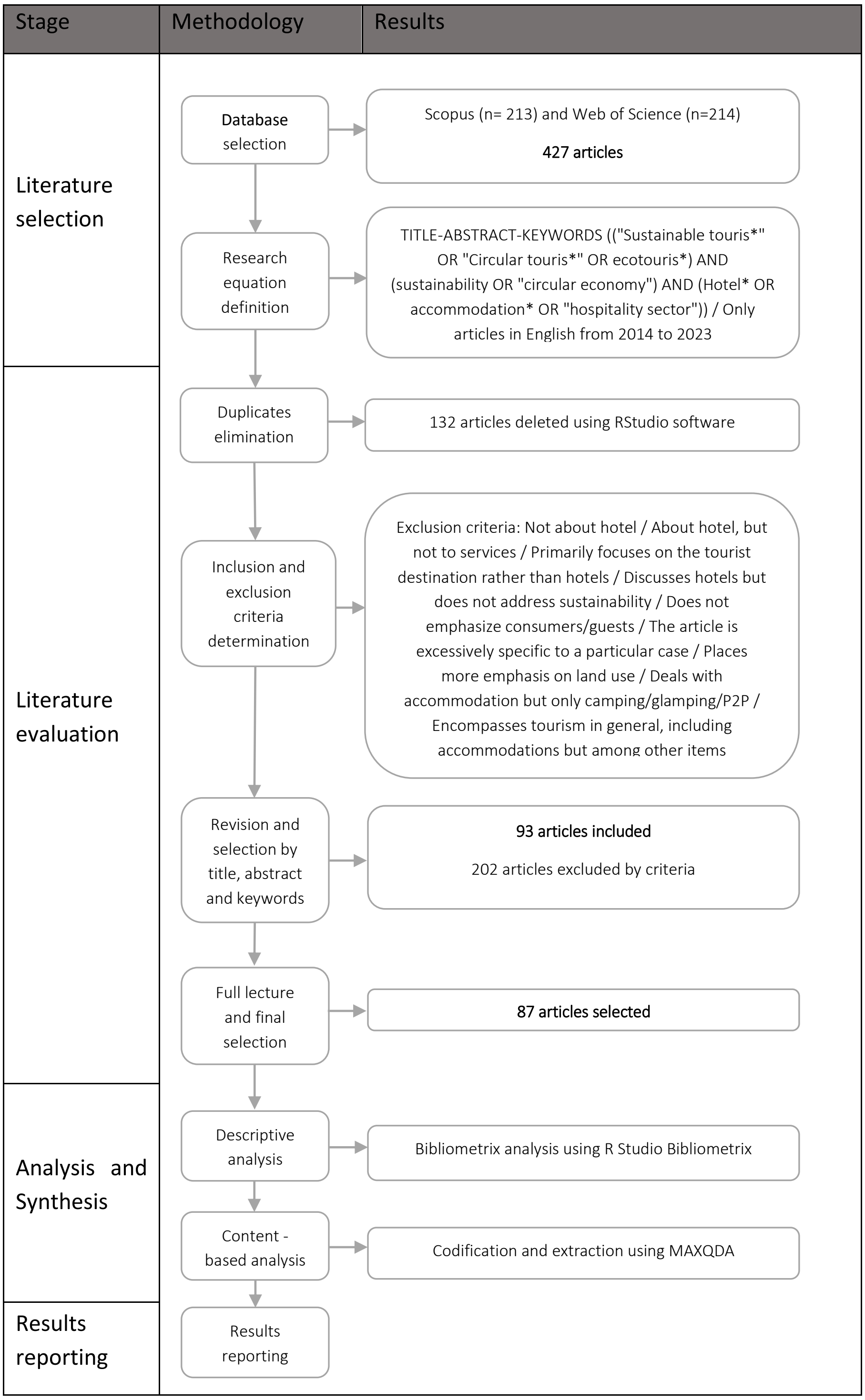

Figure 1*. Literature review procedure.*

In order to study the situation in the Basque Country, the information provided by these companies of thon their websites was studied.

Results and Discussion

After an in-depth analysis of the 87 articles and encoding concepts, it is imperative to highlight several key findings. Firstly, the study emphasizes the pivotal role of small and medium-sized enterprises (SMEs) within the discourse. Furthermore, a recurring theme underscores the importance of effectively communicating sustainability implications through eco-labels Small and Medium-sized Enterprises (SMEs)

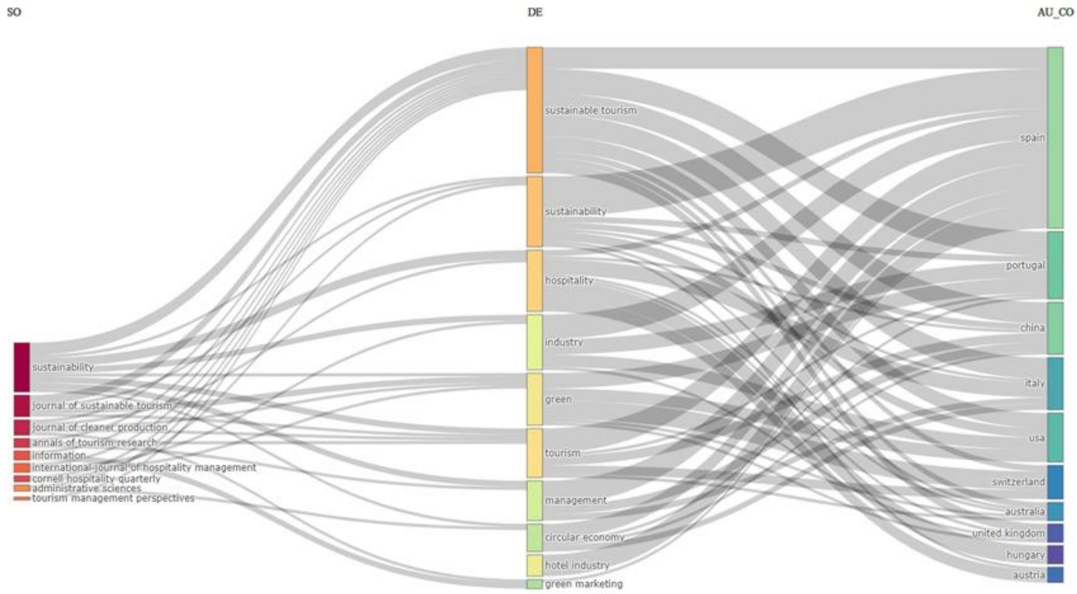

Figure 2. *Sankey diagram*

Small and Medium-sized Enterprises (SMEs)

The important role that small and medium-sized enterprises (SMEs) could play in the race for sustainability cannot be ignored. Much academic and public attention has been paid to sustainability initiatives from large corporations, however, collectively, SMEs are among the most common form of enterprises in Europe (Yildiz et al., 2023). And even though these enterprises can respond slower than larger multinational business to calls for sustainability and reduced environmental impact, their footprint should not be overlooked (Leonidou et al., 2017).

Today, digital transformation and sustainability are increasingly two interrelated challenges for SMEs but at the same time they open new opportunities for these enterprises. Enterprises in hospitality industry and notably hotels, have taken various actions to declare their commitment to sustainable tourism, such as having eco-labels or adopting environmental management systems. (Yildiz et al., 2023).

A circular economy approach encourages even small companies to review their operations, material resource flows and supply chain linkages. Collectively, these strategic considerations can eliminate waste and reduce costs considerably, whilst providing an increased understanding of supply chains, improving the company's brand, competitive profile and innovation potential (Manniche et al., 2021). Adopting a circular economy approach presents an opportunity for tourism business, especially for SMEs to enhance their innovation and achieve resource efficiency through a system-wide approach that impacts the entire value chain, and there is a clear role for governments to play in facilitating this process (Li et al., 2023).

Hotel Energy Solutions (HES) is a UNWTO-initiated project in collaboration with a team of United Nations and EU leading agencies in Tourism and Energy. The project delivers information, technical support and training to help SMEs in the tourism and accommodation sector across the EU 27 to increase their energy efficiency and renewable energy usage (UNWTO, 2023a). The project's focus on SMEs is particularly important, as the utilization of out-dated technologies, lack of human and financial resources and a limited awareness and knowledge on greener alternatives may all be contributing to decrease their competitiveness. In addition, SMEs are usually less proactive about the environment in comparison to larger hotel chains. In response to the challenge of climate change, HES provides an online mitigation toolkit: the HES e-toolkit to help hotels reduce their carbon footprint and operations costs, thus increasing business profit (UNWTO, 2023a).

Hotels are spending in the order of 10% or more of their operational budget on energy and water (Coles et al., 2016). While SMEs can contribute significantly to environmental conservation efforts, the responsibility does not solely rest on management. Guest rooms use over half of the total energy and water in a hotel. Human behavior is therefore a significant factor, and the interplay between technology, occupants' knowledge, cultural routines, and context needs to be better understood (Warren & Becken, 2017).

Eco-labels – Green certificates

All these factors have led to the proliferation of many certifications on issues related to sustainability management in the hotel industry (Rodríguez-García et al., 2023). In this way, certifications are understood as a mean to the commitment of a company toward sustainability, at the same time, that help consumers to identify "responsible" companies (Rodríguez-García et al., 2023).

Eco-labels are "trademarks or logos to communicate the company's environmental credential, with the hopes that customers develop positive attitudes towards their products or services" (Kizanlikli et al., 2023). Eco-labels are widely used mainly because of their benefits in attracting customers, reducing costs, and improving the environmental images of the enterprises. Therefore, eco-labels can be seen as an effective marketing tool. Eco-labels have emerged as evidence that hotels can share to confirm that they adhere to sustainable practices (Lo et al., 2014). The purpose for a sustainability certificate can be varied, such as promoting sustainability in the supply chain, attracting a more sustainable-minded clientele, informing visitors about environmental performance and corporate social responsibility, but perhaps one of the most important is cost reduction through better environmental management (Rodríguez-García et al., 2023).

Past studies have revealed that a hotel's eco-label certificate is effective in determining the buying decision of tourists. Eco-labels can influence consumers toward environmentally sustainable products (Potter et al., 2021). Some studies show that customers are often willing to pay more for environmentally friendly offerings (Kizanlikli et al., 2023). Yildiz et al. (2023) study the impact of the green label on online booking intention for eco-conscious tourists, through the mediating effect of green perceived risk and green trust. Yildiz et al. (2023) consider a green certificate as an important strategy to raise the green image of a hotel and enhance customers' trust in the services offered.

Tiago et al. (2021) show that most firms do not emphasize the sustainable tourism practices they follow in their digital communication nor do they possess any type of eco-label certification. However, because of a local government initiative, several small and medium accommodation firms have adopted a local sustainability accreditation, which indicates the implementation of good environmental practices and corporate social responsibility (CSR). They analyzed the online presence of 40 hotel websites and found that sustainability is still a less-explored dimension in organizational communication. They found that firms tend to communicate sustainable achievements in common text and with low persuasion (Tiago et al., 2021).

To stimulate the intention of booking a sustainable hotel online for the eco-conscious tourists, it is recommended that hotels integrate and/or highlight their sustainability in their communication. This could be done by displaying the green label on the booking site, or by adding this certification on the hotel's offers (Yildiz et al., 2023). While green initiatives are helpful in establishing the image of green hotels, they also play an important role in educating consumers on environmental protection by providing green products and services (Hu et al., 2020).

Drivers of sustainability

The acquisition of eco-labels by tourist accommodations emerges as a driver to attract eco-conscious customers. It is important to understand what other drivers lead hotels to adopt sustainable practices in order to address research question 2.

The hospitality industry initially adopted sustainable practices because of external government pressure and the need to conserve resources. Customer demands, environmental regulations, ethical considerations, and the influence of environmental pressure groups are seen as other driving forces behind the need to practice sustainability in the hospitality sector (Melissen et al., 2016). Also, cost-cutting advantages, enforcement of regulations by authorities, preservation of the environment and increased demand for environmentally friendly practices by customers motivate the adoption of sustainable practices in China (Shereni et al., 2023). Meeting customers' expectations, increasing employee loyalty, and creating a positive image have also been observed as strong motivations for adopting environmental sustainability practices (Shereni et al., 2023).

The growth of customers' attention towards environmental sustainability has encourage hoteliers to transform their business by implementing green practices in their operations which help them in achieving a competitive advantage and increasing their market share through acquiring guest segments that are concern with green sustainability (Abdou et al., 2020).

Accommodation enterprises which had to make great investments for energy, water and waste disposal could reduce their resource utilization via sustainable activities by 20-40% without having to decrease their current performance. With these practices, they reveal how much their effects on the environment have been reduced and the economic advantages they have earned through these efforts. (Kizanlikli et al., 2023). In the hospitality industry, green innovation practices offer businesses the opportunity to differentiate themselves by saving on raw materials, reducing energy consumption, increasing waste recycling, and using fewer resources. In this way, green innovation practices not only reduce negative environmental impact, but also provides a competitive advantage through cost reduction. Green organizational leadership, together with the leader's spirit and commitment, plays an important role in ensuring the successful implementation of green innovation in hotels (Xuan Dam et al., 2023). More stringent and supportive regulations positively affect the implementation of environmental process innovations in the hotel sector (Razumova et al., 2015).

It is also necessary to inform enterprises and investors that the environmentally friendly hotel certification system not only contributes to environmental protection and sustainable tourism but will also translate into savings and profitability for enterprises by decreasing costs in the long term (Kizanlikli et al., 2023). At the same time, as a long-term strategy, green innovation helps hospitality establishments to use materials and energy economically, increase recycling practices and limit or stop the release of hazardous wastes into the environment. Therefore, green innovation not only increases business efficiency but also enhances the eco-friendly image in the eyes of stakeholders (Xuan Dam et al., 2023). The purpose for a sustainability certificate can be varied, such as promoting sustainability in the supply chain, attracting a more sustainable-minded clientele, informing visitors about environmental performance and corporate social responsibility, but perhaps one of the most important is cost reduction through better environmental management (Rodríguez-García et al., 2023).

Within the broader tourism SME literature, drivers and challenges to engage in sustainable practices have been identified. Such drivers are categorized as: cost reduction competitiveness with proprietors implementing measures which provide financial benefits or a competitive advantage; societal legitimization where actions expected by others are implemented, and lifestyle-value drivers which reflect personal values (Hassanli & Ashwell, n.d.).

Hoteliers may feel three major forces for environmental improvements: 1) cost reduction and efficiency reflecting owners' interests; 2) external forces representing pressures from the government, hotel associations, customer demand, business partners, and environmental activists; and, 3) internal factor mirroring the concerns and expectations of hotel managers and corporate headquarters (Salehi et al., 2021). In table 2, the summary of the main drivers separated by stakeholders is presented.

Table 1. *Summary of the main drivers*

Drivers	Stakeholder	Reference
Customer demand for eco-friendly practices	Tourists Guests Customers	Melissen et al., (2016); Shereni et al., (2023); Abdou et al., (2020); Salehi et al., (2021)
Meeting customer expectations		Shereni et al., (2023)
Ethical considerations	Accommodation owners/managers	Melissen et al., (2016); Salehi et al., (2021)
Cost-cutting advantages		Shereni et al., (2023); Abdou et al., (2020); Kizanlikli et al., (2023); Xuan Dam et al., (2023); Rodríguez-García et al., (2023)
Business differentiation		
External government pressure	Government Regulators	Melissen et al., (2016); Shereni et al., (2023); Razumova et al., (2015); Salehi et al., (2021)
Environmental regulations		

The situation of the Basque tourism industry is the best in its history after a year 2023 in which it has reached 4.3 million visits in the first eleven months of the year, 8.6% more than in 2022. The average figure is currently 4.4 nights and around two nights in the same hotel. Moreover, tourism in this community is increasingly seasonal (Aguirre, 2024). The tourist attraction of Basque Country is based on a multitude of issues such as its gastronomy, traditions, culture and heritage, but also for its natural spaces and landscapes both in inland areas and on the coast. In order to know the tourist establishments, a database was obtained from the Basque Government through its web portal, which contains a list of tourist accommodations in the region. The database includes a total of 748 establishments distributed as follows: 42% are hotels, 39% are guesthouses, 17% are apartments and the remaining 2% correspond to hotel-apartments.

The websites of 222 establishments were reviewed. Of these, only 32 showed sustainability-related information on their web portals. Among them, 15 did not have a certified eco-label, but demonstrated environmental awareness. In another 15 cases, the opposite was the case: the image of a certified label was found on their web portals, but then there was no reference whatsoever to sustainable issues.

One way to demonstrate sustainable practices in tourist accommodations is to have an ecolabel. With regard to this issue, in 2021 the Basque country has a relevant position in the ranking of accommodations with European Ecolabel. The 35 tourist accommodations certified with a European Ecolabel that exist in Euskadi represent 69% of the 51 accommodations of this type that exist in Spain with this environmental certification, which demonstrates the degree of commitment to sustainability of the accommodation sector in Euskadi (Basque Government, n.d.).

Conclusions

First and foremost, it is crucial to underscore that the descriptive analysis reveals an exponential surge in publications in recent years, signifying an escalating interest within the scientific community toward sustainability in tourist accommodations. Remarkably, Spain emerges as a frontrunner in terms of authorship, demonstrating a substantial volume of research, followed by Portugal and China.

In the content analysis section, the role played by small and medium-sized enterprises in advancing sustainability efforts was detected. Notably, SMEs comprise a substantial segment of the European economy, accounting for a significant proportion of registered businesses and providing employment to a considerable segment of the workforce. Consequently, their dedication to sustainability stands to catalyze the adoption of responsible practices and the reduction of environmental impact, potentially yielding a multiplier effect across industries.

The articles reviewed highlight the relevance of certifications or eco-labels as tools that reflect a company's commitment to sustainability, thereby facilitating consumer recognition of businesses embracing sustainable practices. These eco-labels enjoy widespread adoption, primarily attributable to their capacity to attract customers, costs reduction and enhance the environmental reputation of companies.

Drivers faced by tourist accommodations in implementing sustainable practices were investigated. Hoteliers can sense three main forces to become more sustainable: 1) cost reduction and efficiency, which reflect the interest or owners; 2) external forces, which represent pressures from government, hotel associations, customer demand, business partners and environmental activists; and 3) the internal factor, which reflects the concerns and expectations of hotel managers and corporate headquarters.

Tourism sector in the Basque Country is economically important and has great potential. However, hotels in this Spanish region still have a long way to go in terms of f sustainability and communicating their sustainable practices to potential clients.

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Neurodiversity in Tourism: A Bibliometric Analysis

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Abstract

One of the major sustainability issues in the tourism industry is accessibility, both for people with physical disabilities and for those with mental disabilities and neurodivergency. This research specifically aims to investigate the sustainability of the tourism sector in terms of accessibility by analyzing the scientific literature produced on this topic, its evolution, and its distribution in terms of geography and source. To achive this objective, a bibliometric analysis has been conducted. Following the established study protocol, pertinent research topics were searched through Scopus database without any time or data restrictions, resulting in the inclusion of 1,127 papers in the sample. Descriptive performance analysis is performed to inquire the production time of literature, relevant source and impacts and also investigate the country-wise citation. The keyword analyses discovered productive nodes of literature and identified five thematic clusters. This study reveals the framework and theoretical underpinnings of the field's research as it uncovers the structure and intellectual base of research on the topics. This study aims to promote greater inclusion of neurodiversity in the tourism sector, addressing both policymakers and the academic community.

Keywords: Tourism, SDGs, Neurodivergent, Social Inclusion, Accessibility

Introduction

The tourism sector is one of the largest and most important globally. After a downturn due to the COVID-19 pandemic, it is experiencing continued growth that is returning it to 2019 levels in terms of the number of people involved. In 2023, international tourism recorded nearly 1.3 billion international tourists (calculated worldwide in terms of overnight stays), up 34 percent from 2022 and reaching 88 percent of pre-pandemic levels (UNWTO, 2024). In economic terms, the closing forecast for 2023 indicated that the contribution of tourism and travel, as a proportion of global Gross Domestic Product (GDP), would grow by 23.3 percent to 9.2 percent of the world economy. The value of the sector was expected to grow to $9.5 trillion, only 5 percent less than the record registered in 2019. Specifically, economies with large travel and tourism sectors show strong economic resilience and solid levels of economic activity. In particular, countries where tourism accounts for a high percentage of GDP have experienced faster recovery from the impacts of the pandemic than economies where tourism is not a significant sector (International Monetary Fund, 2023). For this reason, the tourism sector, which generated 10 percent of the world's GDP through the year 2024, and which has growth prospects of up to 11.34 percent in 2034 (World Travel & Tourism Council 2024), must necessarily recognize its impact and responsibility for sustainability. To call itself "sustainable," tourism needs to rest solidly on all three pillars of environmental, economic and social sustainability.

Although the discussion on sustainable tourism began with the 1987 'Our Common Future' report, also known as the 'Brundtland Report' (Butler, 1999), in the following years, various definitions have been proposed by both institutions and researchers. One definition that can be considered a current reference for sustainable tourism is: 'Tourism that takes full account of its current and future economic, social, and environmental impacts, addressing the needs of visitors, the industry, the environment, and host communities' (UNWTO and UNEP, 2005). In addiction, sustainable tourism can be linked with several goals of the 2030 Agenda for Sustainable Development (UN, 2015), namely SDG 8 (Decent work and economic growth), SDG 11 (Sustainable cities and communities), SDG 12 (Responsible consumption and production), SDG 13 (Combating climate change), SDG 17 (Partnership for the Goals) and even SDG 10 (Reducing inequality). In recent years, focusing on the SDG 10, a stream of the literature proposed an interesting discussion on inclusive or accessible tourism (Quiao et al., 2021), that implies the inclusion and participation of all social groups in the benefits of tourism, ensuring that tourism experiences are accessible and welcoming to people with different abilities and needs, both as consumers and operators (Gillovic and MacIntosh, 2020).

In the literature, most studies focus on accessible tourism for people with disabilities and disorders as a whole without considering the differences and specific needs, primarily those with physical disabilities (Akyildiz & Darcy, 2018). Nevertheless, it is worth emphasizing that, in the last decade, the number of diagnoses of neurodivergent conditions, such as autism spectrum disorder (ASD), has been increasing worldwide. “Neurodivergent” describes individuals whose selective neurocognitive functions/neurodevelopmental differences fall outside prevalent societal norms. They do not necessarily have a neurodevelopmental disorder (Shah et al, 2022). ASD, instead, is “a complex developmental condition involving persistent challenges with social communication, restricted interests and repetitive behavior” (American Psychiatric Association, 2013). According to data from the Centres for Disease Control and Prevention (CDC), the U.S. public health agency, about 1 in 36 children were identified with ASD in 2023. The CDC also noted that ASD occurs in all ethnic and socioeconomic groups (CDC, 2023). Growing awareness and improvements in diagnostic practices have led to greater recognition of these conditions in the sector. This growth underlines the necessity for the tourism industry, even more oriented toward sustainability, to enhance accessibility for all individuals, including those with physical disabilities and neurodivergent persons. As societal awareness of the daily challenges faced by neurodivergent individuals increases, partly due to their own advocacy on social media platforms (Jawed et al., 2023), it becomes apparent that there is a significant gap in research concerning their specific travel experiences and needs.

To address the above research gap, the present paper investigates the state of the art in the literature regarding the accessibility in the hospitality and accommodation field for individuals with disabilities or neurodivergent conditions, both as customers and operators. To achieve this, a bibliometric analysis of the literature was conducted. This method, increasingly applied across various research areas, is particularly useful for managing large volumes of scientific data (Donthu et al., 2021). The article is structured as follows: it begins with a description of the research methodology, followed by a presentation of the main results. The final section discusses the conclusions, limitations, and potential directions for future research.

Methods

An outline the importance of social aspects of sustainable tourism and the inclusion of neurodivergent people were given in the preceding sections. Both ideas are global in scope and centre on the sustainable development agenda. In this section, research design and its importance are elaborated. To analyse these both concepts in depth, this study adopts bibliometric analysis. Bibliometric mapping is a method of graphically organizing connected study topics and presenting scientific knowledge by using quantitative methodologies to bibliographic data. Bartolacci et al. (2020) state that bibliometrics is a branch of scientometrics that analyses the scientific community and the subject of study using statistical methods. Clustering techniques and visual displays of bibliometric maps offer an overview of the main linkages in the literature, even though most researchers focus on the mapping process itself (van Eck & Waltman, 2010). The mapping of scientific knowledge and the performance analysis of a field are the two main pillars.

Through bibliometric analysis, this study will ascertain the state of the discipline and determine the affiliation between Tourism and Neurodivergence. Thus, below mentioned research questions will direct the design of the study:

I. How has the research on tourism and neurodivergence evolved over time, and what are the significant trends in terms of publications, their impact, and the contributions of different countries?
II. What are the primary topics and keyword clusters within this research area, and how have they evolved in terms of significance and density over time?

Data Collection

It is widely accepted that two of the most prestigious and important databases in the world are Scopus and the Web of Science. These two databases, which comprise published articles and citation indexes in all fields of science, have shown to be valuable tools for bibliometric analysis. Scopus provides 20% more coverage than the Web of Science, according to comparison results. Scopus offers a higher indexing rate and more recent and comprehensive publication coverage than other databases. Hence, the literature for this inquiry was gathered using articles from Scopus. In order to find all pertinent papers, this study employed the following search strings

(TITLE-ABS-KEY (touris*) OR TITLE-ABS-KEY (hospitality) OR TITLE-ABS-KEY (hotel*) OR TITLE-ABS-KEY (horeca) OR TITLE-ABS-KEY (accomodation) AND TITLE-ABS-KEY (disability) OR TITLE-ABS-KEY (autism) OR TITLE-ABS-KEY (neurod*))

The search date was June 26th, 2024, and without any time span. An analysis was conducted using 1,127 papers.

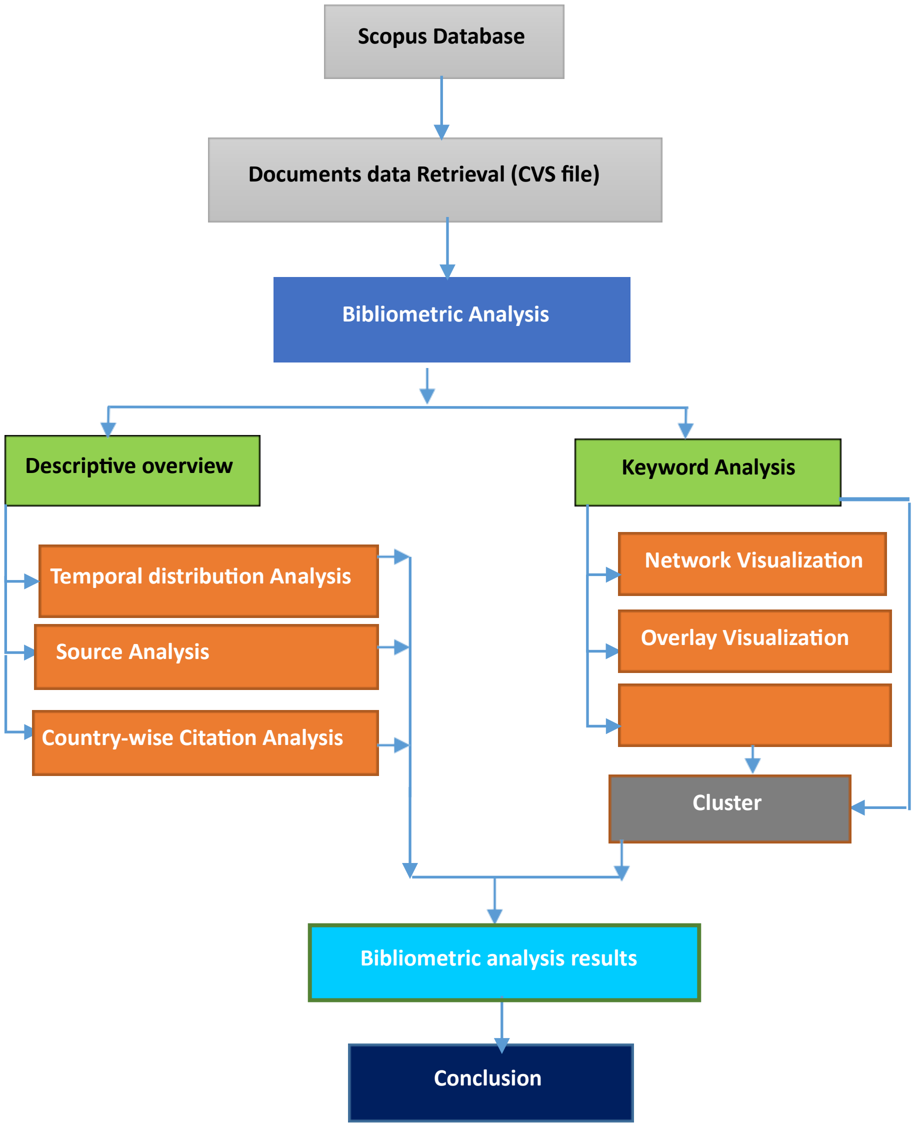

Figure 1. *Framework of research*

Data analysis

Performance measures were the primary focus of the bibliometric analysis in order to determine the contributions of each of the 1,127 publications. Publications are used to gauge productivity, and citations are used to show effect. Then conceptual frameworks of neurodiversity and tourism were mapped using co-word analysis based on keyword occurrence. This approach provided insights into the field's evolution and represented cumulative knowledge (Donthu et al., 2021; Krey & Picot-coupey, 2022)

A software application called VOSviewer is used to create and visualize bibliometric networks. It specializes in the graphical representation of bibliometric maps, making it possible for users to access and analyze the maps with ease (Hockerts et al., 2018). It is considered the best tool to provide text mining, creating and displaying co-occurrence networks that are extracted from several scientific publications. Numerous researches have made substantial use of this tool to analyse articles and display data networks (Liao et al., 2018). Before the bibliometric analysis, data files extracted through Scopus was managed and clean. Similar words, plurals, and nouns (keywords such as *disabled persons* or *disabled people* or *people with disabilities*) were manually combined, and all the nouns such as country names were removed to obtain the genuine weightage of each node. These criteria are adopted to formulate the most efficient, reproducible, and comprehensible research on networks and cluster (Hosseini et al., 2018).

Results and Discussion

This section presents the results of the bibliometric analysis. The initial part offers a descriptive overview of the characteristics of the documents included in the study, while the second part discusses the findings of the co-occurrence analysis of the authors' keywords and describes the identified clusters.

Description Performance Analysis

Performance analysis adopts activity indicators, which analyse bibliographic data to provide information about the volume (e.g., production and frequency), distribution (e.g., country, affiliation, authorship) and the impact (e.g., citations) of published research (Bartolacci et al., 2020). For the descriptive analysis this study performed temporal distribution, source analysis and Country-wise analysis.

Temporal Distribution

In this initial paragraph, the distribution of publications over the years is analysed. This type of indicator helps to understand how the scientific production on the specific topic is evolving in quantitative terms. In the case under investigation, the scientific research interested in the topic of accessible tourism has been continuously growing, with significant advancements observed in 2018 and 2023. The data for 2024 only considers the first six months. Among the publications analysed, the first chronologically is an article published in the *Annals of Tourism Research* in 1987. From that year until 2002, there was consistently only one publication per year. However, a steady increase began thereafter, with notable increments in 2013 and 2020 (17% and 21% increases, respectively, compared to the previous year).

Source analysis

The source analysis allows for the identification of which scientific publications have made the most significant contributions to the research on the topic of this paper. The impact of each source is evaluated using five key indicators: i) the number of documents published, ii) the number of citations received by the documents published, iii) the average number of citations per document published, iv) the number of normalized citations, which is the number of citations divided by the average number of citations of all documents published in the same year, and v) the average publication year of the articles (van Eck and Waltman, 2018). The comprehensive analysis of all these factors provides a complete picture of the sources' contributions. Specifically, the three percentage indicators (iii, iv, v) ensure uniformity that would not be achieved by the raw indicators alone (i and ii). Raw indicators do not account for the different editorial choices or capacities of various source, nor do they consider the their longevity, which affects the absolute number of publications and citations. From the analysis conducted on the 1,127 documents processed by the VosViewer software, it emerges that the journal *Tourism Management* has the highest scores both in terms of average citations and normalized citations. Additionally, it has one of the oldest average publication dates, 2012. The most recent average publication year, 2021, belongs to the journal *Sustainability (Switzerland)*, which also leads in the total number of published documents.

Country Analysis

When we refer to the country associated with a publication, we mean the country of the institutions to which the authors are affiliated. Consequently, in cases of multiple authors affiliated with institutions in different countries, a publication may be counted for two or more countries simultaneously. Similarly to the source analysis, the country analysis utilizes the same five indicators and follows the same analytical logic. A comprehensive interpretation of these indicators allows us to evaluate how research is geographically distributed and whether research in certain countries has approached the topic earlier or more recently. The number of documents originating from the United States (203) is by far the highest, highlighting the significant interest in the topics of neurodivergence and disability in the field of tourism in the country. This aligns with the CDC's recent data on the increase in neurodiversity diagnoses in recent years (CDC, 2023).

Following the United States, there are 105 publications from the United Kingdom and 88 from Australia. After the top three English-speaking countries, there are three Southern European countries where tourism is a major contributor to GDP: Spain (81), Italy (78), and Portugal (74). US research also leads in terms of the number of citations received, with 5,864 citations and normalized citations, followed by the United Kingdom with 3,866 citations. However, in terms of average citations per published document, Australia holds the highest value (42), followed by the United Kingdom (37) and the United States (29). Finally, Portugal and Italy have the most recent average publication years (2021 and 2020, respectively), whereas the USA and the United Kingdom have the oldest average publication years (2012 and 2013, respectively).

Co-occurrence Analysis

In this section, the co-occurrences are analysed to explore the relationships between the keywords used in the 1,127 documents under review. Using VOSViewer software, it is possible to visualize the network of relationships between the different keywords chosen by the authors and identify thematic clusters that group multiple keywords. The size of a word indicates the frequency with which the keyword appears in the publications: the larger the term, the higher the number of publications in which that keyword is present. The correlation is shown through the number of joint occurrences of the words. The lines represent the strongest co-occurrence relationships between the keywords. The distance between terms represents the relationship between two words: the closer the words are, the stronger is their relationship. The colour of each term represents the cluster to which it belongs.

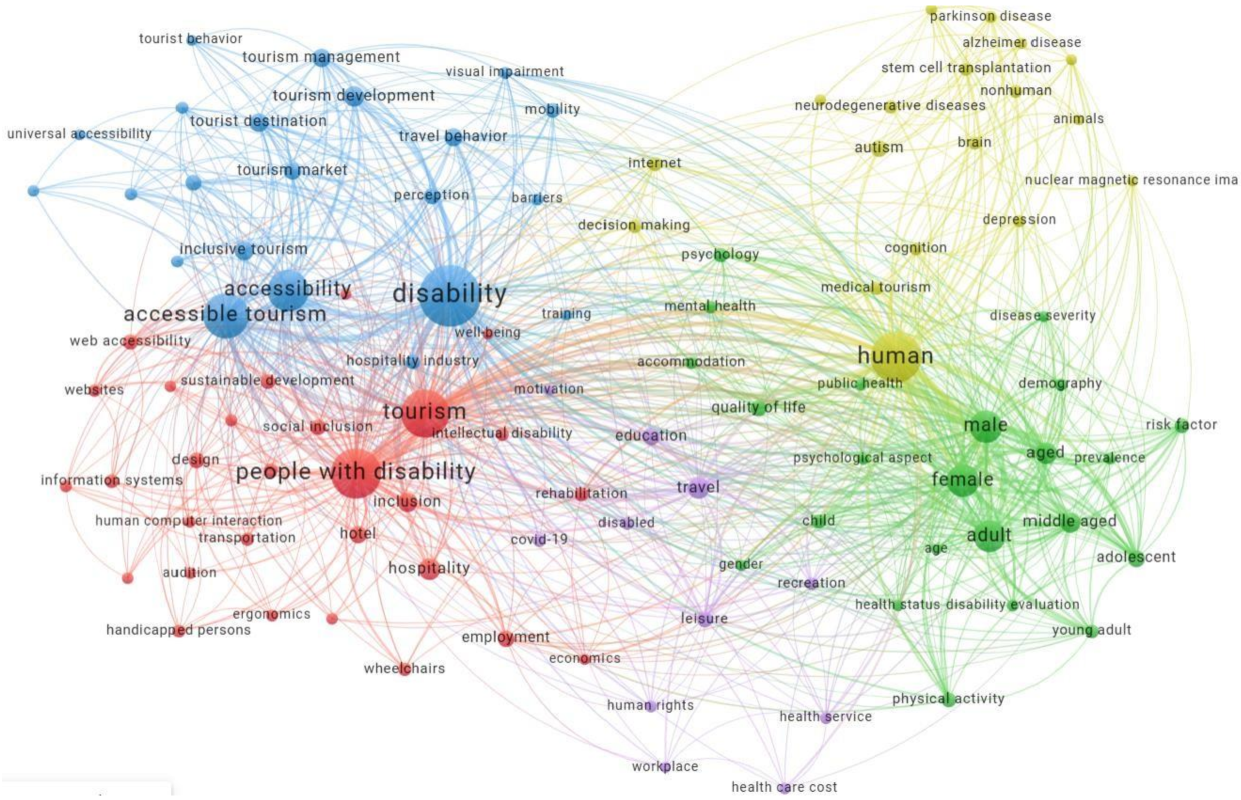

***Figure 2**. Keyword Co-occurrence (network Visualization)*

In this study, five clusters were identified: *i)* Travel Experiences and Inclusion, *ii)* Tourism Advancement for Inclusion *iii)* Leisure and Health Care *iv)* Neurodegenerative and Other Brain Issues
v) Demographic Factors and Health.

The red cluster *i)* includes keywords related to the tourism experiences of people with disabilities, focusing on inclusion and accessibility of tourist facilities. The keyword "people with disability" has significant relevance (209 occurrences) and maintains strong connections with other key terms in the cluster such as "inclusion" and "social inclusion". This cluster also includes terms related to virtual tourism ("web accessibility", "human-computer interaction") and accessibility in terms of employment within the sector ("employment"). The blue cluster *ii)* encompasses keywords pertaining to the social sustainability of tourism. The keyword "disability" has a high number of occurrences (315) and is closely linked with the other two main terms of the cluster: "accessible tourism" (171) and "accessibility" (142). This cluster includes words that look towards the future of the sector such as "tourism development" and "tourism management". The purple cluster *iii)* has "travel" as its most frequently occurring keyword (38 occurrences). The rest of the words in this cluster (e.g., "human rights", "health service", "motivation", "education", "recreation") define this cluster as focused on the specific themes of disability in terms of motivations and desires related to tourist activities. The yellow cluster *iv)* with "humans" (214 occurrences) as the main keyword, groups terms related to diseases and disorders such as "dementia", "spinal cord injury", "depression", and "autism". It also includes "internet", highlighting how virtual experiences are closely tied to accessibility for these types of conditions or divergences. The green cluster *v)* consists of keywords related to demographic characteristics (e.g., "male", "female", "aged", "adolescent") and health status (e.g., "risk factor", "disease severity", "physical activity"). Among the relationships between individual keywords belonging to different clusters, it is interesting to point out the connection between accessible tourism and autism, which is the only pathology or divergence in the yellow cluster to have a relationship with this keyword.

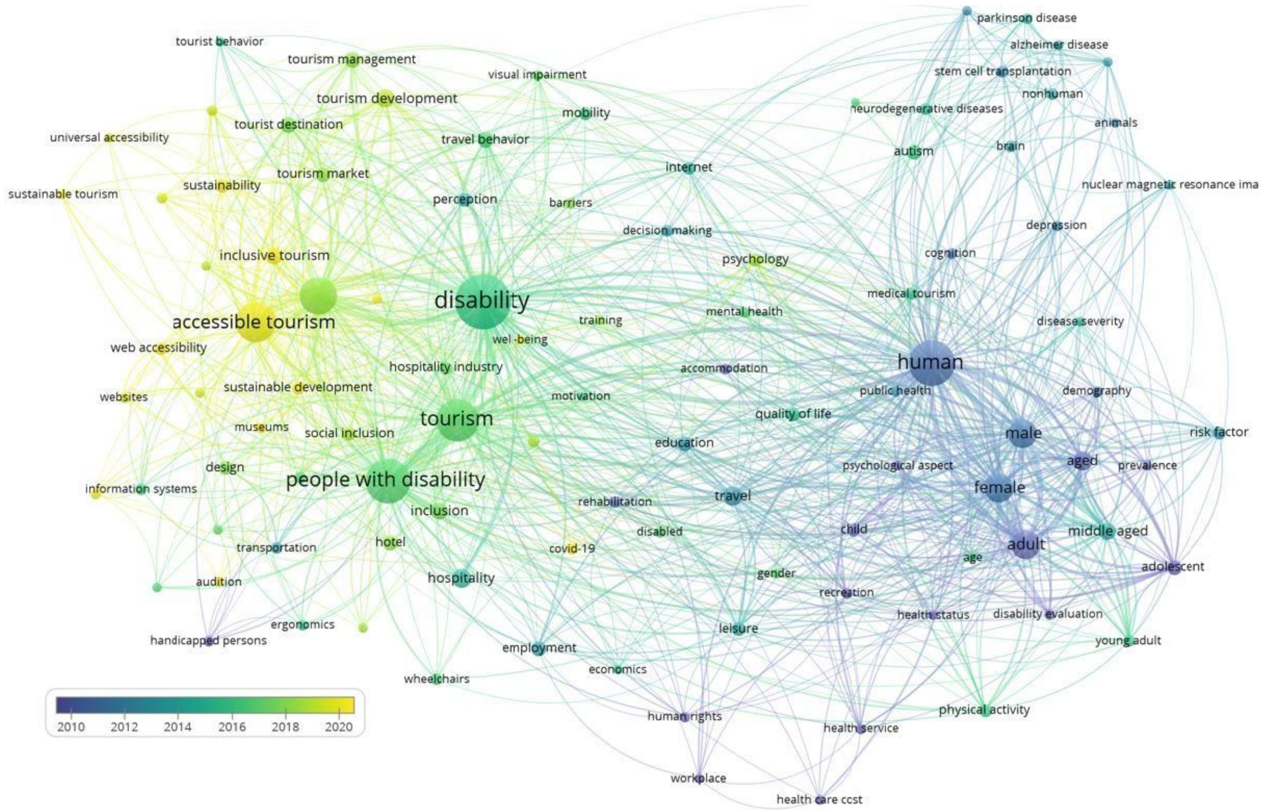

***Figure 3**. Keyword Co-occurrence (Overlay Visualization)*

Introducing the temporal development variable into the network map of keywords, allows for the analysis of the literature and its evolution in terms of co-occurrence. The colour of a word indicates the average publication year of the articles in which the keyword appears. The closer the colour of a word is to blue, the older the publications in which the term appears. Conversely, the closer the colour of a term is to yellow, the more recent the publications in which the word is present. From *Figure 3*, it is evident that the analysed literature initially began to explore and analyse issues related to physical disabilities (e.g., "disability", "transportation", "handicapped person") in general terms. Over time, the focus expanded to investigate the relationships between disabilities and tourism (e.g., "tourism"), incorporating topics related to brain disorders or neurological diversity (e.g., "autism", "neurodegenerative disease"). Ultimately, the literature has come to consider the overall sustainability and accessibility of the tourism sector (e.g., "inclusive tourism", "accessible tourism").

Conclusions

To fill the gaps of the literature, our study carried out a thorough bibliometric examination of tourism and neurodiversity. It examined a collection of 1,127 publications gathered from the Scopus databases. Descriptive performance approaches and advanced bibliometric analysis were employed in the review comprehend the structure of the literature related to the research objectives. Four more relevant descriptive analysis employed to respond to the first research inquiry aims to identify the main source, temporal production, and countries that significantly contribute to the fields of neurodiversity and tourism. Significant advancements were found in both fields from 2001 to 2024 the trends for publications are rising. Citation analysis by country reveals that researchers around the globe have shown a strong interest in examining how neurodiversity in tourism may promote sustainable tourism practices. Nonetheless, there is a noteworthy preponderance of works written by scholars from Western, developed societies. The results show that more research on the social aspect of sustainable tourism in low-middle income country (LMIC) nations is necessary. This would lead to a fairer portrayal of sustainable practices and their effects on the world community, also because in so many LMICs, most of the GDP depends on tourism.

Given that the organizational and cultural contexts have an impact on management methods, this particular topic requires attention. Thus, scholars from developing nations could provide insight into the social and cultural elements that influence sustainable development processes.

Moreover, it was found that the body of knowledge pertaining to the intersection of both concepts was associated with various research fields. The graphical depiction offers a framework for recognizing important literary contributions. Therefore, the main question for research question 2 is on the main subjects covered in the field and the keyword-based clustering. Co-occurrence keyword analysis revealed the 103 most often referenced keywords in a sample of 1,127 texts.

The study offers suggestions for future lines of research through methodology. Frist of all, a thorough research framework would be designed through the co-citation analysis, or content analysis, which would determine the crucial gaps in literature. Secondly, this study chooses the article through the specific keywords, future studies may analyze publications gathered from a certain source. Combining systematic analysis with bibliometrics might be another approach. Future scholars may, for instance, select a single cluster from this work and do a systematic analysis of all the papers belonging to that particular cluster, which will be an extended form of this research.

The results of this research are important for both academics and decision-makers. The findings offer a forum for advancing academic discussion on the tourism’s sociological aspects. For those who are interested in the subject, this study offers a fresh framework. Moreover, clusters identified by keyword analysis give policymakers a summary, so they may prioritize and concentrate on the pertinent regions. There are some limitations that apply to this content. Although other databases like EBSCO or Web of Science could have been considered, a comprehensive study of the Scopus database was carried out. Furthermore, the results of our investigation are inevitably impacted by the terms we choose.an other limitation is the methodology, we only analyzed these concepts through bibliometric, a qualitative research like case study would contribute in a better way.

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How to foster sustainable development of inner areas: key factors for attracting residents and tourists

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Abstract

This paper investigates the main factors influencing people's intention to visit or reside in inner areas for understanding how to foster sustainable development at local level. Inner areas, defined by their distance and marginality from central poles and as places rich in cultural and natural resources (Basile and Cavallo, 2020), are facing major sustainability challenges such as aging and migration, limited socioeconomic opportunities, and environmental degradation. Understanding how to retain locals and attract new tourists and residents is crucial for promoting equitable and inclusive sustainable development (Beatriz-Sànchez et al., 2024). Against this backdrop, an empirical survey was conducted in Italy to analyse what prompts people to visit or reside in inner areas. A survey was administered and a sample of 107 individuals was collected. Gathered data were examined through diverse statistical analyses. The results indicate that the main factor driving people to visit or reside in inner areas is the desire for an authentic living experience surrounded by cultural and natural resources. Moreover, new service innovations driven by digital transitions including smart working and phygital experiences positively impact people’s intentions, along with the perceived accessibility and local essential services. Future research could expand the sample size and explore other contexts to establish broader lines of action. The research contributes to the knowledge of the best strategies to be adopted for the pursuit of socio-economic development in inner areas driven by sustainable tourism and new digital service innovations.

Keywords: sustainable development, innovation, inner area, sustainability

Relevant Topic: sustainability and innovation

Introduction

The UN's Agenda 2030 argues that sustainable development is a complex and multifaceted issue that should be implemented and achieved effectively at both global and local levels. It calls for place-based development strategies to progressively scale up sustainability issues in diverse territories, requiring the assessment of differences and disparities between territories to define local priorities and support cohesion policy objectives.

(UN, 2015; Saiu et al., 2022; Blečić et al., 2023). In this contest, inner areas emerge as a significant hotspot, particularly in light of the increasing socio-economic and environmental degradation affecting these territories. The term "inner area" refers to an urban settlement significantly distant from the central poles; a peripheral place related to the idea of distance and marginality (Battaglia et al., 2019). They are distinguished by three unique characteristics: firstly, the aging population that makes them vulnerable from a socio-demographic perspective; then, the physical and ecological instability caused by the inadequate maintenance of their natural and material capital, and, finally, the large portion of the territorial capital underutilized or unused. Most areas in Mediterranean Europe, as well as those in Central and Eastern Europe and the Scandinavian peninsula, display these three characteristics and often constitute rural, mountainous or coastal areas, representing peripheral zones with respect to the main poles of economic and social development (Barca et al., 2014; Basile and Cavallo, 2020).

At the European level, Inner Areas cover about 45% of the territory and play a crucial role in the conservation of Europe's natural and cultural heritage as well as representing a significant resource for biodiversity and environmental sustainability. Their management has become central to EU cohesion policies, which aim to reduce territorial disparities and promote balanced and sustainable development (Schürmann et al., 2017). In Italy, multiple villages that characterize inner areas, called also "borghi", preserve ancient traditions and monumental and artistic assets of a certain value. They are characterised by a consistent social and historical heritage, high biodiversity and settlements with distinctive morphological and technological features. The significance of these areas in Italy is evident as they span about 60% of the country's territory, hosting a population of over 13,540 million inhabitants, equal to about a quarter of the Italian population divided into over four thousand municipalities (Barca et al., 2014).

In recent decades, peripheral areas have faced new challenges related to a more globalised and interconnected world. Indeed, their peculiarities do not allow them to cope with increasingly dynamic contextual changes leading to a progressive socio-demographic and economic decline and environmental fragility. Moreover, the opportunities linked to greater mobility and the role of information and communication technologies have also led to a different perception of development and welfare; since urban areas have large infrastructures that provide more efficient essential services, they play an attractive role for the population, especially for younger people who tend to move from rural and coastal areas to the cities, causing the growth of youth depopulation and the related hydrogeological degradation and land consumption (Lauria, 2022).

Consequently, the distance from the main industrial and productive urban centres, geographical isolation, difficult accessibility, but also economic changes, earthquakes and natural disasters, triggered these processes of land abandonment and depopulation. However, in recent years, the crisis of globalisation and big cities along with the unexpected Covid-19 pandemic have prompted many actors to rethink their lifestyles shedding light on the potential of unspoilt inner areas for achieving a better quality of life. Various stakeholders, including institutions, organizations, and communities, are actively involved in developing sustainable strategies to adapt remote centres to modern living standards. This shift in values led to the awareness of the historical, socio-cultural and natural importance of inner areas. The need to reverse the depopulation and marginalisation of these territories for a new regeneration of places is at the forefront of the national and international agenda that aims to achieve a more sustainable and equitable future by addressing inequalities and territorial fragmentation.

In line with these considerations, it is important to discussed and analysed sustainable and innovative solutions that facilitate local development and attract new businesses, tourists and citizens.

Many authors stressed how the development of essential services such as health, education, mobility and an effective internet connection are crucial for the sustainable development of villages. They emphasise that accessibility to these services not only improves the living conditions of inhabitants, but is also a prerequisite for attracting tourists, new residents and entrepreneurs, contributing to the economic diversification and resilience of local communities (Rodríguez-Pose and Ketterer ,2020; Camagni and Capello, 2020).

Furthermore, many studies highlight that tourism is a primary tool for local development and, in light of tourists' new interest in cultural and rural tourism experiences, small villages in inner areas can be fascinating destinations, as they are small towns that offer an authentic mix of cultural heritage, natural beauty and authenticity (WTO, 2022).

Moreover, the accelerating digitisation of services has led to multiple possibilities for these villages to integrate new service innovations that fit contemporary life in its various forms, ranging from residence to temporary work with the emergence of co-working areas, art workshops etc (Bianchi, 2021; Smith & Wilson, 2022). The possibility of working remotely has introduced a new lifestyle and promoted a new type of tourism. The COVID-19 pandemic has accelerated this trend, with many people now working remotely and able to spend their time in selected locations, shaping the way they stay in different places independently of their work activities (Berg, 2021). Moreover, some studies highlight how the pandemic period prompted people towards a new lifestyle known as slow living or slow life, changing their habits and tourist destinations, preferring places more in contact with nature and off the most popular tourist routes (Rodriguez-Vazquez, 2022).

The digitisation process has also provided an innovative way of visiting through phygital experiences. These new tourism practices, combining physical and digital elements, are emerging as a new way of doing tourism in villages, enhancing historical and cultural heritage and allowing visitors to have an immersive experience (Montanari, 2020).

Against this backdrop, this study aims to explore the crucial factors influencing the development of inner areas in relation to accessibility, tourism and service innovations to understand how these concepts influence people's intention to visit or reside in these areas. Based on the existing evidence in the literature, this study investigates the following research hypothesis:

H1: the perception of accessibility and essential services influences people's intention to visit or reside in inner areas

H2: the desire for unique and authentic tourist experiences influences people's intention to visit or reside in

inner areas
H3: the desire of people to have smart working in smoother places influences people’s intention to visit or reside in inner areas
H4: the development of phygital experiences influences people's intention to visit or reside in inner areas
This integrated approach contributes to understand and develop effective strategies to promote sustainable growth and resilience of inner areas.
The paper is structured as follows: after introducing the relevant research topics, the authors describe the methodology adopted and present the main results of the analysis. Finally, discussion and conclusions are provided.

Methodology

To achieve the research aim an empirical survey was conducted utilizing a quantitative methodology approach. The primary purpose of the study is to identify and understand the main factors that influence individual’s intention regarding visiting or reside in inner areas. A questionnaire was developed and administered within the Italian national territory targeting a sample size of 107 individuals. The sample was selected through the snowball approach (Guido, 1999; Mugion et al., 2017).

The elaborated questionnaire consists of two sections: the first section is devoted to the socio-demographic characteristics of the respondents, providing an essential context for the data analysis. The second section focuses on the crucial influencing factors identified through an extensive literature review on sustainable regeneration and repopulation strategies for inland areas. Accordingly, the resulting questionnaire was developed to include four sections with 27 items: experience of rural and cultural tourism (8 items); perception of accessibility and essential local services (6 items), phygital experience (5 items) and attractiveness of smart working (8 items).
The questionnaire was designed using existing validated scales to ensure reliability and validity of the responses. Specifically, a 5-point Likert scale was employed, ranging from 1 ("Strongly disagree") to 5 ("Strongly agree") allowing respondents to indicate their level of agreement or disagreement with certain statements. This scaling method is well-suited for measuring attitudes and opinions, providing nuanced data on respondent perceptions.
Data collected from the questionnaire were subjected to various statistical analyses using the SPSS software IBM 17.0 (Muthen and Muthen, 1998): descriptive analysis was performed to delineate sample characteristics and bivariate analysis was carried out using Cronbach's alpha, factor analysis and linear regression analysis to determine the significance and strength of the identified factors.. The following section outlines the results achieved.

Results and Discussion

This section describes the results of the quantitative analysis. Firstly, a demographic analysis of the sample is presented. Next, the results of bivariate analysis are showed, which identifies the main factors influencing people's intention to visit or reside in inner areas.

Demographics

As Table 1 below shows, the sample is 63.2% female and 36.8% male. The "18-25" and "26-35" age groups account for over 40% of the population, those aged "36-45" are 6.6%, and participants aged over 45 make up 48.12%. Most of the survey respondents come from Central Italy (83.02%), followed by Northern Italy at 9.43% and Southern Italy and Islands at 7.55%. There are no participants from foreign countries. More than half of the participants (51.88%) come from villages or towns in the country, followed by those who come from small towns (18.87%), medium-sized towns (15.1%) and large cities (14.15%). The majority of the respondents have a level of education that corresponds to a high school diploma (45.28%), while 21.7% hold a master's degree and 15.1% a bachelor's degree, 8.49% have a middle school diploma, 7.55% a master's degree and 1.88% a doctorate. More than half of the respondents have a profession as an employee (55.66%), 17.92% belong to the category 'Student/Student', the self-employed are 15.1%, the unemployed 8.49%, and pensioners 2.83%.

Table 1: *descriptive analysis*

		fq	fq %
Gender	woman	67	62,61%
	man	40	37,38%
Age	under 25	26	24,29%
	over 25	81	75,70%
Place of origin	Nord of Italy	10	9,34%
	Center of Italy	88	82,24%
	Sud of Italy and islands	9	8,41%
	Other	0	0%
Qualification	Primary school	0	0%
	Secondary school	9	8,41%
	High school	48	44,85%
	Bachelor degree	16	14,95%
	Master degree	24	22,42%
	Master	8	7,47%
	PhD	2	1,88%

Profession	Student	20	18,69%
	Employee	59	55,14%
	Freelancer	16	14,95%
	Unemployed	9	8,19%
	Retired	3	2,80%
city of origin	>200.000	15	14,01%
	200.000-80.000	17	15,88%
	<80.000	75	70,09%

Alpha di Cronbach

To check the internal consistency reliability of the dimensions analysed in the questionnaire, Cronbach's alpha test (Cronbach, 1951) was performed. The Cronbach result of 0.963 obtained from the questionnaire analysis indicate a highly reliability of the scale employed (Table 2).

Table 2: *Cronbach Alpha*

Cronbach Alpha	N. of elements
,963	27

Factor analysis

Factor analysis was employed in this study to synthesize information by examining the interrelationships between variables. This technique aims to identify a smaller number of latent variables (factors) derived from linear combinations of the original variables. A principal components analysis (PCA) was first performed without rotation to determine the number of factors to retain. Subsequently, a second analysis was carried out using the Maximum Likelihood method with VARIMAX rotation for better interpretability.

Before conducting the factor analysis, two tests were used to assess the correlation among the factors: Bartlett's sphericity test and the Kaiser-Meyer-Olkin (KMO) test. Bartlett's test checks if the variables are uncorrelated. A high-test value with a P-value < 0.5 is required to reject the null hypothesis of non-correlation. In this case, the P-value was 0, indicating strong correlations and thus acceptable.

The KMO test assesses the adequacy of the sample, with values greater than 0.7 indicating that the correlation between pairs of variables can be explained by other factors, making factor analysis feasible. In the current analysis, the KMO value was 0.923, confirming the suitability of the data for factor analysis.

Table 3: *test KMO e Bartlett*

Measure of sampling Adequacy (MSA) by Kaiser-Meyer-Olkin (KMO)		,923
Bartlett's test of sphericity	. Chi-square	2677,221
	gl.	351
	Sign.	,000

Next, the communalities were evaluated to determine the amount of variance accounted for by the common factors. Specifically, each value needed to exceed 0.4. The analysis confirmed that all variables met this criterion, allowing the analysis to proceed and the factors to be identified (Table 4).

Table 4: *Comunalities*

Comunalities		
	Initial	Extraction
2	1,000	,798
3	1,000	,796
4	1,000	,617
5	1,000	,731
6	1,000	,743
7	1,000	,712
8	1,000	,709
9	1,000	,619
10	1,000	,564
11	1,000	,787
12	1,000	,631
13	1,000	,611
14	1,000	,592
15	1,000	,614
16	1,000	,682
17	1,000	,855
18	1,000	,873
19	1,000	,837
20	1,000	,844

21	1,000	,782
22	1,000	,734
23	1,000	,819
24	1,000	,759
25	1,000	,806
26	1,000	,726
27	1,000	,649
28	1,000	,732
Extraction method: Principal Component Analysis.		

Table 5 presents the number of factors to be extracted. Factors with an Eigenvalue greater than 1, explaining at least 60% of the total variance, were considered. Based on these criteria, four factors were selected.

Table 5: *Total variance Explained*

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	13,974	51,756	51,756	13,974	51,756	51,756
2	2,467	9,135	60,891	2,467	9,135	60,891
3	1,755	6,500	67,391	1,755	6,500	67,391
4	1,425	5,278	72,670	1,425	5,278	72,670
5	,972	3,600	76,270			
6	,786	2,912	79,182			
7	,642	2,377	81,559			
8	,610	2,258	83,817			
9	,518	1,917	85,734			
10	,445	1,648	87,382			
11	,364	1,347	88,728			
12	,346	1,280	90,008			
13	,329	1,220	91,228			
14	,314	1,163	92,391			
15	,282	1,046	93,437			

16	,268	,994	94,432			
17	,210	,777	95,208			
18	,197	,729	95,938			
19	,180	,667	96,605			
20	,174	,645	97,250			
21	,157	,581	97,831			
22	,140	,518	98,349			
23	,124	,458	98,807			
24	,100	,370	99,177			
25	,086	,317	99,494			
26	,075	,279	99,773			
27	,061	,227	100,000			
Extraction method: Principal Component Analysis.						

After confirming the selection of four factors, the Maximum Likelihood method with VARIMAX rotation was applied to identify the items associated with each factor. Factor loadings (correlations between variables and factors) were examined to ensure they were above 0.4 and that each item loaded predominantly into a single factor (Table 6).

Table 6: *Rotated Component Matrix*

	Component			
	1	2	3	4
23	,817	,204	,270	,154
21	,756	,185	,350	,125
25	,751	,246	,356	,198
22	,743	,241	,243	,142
26	,717	,299	,150	,215
24	,689	,331	,324	,223
28	,671	,357	,195	,273
27	,625	,338	,189	,192
2	,345	,774	,331	,153
3	,336	,733	,373	,226
5	,354	,727	,141	,228

4	,226	,621	,349	,222
6	,355	,603	,189	,358
7	,327	,572	,279	,311
8	,353	,553	,221	,343
9	,307	,443	,289	,426
18	,280	,230	,847	,155
17	,297	,159	,819	,234
20	,314	,247	,804	,098
19	,331	,314	,760	,105
16	,296	,349	,629	,134
11	,141	,063	,009	,846
15	,097	,044	,177	,678
12	,157	,287	,208	,649
14	,173	,261	,120	,625
10	,197	,250	-,051	,600
13	,127	,257	,338	,534
Extraction method: Maximum Likelihood. Rotation Method: Varimax with Kaiser Normalization.				
a. Rotation converged in 6 iterations.				

Finally, the factors were named according to the items most strongly associated with them. The significance of the latent factors was derived from the observed variables with the highest correlations. The final factors are presented in Table 7.

Table 7: *name of the factors*

Factor	Name
1	Attractiveness for smart working
2	Unique and authentic tourism experience
3	Phygital experience
4	Perceived accessibility and essential services

Stepwise multiple regression

To investigate the relationship between the four extracted factors (independent variables x) and the respondents' intention to visit or reside in inner areas (dependent variable y), a stepwise multiple regression was conducted. The stepwise technique begins with an empty model (without predictors) and sequentially adds variables. At each step, the variable with the lowest P-value, among those meeting the 0.05 significance level for predictor entry, is included. Simultaneously, variables that no longer significantly contribute to explaining the variability of y are removed. The process concludes when no additional predictors meet the criteria for entry into the model.

Table 8 illustrates the variables entered and removed during the Stepwise regression. Notably, of the four variables considered, none were eliminated in subsequent steps. Initially, Factor 2 was entered, followed by Factor 1 at the second step, then Factor 3, and finally Factor 4.

Table 8: *variables Entered/removed*

Model	Variables Entered	Variables Removed	Method
1	REGR factor score 2 for analysis 2	.	Stepwise (criteria: Probability-of-F-to-enter <= ,050, Probability-of-F-to-remove >= ,100).
2	REGR factor score 1 for analysis 2	.	Stepwise (criteria: Probability-of-F-to-enter <= ,050, Probability-of-F-to-remove >= ,100).
3	REGR factor score 3 for analysis 2	.	Stepwise (criteria: Probability-of-F-to-enter <= ,050, Probability-of-F-to-remove >= ,100).
4	REGR factor score 4 for analysis 2		
a. Dependent variable y: - I would like to visit or reside in inner areas.			

Table 9 shows the value of the adjusted R-square for each step. In the last step a value of 71% is obtained, i.e. 71% of the variability of the intention to visit or reside in a village is explained by the linear relationship with the variables in the model.

Table 9: *Model summary*

Model	R	R-Square	Adjusted R-Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R-Square Change	F Change	gl1	gl2	Sign. F Change	
1	,688a	,473	,468	,876	,473	94,417	1	105	,000	
2	,800b	,641	,634	,727	,167	48,326	1	104	,000	
3	,827c	,684	,675	,685	,044	14,232	1	103	,000	
4	,851d	,724	,713	,644	,039	14,527	1	102	,000	1,781
a. Predictors: (costant), REGR factor score 2 for analysis 2										
b. Predictor: (costant), REGR factor score 2 for analysis 2, REGR factor score 1 for analysis 2										
c. Predictor: (costant), REGR factor score 2 for analysis 2, REGR factor score 1 for analysis 2, REGR factor score 3 for analysis 2										
d. Predictor: (costant), REGR factor score 2 for analysis 2, REGR factor score 1 for analysis 2, REGR factor score 3 for analysis 2, REGR factor score 4 for analysis 2										
e. Dependent variable y: - I would like to visit or reside in inner areas.										

From Table 10, it is possible to examine whether the explanatory variables have any statistically significant effect on y (i.e. whether an association exists). Specifically, we obtain a value of the test statistic F equal to 66.734 and a relative Pvalue equal to zero; this result leads to the conclusion that at least one x is associated with the variable y.

Table 10: *ANOVA*

ANOVAa						
Model		**Sum of Squares**	**gl**	**Mean Square**	**F**	**Sign.**
1	Regression	72,436	1	72,436	94,417	,000b
	Residual	80,555	105	,767		
	Total	152,991	106			
2	Regression	97,992	2	48,996	92,650	,000c
	Residual	54,998	104	,529		
	Total	152,991	106			
3	Regression	104,669	3	34,890	74,369	,000d
	Residual	48,322	103	,469		
	Total	152,991	106			
4	Regression	110,693	4	27,673	66,734	,000e
	Residual	42,298	102	,415		
	Total	152,991	106			
a. Dependent variable y: - I would like to visit or reside in inner areas.						
b. Predictor: (costant), REGR factor score 2 for analysis 2						
c. Predictor: (costant), REGR factor score 2 for analysis 2, REGR factor score 1 for analysis 2						
d. Predictor: (costant), REGR factor score 2 for analysis 2, REGR factor score 1 for analysis 2, REGR factor score 3 for analysis 2						
e. Predictor: (costant), REGR factor score 2 for analysis 2, REGR factor score 1 for analysis 2, REGR factor score 3 for analysis 2, REGR factor score 4 for analysis 2						

For the model to be valid, there must not be a strong correlation between the independent variables (x). The indicator used to verify the presence of multicollinearity is the Variance Inflation Factor (VIF), which must have a value less than 5. As shown in Table 11, all VIF values are approximately equal to 1, indicating the absence of multicollinearity and allowing the regression analysis to proceed. Additionally, the table provides strong evidence that all variables included in the model are significantly associated with the dependent variable (y). Specifically, the P-values associated with each regression coefficient are all less than the significance level (α=0.05\alpha = 0.05α=0.05).

Therefore, it can be concluded that, based on the analyses conducted, the identified factors (F1, F2, F3, F4) positively influence the intention to visit or reside in inner areas. Among these, Factor 2 has the most significant impact, followed by Factors 1, 3 and 4.

The estimated regression equation is:

$$y = 4.009 + 0.651F1 + 0.396F2 + 0.208F3 + 0.199F4$$

Table 11: *Coefficients*

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sign.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Costant)	4,009	,085		47,349	,000		
	REGR factor score 2 for analysis 2	,885	,091	,688	9,717	,000	1,000	1,000
2	(Costant)	4,009	,070		57,030	,000		
	REGR factor score 2 for analysis 2	,858	,076	,667	11,331	,000	,997	1,003
	REGR factor score 1 for analysis 2	,520	,075	,409	6,952	,000	,997	1,003
3	(Costant)	4,009	,066		60,550	,000		
	REGR factor score 2 for analysis 2	,850	,071	,661	11,913	,000	,996	1,004
	REGR factor score 1 for analysis 2	,510	,070	,401	7,235	,000	,996	1,004
	REGR factor score 3 for analysis 2	,263	,070	,209	3,772	,000	,998	1,002
4	(Costant)	4,009	,062		64,403	,000		
	REGR factor score 2 for analysis 2	,838	,067	,651	12,476	,000	,994	1,006
	REGR factor score 1 for analysis 2	,504	,066	,396	7,595	,000	,995	1,005
	REGR factor score 3 for analysis 2	,261	,065	,208	3,989	,000	,998	1,002
	REGR factor score 4 for analysis 2	,258	,068	,199	3,811	,000	,997	1,003
a. Dependent variable y: - I would like to visit or reside in inner areas.								

Figure 1 shows that the histogram supports the assumption of normality. Additionally, the scatter plot (Figure 2) confirms the hypothesis of a linear relationship between the variables, as no discernible pattern is observed.

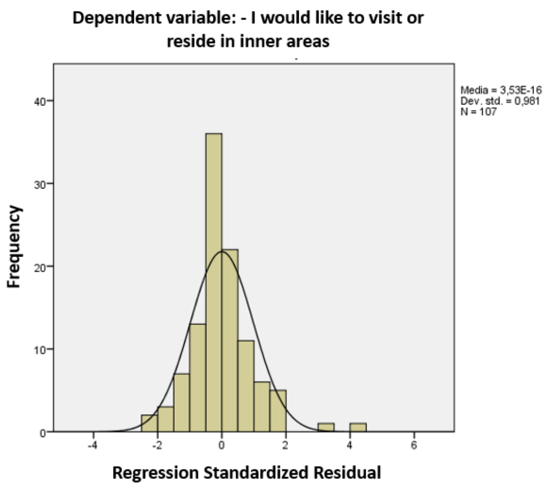

Figure 1: histogram

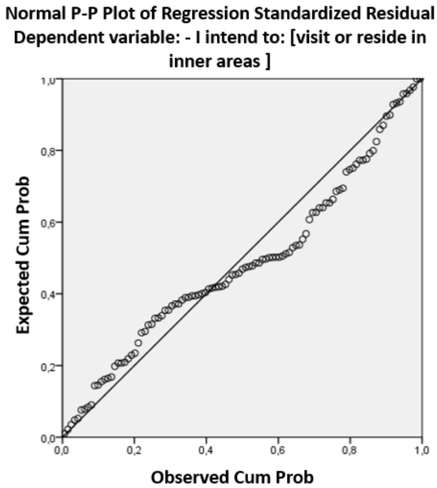

Figure 2: scatter plot

Figure 3 provides a graphical representation of these findings.

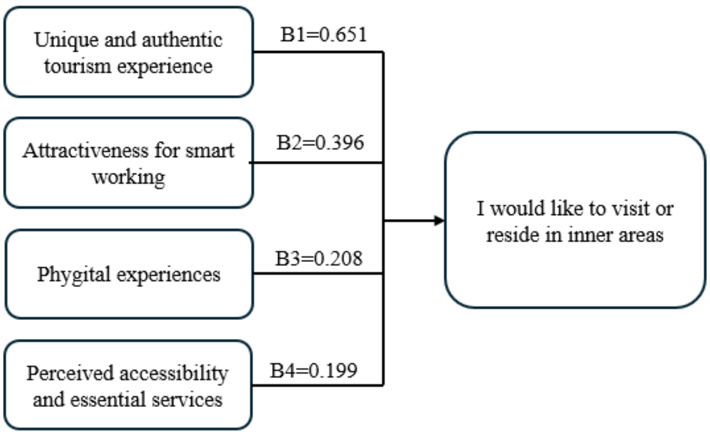

***Figure 3**: regression model*

Discussion and Conclusions

This research shed light on the main factors influencing people's intentions to visit or reside in the inner areas. These results contribute valuable knowledge to ongoing efforts to increase the attractiveness of inner areas, supporting strategies for their repopulation and sustainable development.

A quantitative methodology was employed by administering a questionnaire to a sample of 107 individuals. Four factors were extracted by means of factorial analysis: F1 – attractiveness for smart working; F2 - unique and authentic tourism experience; F3 - phygital experiences, and F4 - perceived accessibility and essential services, which were used as independent variables within a multiple linear regression to verify whether or not they affected the intention to visit or reside in inner areas.

All four factors are significant for intention; among these, the factor with the most significant impact is F2 on the desire to enjoy an authentic and unique tourism experience, followed by F1 on the attractiveness of destinations for smart working, F3 on phygital experiences and finally F4 on the perception of accessibility and availability of essential services.

The predominant factor F2 highlighted how the presence of historical authenticity, cultural and natural richness of these villages could be a potent attractor of tourists interested in cultural and rural tourism experiences. Accordingly, supporting tourism activities that enhance local resources is crucial for the socio-economic development of areas and the regeneration of their villages. Local authorities and tourism organizations must work together to create proposals that enhance these distinctive features, making these places attractive destinations.

The second most significant factor is F1 - attractiveness for smart working. Respondents see rural villages as ideal places for smart working, due to their quietness and perceived higher quality of life than cities. The peaceful environment facilitates concentration and makes remote working more pleasant, positively influencing the intention to visit and stay in the villages. The Covid-19 pandemic prompted the development of new forms of work that should be considered more carefully by companies and governments. These new ways of working can be integrated as effective strategies to repopulate the inner areas, attract new residents and encourage the return of those who left due to lack of job opportunities.

Another significant factor is F3 on the opportunity to experience phygital tourism. The use of virtual reality visors, augmented reality and QR codes makes the visit to the villages more interactive and immersive. This innovative approach enriches the discovery of the culture and history of the place, making the tourist experience more engaging. Digital experiences are becoming increasingly popular among visitors and represent a promising strategy for the development of cultural tourism.

Finally, Factor 4 -perceived accessibility and essential services is the factor that impacts less on the intention to visit villages in inner areas. Indeed, respondents perceive the villages as difficult to reach and lacking in essential services, therefore, the factor is neither a strong motivation nor deterrent to visit villages, since tourists already assume that these elements could be inadequate. Investments in infrastructure, health services, internet connectivity and public transport are crucial to successful repopulation strategies, as they facilitate smoother and pleasant visits as well as sustainable and equitable development of such areas. Governments must ensure accessibility to these resources being properly planned and distributed to support the growth and vitality of local communities.

The research presents some limitations which could be overcome through the development of future research. Firstly, the analysis was carried out on a small sample of individuals and in the Italian context only. Future studies could widen the sample and include other contexts and countries in order to make comparisons on people's propensity regarding inner areas. Moreover, this research only considered the consumer's point of view while further investigations could also include the view of other stakeholders involved in the development strategies of these areas. Finally, other variables could be added to the model to further enrich it with aspects not investigated in the framework proposed in this article.

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Comparison between GRI, ESRS, and ETIS standards for implementing sustainability reporting strategy in the tourism sector

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Abstract

Sustainability reporting (SR) is considered a tool for reporting and communicating the environmental, social, and governance performance of both industrial and service companies. The drafting of SR has increased significantly in recent years as more firms focus on measuring their impacts by promoting responsible and sustainable development. The tourism sector, specifically, consists of a variety of firms, mainly SMEs, which stimulate economic growth and social development, however, at the same time, this sector inevitably provokes environmental consequences. Given the impacts of the tourism industry, and the increasing interest in mitigating its negative externalities, tourism businesses are now required to incorporate sustainability initiatives and strategies, hence the drafting of SR is expected. Since recent initiatives aimed at proposing univocal tools and standards for reporting sustainability performance, by comparing the standards and regulations in force, this research aimed at identifying the most suitable sustainability reporting strategy for this sector. To achieve this goal, the authors conduct an in-depth analysis comparing GRI-ESRS and ETIS tourism-specific standards to highlight whether there is a correlation between them to determine which adjustments are necessary. From this comparison, it emerged that no ETIS economic, environmental, social and cultural criteria were added to the GRI-ESRS standards. However, GRI-ESRS currently fails to cover tourism-specific indicators issued by ETIS, such as "Sustainable tourism public policy", "Customer satisfaction", and supplementary indicators tailored for the different kinds of tourism destinations.

Keywords: Sustainability reporting, ESG, Tourism, Sustainable tourism development.

Relevant Topic: ESG for sustainable development and Green Reporting.

Introduction

Tourism is a significant economic activity in Europe, crucial in stimulating economic growth and social development (European Parliament, 2024). However, this sector inevitably provokes environmental consequences (Danish and Wang, 2018) and contributes to 8% of global greenhouse gas (GHG) emissions (Lenzen et al., 2018). Among many impacts, it provokes high energy consumption, land-use changes (Koçak et al., 2020), crowdedness, and traffic congestion issues (Kim et al., 2013). Additionally, tourists consume twice as much water and produce twice as much waste as residents (Rodríguez et al., 2020; Li et al., 2023). Thus, given the economic, environmental, social, and cultural impacts of the tourism industry (Kim et al., 2013), the economic and social development of the tourism sector needs to progress at the same pace as sustainability achievement. A valuable tool for demonstrating commitment to sustainability is the drafting of sustainability reporting (SR). SR involves including non-financial information related to environmental, social, and governance (ESG) issues by firms (Bosi et al., 2022). It is considered a tool for reporting and communicating the performance and impact of both industrial and service companies about their progress and efforts to reach ESG goals. The drafting of SR has increased significantly in recent years as more firms are focused on measuring their impacts by promoting responsible and sustainable development (Fusco and Ricci, 2019). Further, this tool enables companies to improve their corporate reputation, brand image, transparency, and legitimacy, leading to long-term competitive advantages (Hahn and Kühnen, 2013; Abbas et al., 2022).

To monitor and measure ESG performance results correctly, it is essential to have univocal tools and standards. The European Tourism Indicator System (ETIS), established by the European Commission in 2016, made the first effort to monitor ESG-related information in the tourism sector by building up 43 specific indicators. These indicators represent the sole standardized framework developed by the European Commission for assessing tourism sustainability (Gasparini and Mariotti, 2021). Other standards for assessing the sustainable company's impacts are Global Reporting Initiatives (GRI) guidelines, used worldwide that enable any organization to report their sustainability through a standardized framework (Dienes et al., 2016; La Torre et al., 2018). With the latest normative contribution, the disclosure of non-financial information at the European level has been updated by the Directive 2022/2464/EU, also known as the Corporate Sustainability Reporting Directive (CSRD), which entered into force in January 2023. The CSRD updates and strengthens the rules related to the social and environmental information that companies must provide. As described by the directive, a broader set of companies will be directly required to report on sustainability starting from the 2025 financial year. Additionally, non-obliged companies, such as small and medium-sized enterprises (SMEs), will be indirectly involved in reporting through their partnership with obliged companies in the value chain (Directive 2022/2464/EU). In addition, companies subject to the CSRD will be required to report according to the European Sustainability Reporting Standards (ESRS) developed by the EFRAG (European Commission, n.d.).

Recent initiatives aimed at aligning the standards used for reporting sustainability performance. A notable example is the collaboration between EFRAG and GRI, which has harmonized GRI's universal standards with ESRS's European standards by introducing an interoperability index (EFRAG, 2023). This not only promotes sustainable business practices and the transition to a sustainable and low-carbon economy but also improves the transparency and comparability of sustainability information, helping investors, consumers, and other stakeholders to make informed decisions, supporting the objectives of the European Green Deal (European Commission, 2023).

The tourism sector, specifically, consists of a variety of firms, mainly SMEs (European Parliament, 2024), and due to the CSRD requirements, the tourism industry could be one of the sectors most affected by the reporting obligation. For this reason, this study aims to conduct an in-depth analysis comparing GRI-ESRS with ETIS tourism-specific standards. While GRI standards are universally adopted and ESRS will be used for companies subject to CSRD, ETIS indicators have the advantage of being sector-specific and may better reflect the characteristics of the tourism industry. Hence, this research will determine which adjustments are necessary to tailor the standards to the tourism sector and identify a suitable sustainability strategy.

The article is organized as follows: after this introduction (Section 1), Section 2 presents a brief literature review, Section 3 defines the methodology, Section 4 presents the study's main results and the discussion, and Section 5 includes the conclusions.

Brief literature review

Despite the increasing interest in mitigating tourism's negative externalities, this sector has received less attention in studies on SR compared to the mining, chemical, or manufacturing sectors, which are traditionally considered highly polluting (Uyar et al., 2021a; Hamrouni et al., 2023). As depicted in Figure 1, in the tourism sector, there is little research on SR in the hospitality industry, and it has started to receive attention since last year.

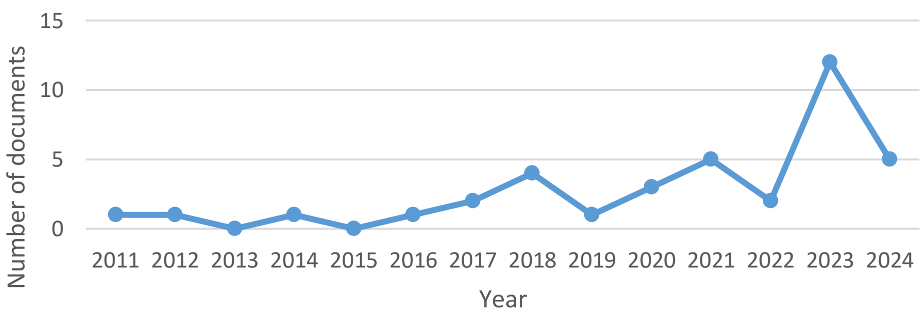

***Figure 1**. Publication time trend for "sustainability reporting" and "tourism" search using Scopus database.*

Among these, Guix et al. (2018) analysed the SR of the 18 largest hotel groups by number of rooms, aiming to investigate four main aspects: organization and report profile, stakeholder identification and engagement, materiality analysis, and responsiveness. The researchers used qualitative content analysis to verify the presence of these elements in the reports and then assigned a score based on their presence. The research revealed several key findings, including different reporting approaches, an abundance of positive information, a lack of negative information, and a general absence of any difficulties encountered in the drafting of the reports.

De Grosbois et al. (2012) conducted a quantitative content analysis study on 150 of the world's leading hotel companies to examine the quantity and type of corporate social responsibility (CSR) information provided in SR, annual reports, and other relevant website content, such as environmental goals, employment quality, diversity and accessibility, society and community wellbeing, and economic prosperity. The study revealed that while most companies mention their commitment to CSR objectives, only a few of them disclose the specific initiatives taken to achieve these goals, and even fewer report on the actual results achieved. This lack of detailed information makes it challenging to compare reports in terms of their purpose, methodologies, and the measures and actions adopted.

In a study by Medrado and Jackson (2016), the sustainability reporting and other relevant documents of thirteen hospitality and tourism (H&T) firms were analysed through content analysis. This included 6 hotels, 6 food and beverage, and 2 cruise industries. A checklist was created to identify relevant issues related to 13 categories of analysis. The study revealed that H&T companies use the GRI standards as guidelines for preparing their reports. The category with the highest number of reported information is "general CSR reporting", with a focus on reducing water usage, energy consumption, and waste production. While the least reported categories are "pays and benefits" and "work-life balance".

Hamrouni et al. (2023) explored how ethics and corporate accountability influence sustainability reporting (SR) choices, external assurance, and the use of GRI standards among 937 H&T-listed firms from 2011 to 2018. They discovered that firms in high-ethical environments are less likely to publish sustainability reports than those in low-ethical environments, while firms in low-accountability environments are more likely to publish such reports with external assurance. No significant link was found between corporate accountability and the adoption of GRI standards.

Uyar et al. (2021b) analysed 478 SRs from H&T firms published on the GRI Sustainability Disclosure Database from 1999 to 2018. They examined changes in report content over time, across regions, and between GRI-standard and free-format reports. The study found that early reports discussed few sustainability topics and were focused more on social issues. Since 2015, reports have become more comprehensive on sustainability topics, particularly recycling. Furthermore, European reports were the most detailed. GRI-standard reports were concise but covered more topics and had greater stakeholder involvement than free-format reports. However, key issues such as biodiversity, discrimination, and pollution were often overlooked.

Summarizing, research on SR in the tourism industry has made it clear that there is a scarcity of detailed information provided in SR, which often expresses only positive sustainability goals achieved rather than the initiatives taken to achieve these results, the difficulties encountered, or the failure to reach the objective or strategy. Moreover, various reporting approaches emerged based on the different standards, guidelines, methodologies, and measures adopted. Often, the predominance of one aspect of sustainability emerges rather than an assessment of all ESG criteria. Furthermore, it highlights the importance of external assurance, despite being more expensive and controversial, as it enhances credibility.

Methods

As the literature review explained, there is still no unified and comprehensive framework for the drafting of SRs for tourism industries. In addition, as highlighted by the analysis conducted by Uyar et al. (2021a) on SRs published in GRI's Sustainability Disclosure Database between 2011 and 2016, 64% were GRI-based and 36% were non-GRI-based SRs. The study also found a growing trend in the use of GRI-based reports, although the tourism sector showed relatively low adoption of GRI guidelines compared to other industries.

Based on this evidence and to reach the goal of this research, the methodology has been organized into two main steps.

In the first step, the authors conduct an in-depth analysis comparing GRI-ESRS and ETIS standards to highlight whether there is a correlation between them. In the second step, after analysing the correlation between these standards, the authors have determined which adjustments are needed to tailor the standards to the tourism sector, identifying a suitable sustainability strategy.

In this way, although the interoperability index harmonized GRI and ESRS, which are and will continue to be the most widely used SR standards, the authors aimed to address potential weaknesses of these current standards by carefully evaluating and critically comparing them with ETIS tourism-specific standards, to develop a clear and comprehensive picture of the most relevant indicators suitable for the drafting of SR for the tourism industries.

Results and Discussion

Before explaining the correlation between the standards, the authors provide a brief description of the GRI, ESRS, and ETIS standards.

The ETIS tourism-specific standards are based on 43 indicators, divided into four categories:

- Destination management (Section A), which includes two criteria: Sustainable tourism public policy, and Customer satisfaction.
- Economic value (Section B): Tourism flow (volume and value) at the destination, Tourism enterprises performance, Quantity and quality of employment, and Tourism supply chain.
- Social and cultural impact (Section C): Community/social impact, Health and safety, Gender equality, Inclusion/accessibility, and Protecting and enhancing cultural heritage, local identity and assets.

- Environmental impact (Section D): Reducing transport impact, Climate change, Solid waste management, Sewage treatment, Water management, Energy usage, and Landscape and biodiversity protection.

Then, ETIS also provided an indicative set of supplementary indicators, tailored for specific type of tourism destinations, such as maritime and coastal areas, and transnational cultural routes (European Commission, 2016).

GRI standards, as Table 1 displays, are divided into three main sections. In the first section, there are the universal standards, which provide a basis for the use of the standards and guidance on how to report the company's information and identify material issues, i.e. those that are most significantly relevant. In the second section, the sector standards, in which the sectors were divided into four groups, from sectors with the highest (group 1) to those with the lowest (group 4) environmental, social, and economic impacts. In this section, additional sector-specific disclosures were added. In the third section, the topic-specific standards, are divided into three macro categories which consider the economic (GRI 200), environmental (GRI 300), and social aspects (GRI 400), precisely:

- GRI 200, which includes the following indicators: economic performance, indirect economic impacts, supplier management, anti-corruption, and anti-competitive behaviour.

- GRI 300: materials, energy, biodiversity, emissions, waste and discharges, environmental compliance, and environmental assessment of suppliers.

- GRI 400: employment, industrial relations, occupational health and safety, training, diversity and equal opportunity, non-discrimination, freedom of association and collective bargaining, human rights compliance assessment, local community, supplier social practices assessment, political contributions, privacy compliance, and socio-economic compliance (GRI, 2024).

Table 1. *GRI standards*

Universal standards	Sector standards	Topic-specific standards
GRI 1 Foundation	Group 1 Basic materials and needs	GRI 200 Economic
GRI 2 General disclosures	Group 2 Industrial	GRI 300 Environmental
GRI 3 Material Topics	Group 3 Transport, infrastructure, and tourism	GRI 400 Social
	Group 4 Other services and light manufacturing	

While ESRS standards, as Table 2 shows, are divided into two sections. Cross-cutting standards apply to all areas of reporting and incorporate general reporting principles and essential information to be disclosed. In the second section, the topical standards are divided into:

- Environmental standards, which include five indicators: Climate Change, Pollution, Water and Marine Resources, Biodiversity and Ecosystems, and Resource Use and Circular Economy.
- Social standards: Own workforce, Workers in the value chain, Affected communities, and Consumers and end users.
- Governance standard: Business Conduct (European Commission, 2023).

Table 2. *ESRS standards.*

Cross cutting standards	Topical standards		
ESRS 1 General requirements	Environmental	Social	Governance
ESRS 2 General disclosure	E1 - Climate change	S1 - Own workforce	G1 - Business conduct
	E2 - Pollution	S2 - Workers in the value chain	
	E3 - Water and marine resource	S3 - Affected communities	
	E4 - Biodiversity	S4 - Consumers and end users	
	E5 - Resource use and circular economy		

The Interoperability Index, as above explained, has been created to relate GRI-ESRS standards, to prevent the need for double reporting without unnecessary complexity (EFRAG, 2023). Therefore, companies may use the GRI or ESRS standard indistinctly. Starting from the Interoperability Index, the authors have done a comparative analysis between GRI-ESRS standards and ETIS-tourism-specific indicators, to highlight their correlation. Tables 3, 4, and 5 explain the standards association.

As shown in Table 3, the authors compare GRI, ESRS, and ETIS economic standards. This table shows that the ETIS indicators do not have the same degree of detail as the GRI-ESRS indicators, however, they were all included and aligned with three GRI-ESRS standards, which are Economic Performance, Indirect Economic Impacts, and Procurement Practices. Further, from the comparison it emerges that ETIS has scarcely reference to the economic impacts generated directly and indirectly on the local community and tourist destination. Conversely, the ETIS is more oriented towards the economic impacts generated by the volumes and value of the tourist flow (such as daily spending per overnight tourist, number of tourist nights per month, and relative contribution of tourism to the destination's economy). Moreover, it is important to highlight that in this section, ETIS inserts employment indicators whereas GRI-ESRS addresses it in the social section. Thus, it is clear that in the economic section, the ETIS standards do not add any tourism-specific indicators for SR than the GRI-ESRS.

Table 3. *Comparison between GRI, ESRS, and ETIS economic standards.*

Standards	GRI	ESRS	ETIS
GRI 201 Economic Performance	201-1	n.a.	B.1.1; B.1.2; B.1.4; B.1.5; B.2.1; B.2.2
	201-2	ESRS 2 SBM-3 §48 (a), and (d) to (e); ESRS E1 §18; E1-3 §26; E1-9 §64	n.a.
	201-3	n.a.	n.a.
	201-4	n.a.	n.a.
GRI 202 Market Presence	202-1	ESRS S1 S1-10 §67-71 and §AR 72 to 73	n.a.
	202-2	ESRS 1 §AR 16	n.a.
GRI 203 Indirect Economic Impacts	203-1	ESRS 1 §AR 16.	n.a.
	203-2	ESRS S1 S1-4 §AR 41; ESRS S2 S2-4 §AR 37; ESRS S3 S3-4 §AR 36	B.1.3
GRI 204 Procurement Practices	204-1	ESRS 1 §AR 16	B.4.1
GRI 205 Anticorruption	205-1	ESRS G1 G1-3 §AR 5	n.a.
	205-2	ESRS G1 G1-3 §20, §21 (b) and (c) and §AR 7 and 8	n.a.
	205-3	ESRS G1 G1-4 §25	n.a.
GRI 206 Anticompetitive Behaviour	206-1	n.a.	n.a.
GRI 207 Tax	207-1	n.a.	n.a.
	207-2	n.a.	n.a.
	207-3	n.a.	n.a.
	207-4	n.a.	n.a.

Note: § means paragraph; n.a.: not available.

As displayed in Table 4, the authors compare GRI, ESRS, and ETIS environmental standards. This table shows that the ETIS criteria have almost the same degree of detail as the GRI-ESRS indicators and have been included and aligned with almost all GRI-ESRS standards. From this comparison, it emerges that, as in the case of the economic indicators, no ETIS environmental criteria were added to the GRI and ESRS standards, which are therefore valuable for the tourism sector.

Table 4. *Comparison between GRI, ESRS, and ETIS environmental standards.*

Standards	GRI	ESRS	ETIS
GRI 301 Materials	301-1	ESRS E5 E5-4 §31 (a)	n.a.
	301-2	ESRS E5 E5-4 §31 (c)	n.a.
	301-3	ESRS 1 §AR 16	n.a.
GRI 302 Energy	302-1	ESRS E1 E1-5 §37; §38; §AR 32 (a), (c), (e) and (f)	D.6.1; D.6.2; D.6.3
	302-2	ESRS 1 §AR 16.	n.a.
	302-3	ESRS E1 E1-5 §40 to §42	n.a.
	302-4	ESRS 1 §AR 16	n.a.
	302-5	ESRS 1 §AR 16	D.6.2
GRI 303 Water and Effluents	303-1	ESRS 2 SBM-3 §48 (a); MDR-T §80 (f); ESRS E3 §8 (a); §AR 15 (a); E3-2 §15, §AR 20	D.5.2; D.5.3
	303-2	ESRS E2 E2-3 §24	D.4.1
	303-3	ESRS 1 §AR 16	D.5.1; D.5.2; D.5.3
	303-4	ESRS 1 §AR 16	D.5.1; D.5.2; D.5.3
	303-5	ESRS E3 E3-4 §28 (a), (b), (d) and (e)	D.5.1; D.5.2; D.5.3
GRI 304 Biodiversity	304-1	ESRS E4 §16 (a) i; §19 (a); E4-5 §35	D.7.1
	304-2	ESRS E4 E4-5 §35, §38, §39, §40 (a) and (c)	D.7.1
	304-3	ESRS E4 E4-3 §28 (b) and §AR 20 (e); E4-4 §AR 26 (a)	D.7.1
	304-4	ESRS E4 E4-5 §40 (d) i	D.7.1
GRI 305 Emissions	305-1	ESRS E1 E1-4 §34 (c); E1-6 §44 (a); §46; §50; §AR 25 (b) and (c); §AR 39 (a) to (d); §AR 40; AR §43 (c) to (d)	D.1.1; D.1.2; D.1.3; D.1.4
	305-2	ESRS E1 E1-4 §34 (c); E1-6 §44 (b); §46; §49; §50; §AR 25 (b) and (c); §AR 39 (a) to (d); §AR 40; §AR 45 (a), (c), (d), and (f)	D.1.1; D.1.2; D.1.3; D.1.4

	305-3	ESRS E1 E1-4 §34 (c); E1-6 §44 (c); §51; §AR 25 (b) and (c); §AR 39 (a) to (d); §AR 46 (a) (i) to (k)	D.1.1; D.1.2; D.1.3; D.1.4
	305-4	ESRS E1 E1-6 §53; §54; §AR 39 (c); §AR 53 (a)	n.a.
	305-5	ESRS E1 E1-3 §29 (b); E1-4 §34 (c); §AR 25 (b) and (c); E1-7 §56	D.2.1; D.2.2
	305-6	ESRS 1 §AR 16	n.a.
	305-7	ESRS E2 E2-4 §28 (a); §30 (b) and (c); §31; §AR 21; §AR 26	n.a.
GRI 306 Effluents and Waste	306-3	ESRS 1 §AR 16	n.a.
GRI 306 Waste	306-1	ESRS 2 SBM-3 §48 (a), (c) ii and iv; ESRS E5 E5-4 §30	D.3.1
	306-2	ESRS E5 E5-2 §17 and §20 (e) and (f); E5-5 §40 and §AR 33 (c)	D.3.1
	306-3	ESRS E5 E5-5 §37 (a), §38 to §40	D.3.1
	306-4	ESRS E5 E5-5 §37 (b), §38 and §40	D.3.2; D.3.3
	306-5	ESRS E5 E5-5 §37 (c), §38 and §40	D.3.2; D.3.3
GRI 308 Supplier Environmental Assessment	308-1	ESRS G1 G1-2 §15 (b)	n.a.
	308-2	ESRS 2 SBM-3 §48 (c) i and iv	n.a.

Note: § means paragraph; n.a.: not available.

As shown in Table 5, the authors compare GRI, ESRS, and ETIS social and cultural standards. This table shows that the ETIS indicators do not have the same degree of detail as the GRI-ESRS indicators; however, they were all included and aligned with only four GRI-ESRS standards, which are Employment, Diversity and Equal Opportunity, Local Communities, Customer Health and Safety. From this comparison, it emerges that also in this section, no ETIS social criteria were added to the GRI and ESRS standards.

Table 5. *Comparison between GRI, ESRS, and ETIS social and cultural standards.*

Standards	GRI	ESRS	ETIS
GRI 401 Employment	401-1	ESRS S1 S1-6 §50 (c)	B.3.1; B.3.2
	401-2	ESRS S1 S1-11 §74; §75; §AR 75	n.a.

	401-3	ESRS S1 S1-15 §93	n.a.
GRI 402 Labor/Management Relations	402-1	ESRS 1 §AR 16	n.a.
GRI 403 Occupational Health and Safety	403-1	ESRS S1 S1-1 §23	n.a.
	403-2	ESRS S1 S1-3 §32 (b) and §33	n.a.
	403-3	ESRS 1 §AR 16	n.a.
	403-4	ESRS 1 §AR 16	n.a.
	403-5	ESRS 1 §AR 16	n.a.
	403-6	ESRS 1 §AR 16	n.a.
	403-7	ESRS S2 S2-4 §32 (a)	n.a.
	403-8	ESRS S1 S1-14 §88 (a); §90	n.a.
	403-9	ESRS S1 S1-4, §38 (a); S1-14 §88 (b) and (c); §AR 82	n.a.
	403-10	ESRS S1 S1-4, §38 (a); S1-14 §88 (b) and (d); §89; §AR 82	n.a.
GRI 404 Training and Education	404-1	ESRS S1 S1-13 §83 (b) and §84	n.a.
	404-2	ESRS S1 S1-1 §AR 17 (h)	n.a.
	404-3	ESRS S1 S1-13 §83 (a) and §84	n.a.
GRI 405 Diversity and Equal Opportunity	405-1	ESRS 2 GOV-1 §21 (d); ESRS S1 S1-6 §50 (a); S1-9 §66 (a) to (b); S1-12 §79	C.3.1; C.3.2; C.4.1; C.4.2; C.4.3; C.4.4
	405-2	ESRS S1 S1-16 §97 and §98	n.a.
GRI 406 Non-discrimination	406-1	ESRS S1 S1-17 §97, §103 (a), §AR 103	n.a.
GRI 407 Freedom of Association and Collective Bargaining	407-1	ESRS 1 §AR 16	n.a.
GRI 408 Child labour	408-1	ESRS S1 §14 (g); S1-1 §22 ESRS S2 §11 (b); S2-1 §18	n.a.
GRI 409 Forced or Compulsory Labor	409-1	ESRS S1 §14 (f); S1-1 §22 ESRS S2 §11 (b); S2-1 §18	n.a.
GRI 410	410-1	ESRS 1 §AR 16	n.a.

Security Practices			
GRI 411 Rights of Indigenous Peoples	411-1	ESRS S3 S3-1 §16 (c), AR 12; S3-4 §30, §32 (b), §33 (b), §36	n.a.
GRI 413 Local Communities	413-1	ESRS S3 S3-2 §19; S3-3 §25; S3-4 §AR 34 (c)	C.5.2
	413-2	ESRS 2 SBM-3 48 (c); ESRS S3 §9 (a) i and (b)	C.1.1; C.1.2; C.1.3; C.1.4; C.5.1
GRI 414 Supplier Social Assessment	414-1	ESRS G1 G1-2 §15 (b)	n.a.
	414-2	ESRS 2 SBM-3 §48 (c) i and iv	n.a.
GRI 415 Public Policy	415-1	ESRS G1 G1-5 §29 (b)	n.a.
GRI 416 Customer Health and Safety	416-1	ESRS 1 §AR 16	C.2.1
	416-2	ESRS S4 S4-4 §35	C.2.1
GRI 417 Marketing and Labeling	417-1	ESRS 1 §AR 16	n.a.
	417-2	ESRS S4 S4-4 §35	n.a.
	417-3	ESRS S4 S4-4 §35	n.a.
GRI 418 Customer Privacy	418-1	ESRS S4 S4-3 §AR 23; S4-4 §35	n.a.

Note: § means paragraph; n.a.: not available.

Therefore, from Tables 3, 4, and 5, it is noted that all ETIS criteria of the economic, environmental, and social and cultural sections can be correlated with GRI-ESRS standards. While no ETIS Destination Management criteria (Section A) are correlated with the GRI and ESRS standards. Due to the sectoral focus, this specific section refers to two criteria "Sustainable tourism public policy" and "Customer satisfaction", and precisely they investigate the sustainability policy of tourism enterprises and any certifications achieved, as well as refer to the issue of tourist experience satisfaction and customer retention. This finding could be considered the first contribution that ETIS can provide to the GRI-ESRS.

In addition, ETIS proposed an indicative list of supplementary indicators, which can be adapted to specific types of companies, depending on their location. To make an example, ETIS proposed specific additional indicators for "maritime and coastal tourism", "transnational cultural routes", and "accessible tourism". Starting with coastal and maritime tourism, there are indicators that some tourism companies should assess and monitor, such as:

- Level of pollution in seawater per 100 ml,
- Percentage of beaches awarded the Blue Flag,

- Total km of free beaches relative to total km of beaches,
- Percentage of beaches accessible to all,
- Number of days per year the beach/shore is closed due to contamination.

While considering the transnational cultural routes, other relevant indicators could be considered, for example:

- The percentage of cultural events linked to the cultural route in the destination,
- The percentage of the local community involved in the actions organised within the framework of the cultural route's activities,
- Effect of the cultural route on the distinctiveness and local identity, culture and heritage of the destination (European Commission, 2016).

To this end, different indicators need to be addressed and adapted to the requirements of the SR for the tourism sector, tailored to the context of destinations (maritime, cultural routes, mountain, natural parks, etc.). This finding could be considered the second contribution that ETIS can provide to the GRI-ESRS.

It should be noted that ETIS standards only cover the tourism sector, and currently, these indicators do not provide a comprehensive analysis of the sustainability impacts and aspects of the tourism sector. ETIS provides a limited framework compared to GRI and ESRS. The GRI-ESRS standards remain the most widely used SR standards globally, providing a common global language for communicating ESG impacts. However, this research has found that there is a need to provide adjustments to the standards to develop a comprehensive framework with specific indicators relevant to the tourism industry when drafting sustainability reports.

Conclusions

The tourism sector, specifically, consists of a variety of firms, mainly SMEs, which stimulate economic growth and social development, however, at the same time, this sector inevitably provokes environmental consequences. The SR is a valuable tool for monitoring and measuring the ESG performance of firms. Recent initiatives aimed at proposing univocal tools and standards for reporting sustainability performance. The interoperability index, which aligned GRI with ESRS standards is an example. In this research, the authors conduct an in-depth analysis comparing GRI-ESRS and ETIS tourism-specific standards to highlight whether there was a correlation between them. After that, the authors have pointed out which adjustments are necessary to tailor the standards to the tourism sector and identify a suitable sustainability strategy. From the comparison of GRI-ESRS and ETIS standards, it emerged that no ETIS economic, environmental, and social and cultural criteria were added to the GRI-ESRS standards. This means that although tourism firms showed relatively low adoption of GRI guidelines compared to other industries, GRI-ESRS indicators are aligned with the ESG objectives of the tourism sector. Although GRI and ESRS are and will continue to be the most widely used SR standards, it is necessary to adapt them with additional standards, such as those issued by ETIS, since GRI-ESRS currently fail to cover specific indicators about "Sustainable tourism public policy" and "Customer satisfaction", as well as specific standards tailored for the different types of tourism destinations (maritime, cultural routes, mountain, natural parks, etc.). From these findings, adjustments are necessary to develop a clear and comprehensive picture of the most relevant indicators suitable for the drafting of SR for the tourism industries.

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Circular Tourism: defining a new model based on Circular Economy, Social Innovation and Sustainable Tourism

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Abstract

The long-term impact of tourism on the local economy, environment, and culture emphasizes sustainable tourism as a universal goal for all tourism scales, aligning with both large and small-scale practices. This paper wants to provide a definition of “circular tourism” by combining the largely adopted definition of sustainable tourism, eco-tourism, community-based tourism with the concepts of circular economy and social innovation. On one hand, circular economy aims to reduce waste and maximise efficiency through the reuse, recycling and regeneration of materials. On the other hand, social innovation focuses on creative solutions to social and environmental challenges through collaboration between different actors. Sustainable tourism includes many of these principles. In addition, eco-tourism emphasises environmental conservation, ecological education and the involvement of local communities for a positive impact on the planet. More, community-based tourism focuses on empowering local communities by involving them in the development and management of tourism activities to foster social and economic sustainability.

In the paper, it is highlighted the importance of active community involvement to promote circular tourism, as a catalyst for sustainable development and positive environmental impact. In addition, by emphasising sustainability, community involvement and innovation could inspire thoughtful and forward-looking approaches to tourism management and promotion. In the provided definition of “circular tourism” are included pillars like environmental sustainability, the promotion of active involvement of local communities, driving sustainable economic growth. This integrated approach promotes responsible and conscious tourism practices considering the interconnection between environment, economy and society.

Keywords: Circular Tourism, Social Innovation, Environment, Community, Sustainable Tourism

Introduction

The evolution of the tourism sector has highlighted the importance of considering the long-term impact on local economies, the environment, and the cultures of host communities. Thus, over recent decades, tourism has consistently grown and diversified, emerging as one of the largest and fastest-growing economic sectors globally. It plays a crucial role in socio-economic development by generating jobs and enterprises, increasing export revenues, and promoting infrastructure development (UNWTO, 2017). Sustainable tourism has since been recognized as a universal goal for all forms of tourism, emphasizing the integration of large and small-scale tourism practices (Clarke, 1997). With the growing awareness of these issues, there is an urgent need to adopt sustainable tourism strategies at all levels. This paper discusses about the definition of the concept of "circular tourism" whit the combination of main pillars and characteristics of largely recognized models like eco-tourism, community-based tourism, circular economy, and social innovation. Worldwide, the concept of circular economy is based on the idea of reducing waste and maximizing efficiency through the recovery, recycling, and regeneration of materials, in line with the mission of the circular economy (Kirchherr et al., 2017). This approach not only aims to minimize environmental impact but also to create a more resilient and self-sufficient system. The circular economy envisions a system where waste is eliminated through innovative design strategies applied to materials, products, systems, and business models (Ellen MacArthur Foundation, 2015). At the micro level, strategic planning can foster a closed-loop system by connecting producers, distributors, consumers, and recyclers. This paradigm primarily intersects with the fields of environmental economics and industrial ecology (Pinelli et al., 2018). Simultaneously, social innovation focuses on finding creative solutions to address social and environmental challenges by promoting collaboration between different actors (Moulaert et al., 2013). This involves developing new business models, technologies, and practices that can support systemic change towards sustainability. This has also introduced the idea that measuring societal progress requires developing new objectives linked to a new orientation of values and a new concept of politics and citizenship (Biggeri et al., 2014). Furthermore, eco-tourism is distinguished by its commitment to environmental conservation, ecological education, and the involvement of local communities to generate a positive impact on the planet (Fennell, 2014). This type of tourism encourages visitors to become stewards of the environment while supporting the conservation of natural resources and biodiversity. On the other hand, community-based tourism focuses on empowering local communities through active participation in the development and management of tourism activities, promoting economic and social sustainability (Hall, 2010). This approach ensures that the benefits of tourism are equitably distributed among all community members, improving quality of life and preserving cultural traditions.

This paper aims to define "circular tourism" by emphasizing the crucial role of community involvement and innovative approaches in promoting sustainable development and environmental benefits. By advocating for a balance between responsible tourism practices and innovative solutions, the objective is to enhance sustainable tourism strategies and promote forward-thinking tourism management. The comprehensive definition of "circular tourism" integrates environmental sustainability, active local community participation, and the stimulation of sustainable economic growth. This holistic approach supports conscious and responsible tourism practices, acknowledging the interconnections between environment, economy, and society. In essence, circular tourism could offer a tangible response to the global challenges facing contemporary tourism. By integrating sustainable principles and adopting innovative practices, tourism can act as a catalyst for positive change, contributing to environmental protection, the well-being of local communities, and long-term economic prosperity. This paper presents an integrated vision that can guide future policies and practices, offering a model for tourism development that is both sustainable and equitable.

Methods

The methodology adopted is based on the analysis and synthesis of the most significant definitions of key concepts such as circular economy, ecotourism, community-based tourism and social innovation found in the scientific literature. The main objective is to identify the core characteristics and pillars of each concept to formulate an integrated definition of circular tourism that incorporates sustainable principles and practices. First, the literature concerning the circular economy was reviewed, focusing on the concept of reducing waste and maximising efficiency through the reuse, recycling and regeneration of materials. This review identified the key strategies and principles that define the circular approach in the economic and environmental spheres. Next, a review of the literature on eco-tourism and on community-based tourism was conducted, focusing on aspects of environmental conservation, ecological education and community involvement. This analysis identified the key principles that characterise the sustainable approach of eco-tourism and its importance in promoting responsible tourism practices. Finally, the literature on social innovation was reviewed, focusing on creative solutions to address social and environmental challenges through collaboration between different actors. This analysis enabled the identification of strategies and methodologies that favour the implementation of innovative solutions for the promotion of sustainable development in the tourism sector. Building on the nine principles of sustainable tourism outlined in ISO 23405, we have expanded these principles by incorporating elements from circular economy, social innovation, ecotourism, and community-based tourism. This comprehensive approach has led to the development of principles specifically tailored for circular tourism. The resulting principles not only uphold the core values of sustainability but also emphasize the importance of innovation, local community engagement, and environmental stewardship in tourism practices.

Results and Discussion

The need to define circular tourism stems from the current situation in which the tourism sector finds itself, plagued by the issues related to the climate crisis, exacerbated by overtourism, as well as the growing impact that tourism has generated in terms of the concentration of flows on a few major tourist destinations around the world and the issues related to the governance of the tourism phenomenon (Capocchi et al., 2019). According to international standard ISO 23405:2002 - Tourism and related services — Sustainable tourism — Principles, vocabulary and model, sustainable tourism is defined as: “tourism sector that takes full account of its current and future economic, social and environmental impacts, addressing the needs of visitors, employees, the industry, host communities and climate change among others, while working closely with interested parties on the implementation of sustainability". The principles of sustainable tourism as outlined in ISO 23405 emphasize nine key areas: i) Effective management of sustainable tourism requires ethical business processes that align with corporate social, economic, and environmental responsibilities, promoting the circular economy and sustainability goals; ii) Ensuring the rights of local communities involves advocating for social and environmental responsibility, economic equality, human rights, and the well-being of employees and communities; iii) Conservation of the natural environment and biodiversity is crucial, adopting practices that minimize impact and protect wildlife; iv) Recognizing and respecting cultural heritage and local values ensures tourism activities are harmonious with cultural traditions; v) Stimulating social and economic development involves strengthening the local economy, enhancing skills, generating jobs, and fostering responsible local supply chains; vi) Guaranteeing quality in tourism includes providing reliable information, evaluating tourist satisfaction, and adhering to recognized standards; vii) Health, safety, and security measures are essential to enhance destination conditions and protect against health risks; viii) Legal compliance and ix) preparation for emergencies, such as pandemics and environmental crises, are also critical components of sustainable tourism management. Starting from the principles of sustainable tourism, it was essential to further consider ecotourism and community-based tourism due to their specialized focus on environmental conservation and local community collaboration. These forms of tourism embody core values of sustainable tourism but apply them in specific, impactful ways that enhance the overall sustainability framework. By considering both ecotourism and community-based tourism, we intend to address sustainable tourism to specific environmental and social goals: ecotourism fosters environmental stewardship and educates tourists on the importance of preserving natural ecosystems and biodiversity; community-based tourism empowers local communities by involving them in the planning and management of tourism activities, ensuring that the economic benefits of tourism are equitably distributed and that cultural traditions are preserved.

Circular economy represents a systemic and integrated approach that aims to reduce waste, promote the reuse and recycling of materials, and create value through efficient resource management. The firsts theorisations of circular economy, as already reported, are from the 90s. A review of 2017 identifies multiple definitions (Kirchherr, Reike and Hekkert, 2017), which have been synthesised as follows: "circular economy describes an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations." (Kirchherr et al., 2017). And "Circular economy is a systems solution framework that tackles global challenges like climate change, biodiversity loss, waste, and pollution. It is based on three principles, driven by design: eliminate waste and pollution, circulate products and materials (at their highest value), regenerate nature" (Ellen MacArthur Foundation, 2013). Furthermore, still according to Ellen MacArthur Foundation (2014), the circular economy is a regenerative system in which materials and products retain their value for as long as possible while minimising waste generation. It is based on the principles of reducing, reusing, recycling, and rethinking production processes. Thus, circular economy is an alternative to the traditional linear model based on production, consumption, and disposal, promoting the transition to a more sustainable and resource-efficient system (Kirchherr et al., 2017). In addition to its environmental benefits, the circular economy also encompasses significant social dimensions. It fosters job creation, improves resource security, and enhances social equity. According to ISO 21401:2018, circular economy is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles. By promoting local production and recycling initiatives, the circular economy can generate employment opportunities within communities, contributing to economic stability and resilience (Stahel, 2016). Furthermore, it supports social inclusion by encouraging collaborative consumption and the sharing economy, which can reduce inequality by providing access to goods and services for a broader population (Murray et al., 2017). It should be noted, the scale of implementation of circular economy can vary from micro to meso to macro. The engagement of all levels is essential to reach a holistic approach. The macro-level efforts refer to policy changes on national and regional levels, the meso level includes industrial networks and symbiosis between companies, while micro level focuses on the companies and citizens as consumers. So far, the circular economy represents a sustainable way able to preserve the environment while maintaining high-quality life standards (Borsacchi et al., 2020). Moving toward a circular model could bring several benefits. The European Parliament reports that measures such as waste prevention, eco-design and re-use could save companies money while also reducing total annual greenhouse gas emissions. Currently, the production of materials utilised everyday within Europe territory accounts for 45% of the CO_2 emissions (European Parliament, 2022). Moving towards a more circular economy could deliver benefits such as reducing pressure on the environment, improving the security of the supply of raw materials, increasing competitiveness, stimulating innovation, boosting economic growth, and creating jobs (European Parliament, 2022). Circular economy applied to the tourism sector entails for example, hotels and resorts that can adopt measures such as water-saving technologies, renewable energy sources, and waste recycling programmes. These practices not only reduce environmental impact but also lower operating costs, making them cost-effective. The integration of circular economy principles into tourism practices could represent significant progress towards sustainable development. By adopting strategies that reduce waste and maximise resource efficiency, the tourism sector can mitigate its environmental impact and contribute to broader sustainability goals. Moreover, the social benefits of circular tourism include increased local employment and enhanced community well-being through sustainable practices. The findings suggest that circular tourism can serve as a model for other sectors seeking to balance economic growth with environmental stewardship and social responsibility.

Social innovation represents a creative and collaborative approach that aims to solve social challenges through sustainable and inclusive solutions. According to Phills, Deiglmeier and Miller (2008), social innovation is the process through which new ideas and practices are developed to address social challenges in an effective and sustainable way. It focuses on social impact and community empowerment. Furthermore, according to Mulgan (2007), social innovation represents an opportunity to create social value through creative and sustainable solutions that address inequalities and promote collective well-being. Social innovation differs from traditional innovation in that it focuses not only on economic profit, but also on positive impact on society. Social innovation initiatives can come from various sources, including individuals, businesses, non-profit organisations and public institutions, and often involve collaboration between different actors. Social innovation can play a crucial role in promoting sustainable tourism by fostering collaboration and creative problem solving. Case studies and examples identified in the literature highlight the potential of innovative approaches to address complex challenges in the tourism sector. Stakeholders should invest in research and development to explore new solutions and support the implementation of successful models. By doing so, the tourism industry can become a catalyst for positive social and environmental change.

Among the fastest-growing segments in the industry is ecotourism (Donohoe and Needham, 2006). Originally describing nature tourism, the term 'ecotourism' has expanded since the 1980s to encompass broader ethical considerations (Blamey, 2001). Today, it is understood as a multifaceted approach that integrates social, ecological, and economic dimensions, focusing on the ethical balance between conservation and tourism development (Björk, 2000; Weaver, 2005; Donohoe and Needham, 2006). Ecotourism is a growing sector that promotes responsible and sustainable travel, contributing to the preservation of the natural environment and the well-being of local communities. According to the International Ecotourism Society (1990), ecotourism is defined as 'a responsible approach to travel to natural areas that conserves the environment and improves the well-being of local people' (TIES, 1990). This approach focuses on authentic experience, environmental awareness and support for conservation initiatives. Weaver (2008) further elaborates on the definition, indicating that ecotourism is characterised by respectful interaction with the natural environment, the enhancement of local cultures and the active involvement of communities in the tourism process. This form of tourism not only reduces environmental impact, but also promotes practices that sustain biodiversity and cultural traditions, creating a mutual benefit for tourists and host communities (Weaver, 2008). Furthermore, Fennell (2014) emphasises the importance of environmental education in ecotourism, highlighting how this practice enables travellers to become more aware of environmental issues and actively participate in the conservation of natural resources. The literature review on ecotourism has emphasised the importance of environmental conservation, ecological education and community involvement. There is a close relationship between tourism sector and landscape, its beauty, its attractiveness, its accessibility and the landscape must be considered as a “complex system” consisting of combinations of and interaction among six perceived landscapes: natural, man-made, man-made/cultural, financial, social, and human landscape (Fusco, 2014). Ecotourism initiatives that prioritise the protection of natural habitats and wildlife can generate significant positive environmental outcomes (Fennell, 2014). Programmes that educate tourists about local ecosystems and conservation efforts can foster a deeper appreciation and respect for nature. Furthermore, the involvement of local communities in these initiatives ensures that the benefits of tourism are more equitably distributed and that conservation efforts are supported by those most directly affected. Ecotourism has demonstrated its potential in improving environmental and social outcomes. By prioritising conservation and education, ecotourism initiatives can protect natural resources and promote a sense of environmental responsibility among tourists. Furthermore, the involvement of local communities in these initiatives ensures that the benefits of tourism are shared and that conservation efforts are culturally and socially appropriate. Future research should explore ways to scale these benefits and address potential challenges, such as overtourism and resource depletion.

Community-based tourism (CBT) is a participatory approach that actively involves local communities in the management and development of tourism activities, promoting a more sustainable and inclusive tourism. According to Murphy (1985), CBT is a type of tourism that actively involves local communities in decision-making and in the economic benefits derived from tourism activities. This approach is based on participation, empowerment and shared management of resources (Murphy, 1985). Ashley et al. (2001) point out that CBT fosters the sustainable development of tourism destinations by promoting local resource enhancement, environmental conservation and social inclusion. This tourism model aims to ensure that local communities directly benefit from tourism activities, contributing to the improvement of socio-economic conditions and environmental protection (Ashley et al., 2001). Furthermore, Scheyvens (1999) argues that CBT can increase local communities' sense of pride and cultural identity, while improving their capacity to manage and control tourism resources. This approach helps to create a stronger bond between tourists and host communities, fostering authentic and reciprocal experiences (Scheyvens, 1999). Community-based tourism offers a powerful tool for strengthening local communities and promoting sustainable development. The participatory nature of CBT ensures that tourism development is more inclusive and responsive to local needs. This approach can lead to more sustainable and resilient tourism models, better equipped to withstand economic and environmental shocks. Policymakers and practitioners should support CBT initiatives through capacity building, funding and the creation of supportive regulatory frameworks.

Figure 1. *Circular tourism model. Source: authors*

Building on the main pillars of the four above mentioned models, an attempt has been made to provide a set of principles for circular tourism. Circular tourism (see figure 1) includes the main concepts of circular economy, ecotourism, community-based tourism and social innovation into 11 principles, promoting a more sustainable and equitable model of tourism. The proposed principles are the following:

Innovation and sustainable technology: By adopting innovative solutions and sustainable technologies, circular tourism seeks to improve resource efficiency and promote environmental sustainability in the tourism sector. This includes the use of renewable energies, such as solar and wind energy, the implementation of intelligent water and energy resource management systems, and the adoption of technologies for emission reduction. Hotels and tourist facilities can adopt smart solutions for energy and water efficiency, such as motion sensors for lighting and rainwater harvesting systems.

Fair Distribution of Benefits: Circular tourism commits to ensuring a fair distribution of the economic benefits generated by tourism activities, contributing to the well-being of local communities and reducing social inequalities. This means that the profits derived from tourism should be reinvested in the community, improving infrastructure, public services, and local job opportunities. Supporting local entrepreneurship, offering training and professional development opportunities, and ensuring decent working conditions in the tourism sector are key elements for inclusive and sustainable growth.

Involvement of Local Communities: An essential element of circular tourism is the active and participatory involvement of local communities in decisions and benefits derived from tourism. This involvement ensures that the needs and desires of the communities are considered, creating tourism that is not only sustainable but also equitable. Local communities must be active partners, participating in the planning and management of tourism activities. This can be achieved through public consultations, community forums, and cooperative projects that promote responsible and inclusive tourism.

Minimization of Waste: Optimizing processes and promoting recycling are at the heart of circular tourism. This involves adopting strategies to minimize waste production, such as the use of recyclable, compostable, or biodegradable materials, and implementing efficient waste management systems. Tourism operators can encourage tourists to participate in recycling programs, reduce the consumption of single-use plastics, and promote the use of renewable resources. Additionally, adopting advanced technologies for waste and energy management can significantly reduce environmental impact.

Promotion of Environmental Conservation: Circular tourism commits to supporting the conservation of the natural environment, promoting biodiversity, and adopting practices that reduce negative impacts on the territory. This includes the protection of natural areas, the reduction of CO_2 emissions, and the adoption of sustainable agricultural and forestry practices. Tourism initiatives can include reforestation projects, support for natural parks and reserves, and the promotion of low-impact tourist activities such as trekking, birdwatching, and ecotourism. Educating tourists about conservation and involving them in environmental volunteer activities can further strengthen these efforts.

Enhancement of Local Resources: Circular tourism aims to enhance and preserve local natural and cultural resources. This means promoting the historical heritage, traditions, and environmental peculiarities of the territory, encouraging the sustainable use of these resources. For example, promoting local agricultural products, typical craftsmanship, and activities that respect the ecosystem, thus ensuring that tourism contributes to the conservation and not the deterioration of local beauties. It is essential to involve local guides, artisans, and producers, creating a virtuous cycle that supports the local economy.

Continuous Research and Improvement: Supporting research and innovation to constantly develop new practices and solutions for increasingly effective and sustainable circular tourism. Investing in scientific studies, experiments, and emerging technologies allows new opportunities to be identified to reduce environmental impact and improve resource efficiency. Promoting a culture of continuous improvement within the tourism sector through ongoing training, exchange of experiences, and participation in research networks and consortia contributes to a constant evolution towards more sustainable and responsible practices.

Monitoring and Evaluation: Adopting monitoring and evaluation systems is fundamental to measure the impact of circular tourism initiatives, identify areas for improvement, and make corrections to ensure long-term sustainability. Using clear and measurable indicators allows the effectiveness of implemented policies and practices to be evaluated and adapted based on the results obtained. Continuous monitoring and transparency in communicating results are essential for building trust among stakeholders and ensuring constant improvement in sustainability practices.

Legal compliance and risk management: Stakeholders in the tourism sector must recognize and comply with relevant legal regulations. They should also develop procedures to address potential emergency situations and implement robust risk management strategies within the framework of circular tourism.

Education and Awareness: Circular tourism promotes the education and awareness of tourists and industry operators on sustainability issues, encouraging responsible and conscious behaviors. This can be achieved through information campaigns, educational programs, workshops, and practical activities that teach tourists the importance of respecting the environment and local cultures. Providing clear and accessible information on how to reduce ecological impact while traveling, and promoting sustainable practices such as slow tourism and respecting local rules, is essential to creating a shared environmental consciousness.

Collaboration and Partnerships: Collaboration between public and private stakeholders is essential to successfully implement circular tourism practices, fostering the sharing of knowledge and resources to achieve common sustainability goals. This involves local governments, companies, NGOs, local communities, and tourists working together to develop and implement sustainable strategies. Partnerships can lead to innovative projects, such as co-financing ecological infrastructure, creating sustainable transport networks, and promoting environmental certifications for tourist facilities.

The following Table 1 provides a synoptic overview of the correspondence between the principles of sustainable tourism according to ISO 23405, their relationship with the requirements and best practices of circular economy, social innovation, ecotourism, and community-based tourism, and finally the 11 principles of circular tourism. Each principle of circular tourism is also associated with relevant SDGs.

Table 1. *Proposal of 11 circular tourism principles. Source: authors*

Principles of sustainable tourism (ISO 23405)		Circular economy	Social Innovation	Ecotourism	Community based tourism	Principles of circular tourism (proposal)		SDGs
Manage sustainable tourism effectively	Ethical business processes that align with corporate social, economic, and environmental responsibilities, promoting the circular economy and sustainability goals	Adoption of innovative technologies that enable recycling, reuse, and reduction of waste in tourism operations. This includes water-saving systems, energy-efficient buildings.	Development of community-driven technological solutions that address local sustainability challenges, fostering local innovation.	Utilize sustainable technologies to minimize ecological footprints, such as eco-friendly transportation options, and advanced waste management systems in natural areas.	Implement community-centric technologies that enhance local management.	**i) Innovation and sustainable technology**	By adopting innovative solutions and sustainable technologies, circular tourism seeks to improve resource efficiency and promote environmental sustainability in the tourism sector.	All SDGs
		Implement profit-sharing models and reinvest tourism revenues into local circular economy initiatives.	Develop cooperative business models and social enterprises that distribute profits among community members. Encourage inclusive policies that ensure marginalized groups benefit from tourism revenues.	Ensure that a significant portion of ecotourism revenue is allocated to conservation efforts and local community development. Create transparent mechanisms for profit-sharing with local stakeholders who contribute to and support ecotourism activities.	Promote community-led tourism ventures where profits are equitably distributed among residents. Establish community funds sourced from tourism income to support local projects, healthcare, education, and infrastructure improvements.	**ii) Fair distribution of benefits**	Circular tourism commits to ensuring a fair distribution of the economic benefits generated by tourism activities, contributing to the well-being of local communities and reducing social inequalities	
Guarantee the rights of local communities	Involves advocating for social and environmental responsibility, economic equality, human rights, and the well-being of employees and communities	Engage local communities in the planning and implementation of circular economy initiatives within tourism, such as waste management, resource recovery, and sustainable product design.	Foster participatory governance models that include local communities in decision-making processes related to tourism development. Implement platforms for community feedback and collaboration on	Integrate local knowledge and practices in ecotourism activities, ensuring that community members are involved in guiding, managing, and benefiting from ecotourism. Develop partnerships with local conservation groups and stakeholders.	Ensure that local communities lead the development and management of tourism initiatives. Facilitate community meetings, workshops, and committees to discuss and decide on tourism-related matters, ensuring that community voices are heard and respected.	**iii) Involvement of local communities**	Active and participatory involvement of local communities in decisions and benefits derived from tourism.	5, 10, 11, 12, 15

			tourism projects and innovations.					
Conserve the natural environment and its biodiversity	Adopting practices that minimize impact and protect wildlife	Implement comprehensive waste management systems that prioritize recycling, composting, and the reduction of single-use products within the tourism sector. Encourage the use of circular design principles to minimize waste at the source.	Develop community-driven waste reduction programs and educational campaigns that promote sustainable waste practices. Innovate social enterprises focused on upcycling and repurposing waste materials generated by tourism activities.	Adopt adequate waste policies in ecotourism operations, including sustainable packaging, eco-friendly accommodations, and waste-free dining experiences.	Engage local communities in waste minimization efforts, such as establishing local recycling centers and promoting sustainable waste practices among residents and tourists.	**iv) Minimization of waste**	Optimizing processes and promoting recycling are at the heart of circular tourism.	6, 7, 11, 12, 13, 14, 15
		Implement environmentally friendly practices that align with circular economy principles, such as sustainable sourcing of materials, energy-efficient technologies, and practices that minimize environmental footprints in tourism operations. Promote circular supply chains that support conservation efforts.	Foster community-led conservation initiatives and eco-friendly practices through innovative projects and educational programs. Support social enterprises that prioritize environmental sustainability and conservation as core values.	Design and manage ecotourism activities that prioritize conservation and biodiversity. Collaborate with local conservation organizations to protect natural habitats and wildlife, ensuring minimal disturbance and promoting sustainable tourism practices.	Engage local communities in conservation efforts, such as reforestation projects, wildlife protection programs, and sustainable land use practices. Empower community members to act as stewards of their natural environment, integrating conservation into tourism planning and activities.	**v) Promotion of environmental conservation**	Circular tourism commits to supporting the conservation of the natural environment, promoting biodiversity, and adopting practices that reduce negative impacts on the territory.	11,12
Consider cultural heritage and local values	Tourism activities are harmonious with cultural traditions	Encourage the sustainable use of local materials and resources in tourism activities, promoting	Develop initiatives that integrate local culture and traditions into tourism	Highlight and protect the unique environmental features of the area by incorporating them into	Engage local communities in showcasing their heritage and traditions through community-led	**vi) Enhancement of local resources**	Promoting the historical heritage, traditions, and environmental peculiarities of the	8, 9, 11, 12

		products that are locally sourced and environmentally friendly. Support circular practices that enhance and preserve local resources, such as sustainable agriculture and artisanal production.	experiences, fostering a sense of pride and ownership among community members. Innovate ways to share and preserve local heritage through digital platforms, community workshops, and cultural festivals.	ecotourism activities. Provide educational programs and tours that focus on the natural and cultural heritage, encouraging sustainable interaction with the environment.	tourism initiatives. Promote local storytelling, traditional crafts, and cultural performances, ensuring that tourism development aligns with the preservation of local identity and resources.		territory, encouraging the sustainable use of these resources.	
Stimulate the social and economic development of tourism destinations	Strengthening the local economy, enhancing skills, generating jobs, and fostering responsible local supply chains	Invest in research to develop innovative circular economy practices within the tourism sector.	Foster collaborations between academia, local communities, and tourism businesses to research and develop socially innovative solutions. Encourage pilot projects and case studies that explore new ways to integrate social innovation into tourism.	Conduct research on the impacts of ecotourism on natural environments and biodiversity.	Promote the sharing of best practices and lessons learned through workshops, conferences, and collaborative platforms.	**vii) Continuous research and improvement**	Supporting research and innovation to constantly develop new practices and solutions for increasingly effective and sustainable circular tourism.	8, 9, 11, 12
Guarantee the quality of products, processes and attitudes	Providing reliable information, evaluating tourist satisfaction, and adhering to recognized standards	Implement robust tracking systems to monitor resource use, waste generation, and recycling rates within tourism operations.	Regularly collect feedback and use it to refine and improve socially innovative practices and policies.	Establish environmental monitoring programs to track biodiversity, ecosystem health, and the ecological footprint of ecotourism activities.	Create community-based monitoring and evaluation systems that measure the economic, social, and environmental impacts of tourism. Engage local stakeholders in the evaluation process to ensure transparency	**viii) Monitoring and evaluation**	Adopting monitoring and evaluation systems is fundamental to measure the impact of circular tourism initiatives, identify areas for improvement, and make corrections to	3, 9, 12

					and accountability, and to inform decision-making.		ensure long-term sustainability	
Provide for the health, safety and security of destinations	Enhance destination conditions and protect against health risks	Ensure compliance with environmental regulations and standards related to waste management, resource use, and sustainability. Develop risk management strategies to address potential disruptions in the supply chain and mitigate environmental risks.	Promote awareness and adherence to social and labor laws, including fair wages and working conditions. Implement risk management procedures to protect vulnerable groups and ensure social equity in tourism activities.	Comply with environmental protection laws and regulations, especially those pertaining to wildlife conservation and protected areas. Develop contingency plans for natural disasters, climate change impacts, and other environmental emergencies.	Ensure that tourism activities adhere to local, national, and international legal frameworks. Establish community-driven emergency response plans and risk management strategies to safeguard both tourists and residents during unforeseen events.	**ix) Legal compliance and risk management**	Interested parties in the tourism sector shall identify and be aware of applicable legal requirements. Interested parties should establish procedures to respond to potential emergency situations and have in place an effective risk management	3, 11, 12, 16
Take legal compliance into consideration	Interested parties in the tourism sector shall identify and be aware of applicable legal requirements							
Prepare for emergencies and establish response procedures	Interested parties in the tourism sector should establish procedures to respond to potential emergency situations							
//	//	Provide training on best practices for reducing waste and supporting circular initiatives. Implement campaigns to inform tourists and industry operators about circular economy principles, such as resource efficiency, recycling, and sustainable consumption.	Develop awareness campaigns that highlight the social impacts of tourism and promote inclusive, equitable practices.	Train ecotourism operators on sustainable practices and the ecological impacts of their activities. Educate tourists on the importance of environmental conservation and biodiversity protection through guided tours, informational materials, and interactive experiences.	Promote the cultural and environmental values of the local community through educational initiatives aimed at both tourists and residents. Provide resources and training to community members to enhance their understanding of sustainable tourism and its benefits.	**x) Education and awareness**	Circular tourism promotes the education and awareness of tourists and industry operators on sustainability issues, encouraging responsible and conscious behaviors.	4

//	//	Encourage partnerships between institutions, citizens, universities, organizations to promote circular economy practices in tourism.	Facilitate collaboration between local stakeholders to foster social challenges. Promote joint initiatives that enhance social equity and inclusion within the tourism sector.	Partner with environmental organizations, local governments, and ecotourism operators to protect natural habitats and biodiversity.	Establish cooperative efforts and foster partnerships that provide technical assistance, funding, and capacity-building to enhance local tourism development.	**xi) Collaboration and partnerships**	Collaboration between public and private stakeholders is essential to successfully implement circular tourism practices, fostering the sharing of knowledge and resources to achieve common sustainability goals	17

Based on the proposed 11 principles of circular tourism, the suggested definition of circular tourism is the following: ”Circular tourism integrates sustainability, circular economy, social innovation, ecotourism, and community-based tourism principles. It enhances resource efficiency, minimizes waste, and promotes environmental conservation while ensuring fair economic benefits and community involvement. Emphasizing innovative technologies, continuous improvement, and robust monitoring, it fosters stakeholder collaboration, prioritizes sustainability education, and implements effective risk management. This holistic model supports environmental stewardship, social equity, and economic resilience for the long-term well-being of destinations and their communities”.

Conclusions

This paper underscores the critical importance of adopting circular tourism as a holistic and sustainable model for the future of the tourism industry. The proposed definition fo circular tourism integrates principles from the circular economy, eco-tourism, community-based tourism, and social innovation to address the multifaceted challenges posed by contemporary tourism practices. Indeed, the implementation of circular economy principles within the tourism sector offers a robust framework for reducing waste, maximizing resource efficiency, and promoting the regeneration of materials. Moreover, social innovation is highlighted as a key driver in developing creative solutions to social and environmental challenges. It should be noted that, circular tourism must be seen as a comprehensive strategy that integrates environmental sustainability, active community involvement, and the stimulation of sustainable economic growth. The evolution of tourism towards a circular model could represent a transformative opportunity to address the multifaceted challenges faced by the industry today. Circular tourism can guide the development and implementation of tourism policies and practices. Active participation and collaboration among stakeholders, continuous research and improvement, and robust monitoring and evaluation systems are crucial for the success of this model. Moreover, the commitment to education and awareness, legal compliance, and effective risk management ensures that circular tourism is not only sustainable but also adaptable to changing circumstances and future challenges. It offers a pathway to a more sustainable, inclusive, and prosperous future for the global tourism industry.

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Track 4: Sustainability in Agrifood

Perceived vs Actual Water Footprint: analysis of the consumers' awareness related to agrifood products

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Abstract

Starting from the water footprint (WF) concept, this study investigates the consumers' awareness towards more water sustainable consumption choices in the Italian context. The analysis of consumers' awareness about the indirect water consumption related to the agrifood products represents an essential tool for supporting decision-making towards marketing strategies in line with the challenges that emerge from water scarcity. For data collection, a questionnaire was developed to assess the perceived water footprint (PWF) of 21 different agrifood products, recording a total of 841 responses. The perceived water footprint (PWF) related to different agrifood products is evaluated, testing the Root Mean Square Error (RMSE) of this perception on the actual water footprint (AWF) related to the same products, obtained from WaterPub, the world's largest repository of publications on water footprint. The results of RMSE indicate that the products for which consumers have a lower PWF compared to the AWF are crops and their derivates (RMSE equals to 0.316) rather than animal products and derivates (RMSE equals to 0.312). Going more into detail, olive oil (0.386) and sheep meat (0.364) represent the products with highest RMSE for each of two category, both characterized by a consumers' inclination to underestimated the related WF. By providing helpful information about direct and indirect water consumption, the WF approach can be useful in the context of green marketing. Public awareness in water issues can affect consumers who are willing to contribute to water sustainability, by changing their consumption behavior.

Keywords: perception, virtual water, consumer behavior, life-cycle approaches, sustainability.

Relevant Topic: Sustainable Supply Chain Management, green supply chain and quality

Introduction

With the world population projected to reach 9.8 billion by 2050, the rise in consumption of primary natural resources (such as water, energy and raw materials) to meet the growing demands will inevitably result in an unsustainable ecosystem (Agnusdei et al., 2023). Achieving sustainable development goals represents a fundamental issue in modern economies, which face extensive processes of globalization of production flows and an intensification of sustainability challenges, including the intensive use of water resources and persistent droughts (Andrei et al., 2020). Water plays a key role in human life and activities, but also for the socio-economic progress. Over the last decade, there has been a growing global focus on sustainable water management, as highlighted by the establishment of the Sustainable Development Goals (SDGs) by the United Nations, among which SDG 6 aims to enhance water quality and reduce water withdrawals (Jarzebski et al., 2024). In this context, agrifood systems are the leading consumers of the world's freshwater resources, with over than 70% of global water withdrawals. One of the most spread indicators to assess the water resources utilization is the Water Footprint (WF), a volumetric measure of water consumption and pollution, which allows to assess the impact of human activities on water resources (Miglietta et al., 2018). It accounts for not only the water used directly in production but also the water consumed and polluted during the process. In particular, WF consists of three components: *green water footprint* that measures the amount of rainwater used in the production of a product; *blue water footprint* concerning the amount of surface or groundwater used in the production of a product; *grey water footprint* that measures the amount of water needed to dilute the pollutants present in the water used in the production of a product (Serio et al., 2018). Water footprint assessment is very important in evaluating the environmental impacts of crops, animals and their derivate products. For these reasons, several studies have delved into estimating and analyzing the water footprint associated with several agrifood products. In particular, Tozzini et al. (2021) conducted a study aimed to understand the amount of water (in litres) needed to produce a ton of soybeans, wheat and maize in the Pergamino district. Luan et al. (2018) developed a method to calculate the regional- scale water footprint of crop production, quantifying blue and green water use through an analysis of hydrological processes during crop growth. Another important study proposed a method for reviewing the actual agricultural water usage in arid regions in order to avoid underestimating it (Ma et al., 2024). Li et al. (2018) found that in Jinlin province, the water footprint of rice relies heavily on blue water, especially in drier years when the green water footprint is lower. Similarly, Rodriguez et al. (2015) reported that in the Pampean region of Argentina, potatoes primarily depend on blue water. Also animal products and their derivates can be considered significantly water-intensive, requiring an in-depth scientific analysis. In particular, livestock production requires a substantial amount of water, including what is consumed directly by animals, but also the significant quantities needed for growing their feed and processing their products (Hoekstra, 2012). In their study, Xing et al. (2023) aimed to evaluate the green, blue, and gray water footprints of three animal products and two derivates across 31 Chinese provinces from 2000 to 2017, conducting also a driving force analysis using the Kaya equation and LMDI method. Toro-Mujica et al. (2016) used simulations to evaluate the water footprint of sheep meat in central Chile, taking into account the type of farm, how it is managed, and rainfall in a dry environment. Similarly, Ibidhi et al. (2017) calculated the water footprint of sheep meat in Tunisia using different farming systems with the Water Footprint Network method.

The water needs can vary greatly depending on several factors such as the climatic conditions, soil type, production practices, type of feed provided to the animals and the agricultural practices employed. Moreover, the total water footprint of agricultural products is highly dependent on the country-specific context, emphasizing the need for region-specific assessments. Therefore, consumers' awareness on agrifood water footprints became of fundamental importance to foster a more water-sustainable food consumption and to address the challenges of water scarcity.

Methods

Data Collection

In this study, it has been performed a comparison between the Actual Water Footprint (AWF) and the Perceived Water Footprint (PWF) of 21 agri-food products referred to Italian context. These products can be classified in two categories: "crops and derivates" (12) including potatoes, apples, lettuce, wine, tomato sauce, pasta, flour, olive oil, hazelnuts, coffee, lentils and sugar and "animals and derivates" (9) including chicken meat, sheep meat, bovine meat, pork meat, dairy products, eggs, butter, seasoned cheeses and milk. For data collection regarding the PWF, a questionnaire was developed in which respondents were asked about their perception on water consumption impact of each agri-food product along their production lifecycles, by indicating a value on a scale ranging from 1 to 7. The questionnaire yielded 841 responses, ensuring the heterogeneity of participants sample, including farmers, stakeholders, agricultural entrepreneurs, students and researchers. Data on the AWF referred to Italy, instead, were obtained from WaterPub, the largest world repository of publications on water footprint. In particular, the AWF values of crops and derivates (Table 1) were extracted from the research report of Mekonnen and Hoekstra (2011), while the AWF values of animal products and derivates (Table 2) were obtained from the research report of Mekonnen and Hoekstra (2010). Each product was uniquely identified through its Harmonized system (HS) code. Since AWF values are expressed in m^3/ton, these values were normalized in a scale ranging from 1 to 7, in order to make them comparable with PWF values of the same product.

Table 1. AWF for crops and derivates.

Product	HS code	AWF [m^3/ton]	Normalized AWF
Sugar	170199	1782	4
Salad	070511	216	3
Potato	070190	217	3
Apples	080810	230	3
Flour	110100	1407	4
Olive Oil	150990	9289	5
Lentils	071340	4677	4
Hazelnut	080221	4610	4
Coffee	090121	18925	5
Pasta (dry)	110100b	1407	4
Tomato Sauce	070200c	271	3
Wine	220421	568	3

Table 2. AWF for animal products and derivates.

Product	HS code	AWF [m^3/ton]	Normalized AWF
Milk	040120	805	3
Egg	040700	1341	4
Chicken Meat	020711	4325	4
Butter	040510	4240	4
Pork Meat	020311	6092	4
Sheep Meat	020423	9364	5
Bovine Meat	020130	11500	5
Dairy product	040610	2426	4
Seasoned Cheese	040690	3867	4

Statistical Analysis

The Root Mean Square Error (RMSE) allows to measure error in statistical models by using the average squared difference between predicted and actual values. In this study, it is adopted to quantify the percentage error between the consumers' perceptions and the actual value of water footprint for the selected agrifood products. Since the RMSE is calculated for each of the 21 agricultural products, its value relative to each product was considered, as shown in Equation 1:

$$RMSE_i = \sqrt{\sum_{j=1}^{n} \frac{\left(\frac{PWF_{ij} - AWF_i}{PWF_{max} - PWF_{min}}\right)^2}{n}} \qquad (1)$$

Where:

- *i* represents the agrifood product;
- *j* indicates each consumers included in the sample;

- n represents the total number of consumers included in the sample;
- PWF_{max} and PWF_{min} represent respectively the maximum and minimum value that consumers could indicate in the questionnaire.

Results and Discussion

Consumers must have a clear understanding of the water footprint associated with agrifood products. This knowledge allows them to make informed choices about the environmental impact of their food consumption. With increased awareness, demand for more sustainable products can rise, prompting Producers to adopt water-efficient practices. The results of this study, through the analysis of RMSE, allow to reveal the overall consumers' perception of agrifood WF but also their perception for each singular product. In particular, $RMSE_{overall}$ assumes a value equals to 0.314, highlighting that for the selected agrifood products, consumers' perceptions and the actual values of the WF are not significantly different. This suggests that consumers are generally well-informed about the water usage involved in the production of these products, which is essential for promoting more sustainable consumption choices. Despite this widespread awareness, consumers' tends to underestimate the agrifoods WF. This is particularly evident in Figure 1, where the x-axis represents the difference values between the perceived water footprint (PWF) and the actual water footprint (AWF) for each respondent, while the y-axis represents the frequency with which each difference value occurs. Notably, the frequency distribution is skewed to the left of the y-axis (PWF - AWF = 0), indicating an underestimation of the water footprint.

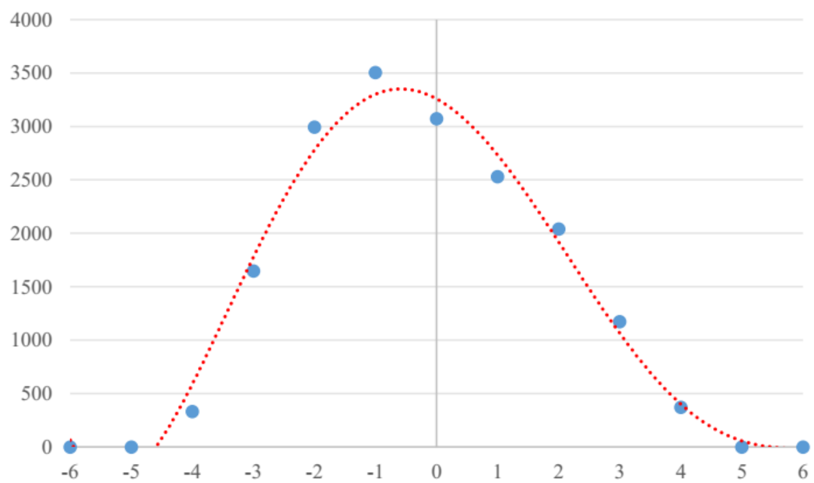

Figure 1. *Frequency distribution of (PWF- AWF) values for all products.*

Considering the two product categories, it can be noted that the RMSE value is slightly higher for crops and derivatives (0.316) compared to animal products and derivatives (0.312), as shown in Figure 2. Nevertheless, animal products are characterized by a greater underestimation compared to plant-based products, as illustrated in Figures 3(a) and 3(b).

This may be due to the fact that consumers do not take into account the water required by animal products and derivates for drinking, cleaning, and processing them, as well as the great amount of water need to irrigate feed crops. In addition, consumers do not consider that a large portion of the diet of livestock comes from rain-fed pastures, significantly contributing to the green WF for animal products (Legesse et al., 2017).

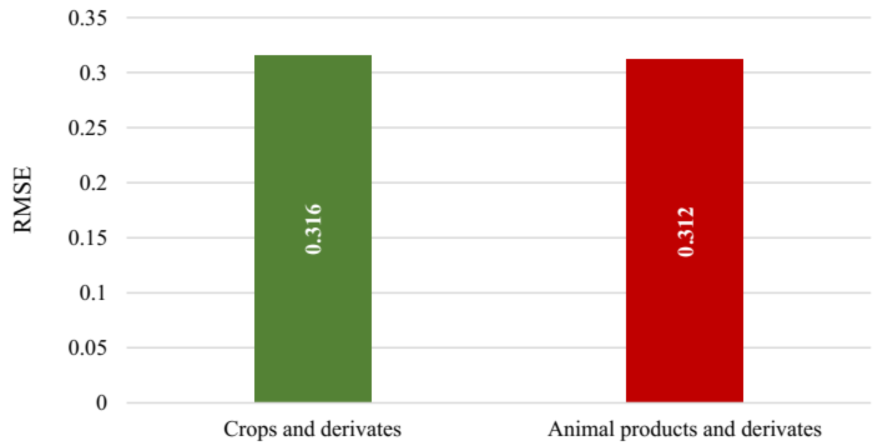

Figure 2. *RMSE for Crops and derivates and Animal products and derivates*

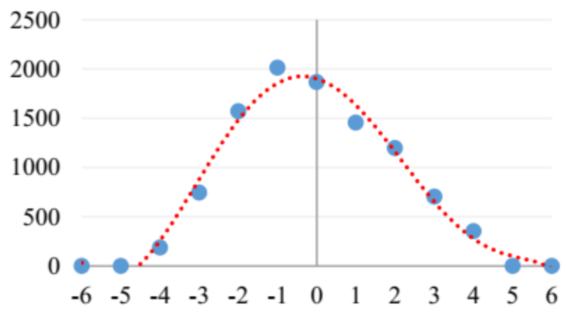

Figure 3(a). *Frequency distribution of (PWF- AWF) values for Crops and derivates.*

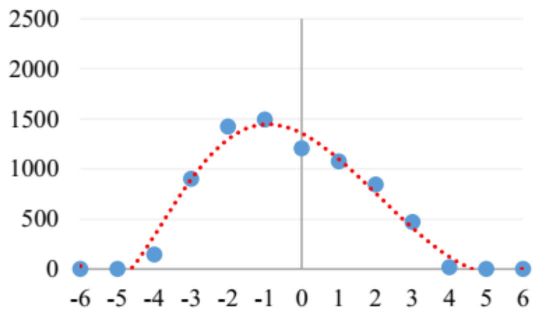

Figure 3(b). *Frequency distribution of (PWF- AWF) values for Crops and derivates*

Analyzing individual products for crops and their derivates reveals that olive oil has the highest RMSE (0.386), followed by coffee (0.362) and potato (0.355), as highlighted in Figure 4. Moreover, in Figure 5, it can be noted that the consumers' PWF of olive oil in Italy is strongly underestimated. This can be due to the consumers' assumption that olive trees do not require irrigation. However, in Italy many olive groves are irrigated to enhance yields, particularly in regions with arid conditions, contributing to the blue water footprint. Moreover, the water footprint of Italian olive oil also encompasses the green water footprint—rainwater utilized by the olive trees—and the grey water footprint, which accounts for the water needed to dilute pollutants from fertilizers and pesticides. This comprehensive perspective highlights that the actual water footprint of olive oil in Italy is likely much higher than consumers perception.

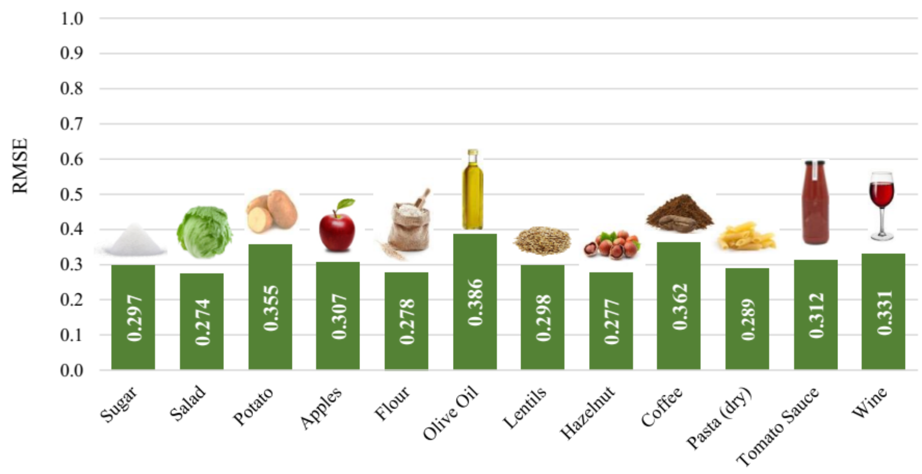

Figure 4. *RMSE for animal products and derivates.*

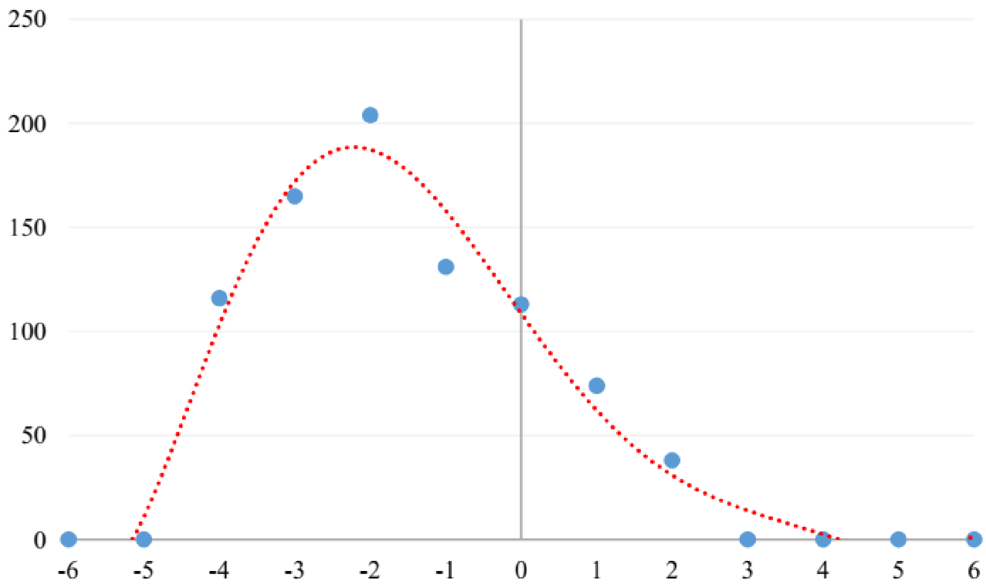

Figure 5. *Frequency distribution of (PWF- AWF) values for olive oil.*

For animal products and their derivates, instead, the item with the highest RMSE is sheep meat (0.364). However, also bovine meat assumes a similar value (0.363) while the third position in term of RMSE is occupied by chicken meat (0.314), as highlighted in Figure 6. Regarding sheep meat, Figure 7 highlights the strong underestimation of WF in Italy is strongly underestimated, according to the previous results related to animal products and derivates.

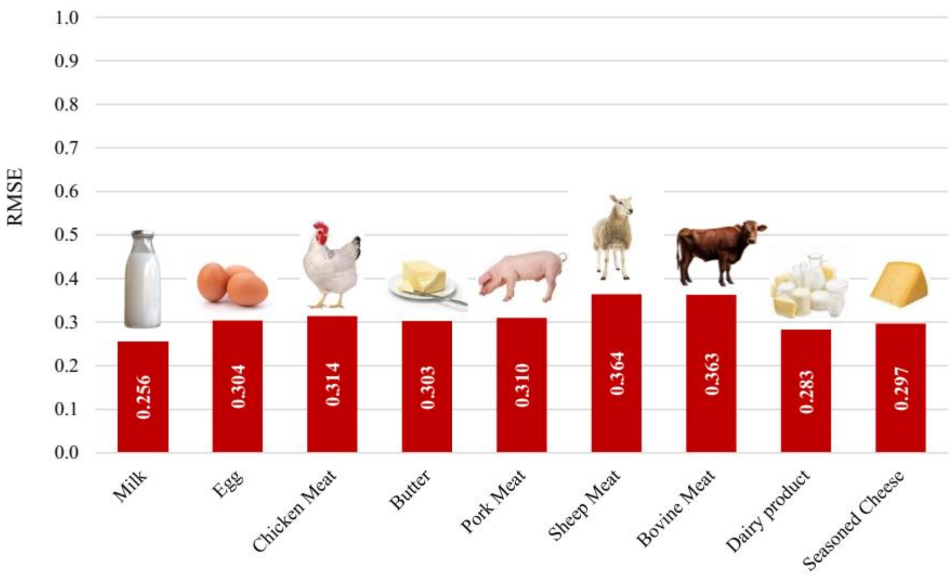

Figure 6. *RMSE for animal products and derivates.*

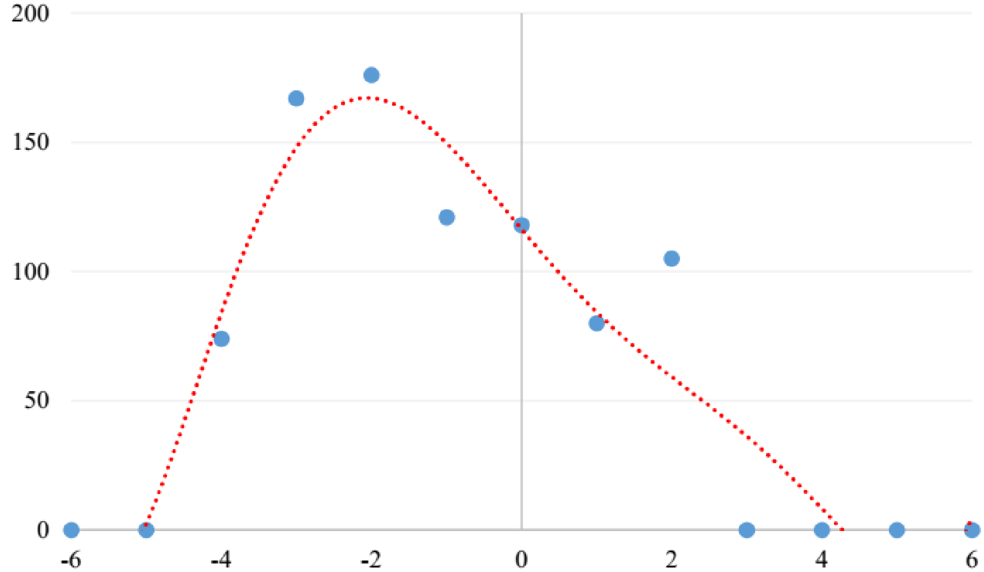

Figure 7. *Frequency distribution of (PWF- AWF) values for sheep meat.*

Conclusions

This study examined the comparison between consumers' perceived water footprint (PWF) and the actual water footprint (AWF) for 21 agrifood products in Italy. The analysis revealed several key findings. Firstly, the overall RMSE was 0.314, indicating that consumers have a reasonably accurate perception of the WF of these products. However, a deeper look into specific product categories showed a slight difference: the RMSE for crops and derivatives was marginally higher at 0.316, compared to 0.312 for animal products and derivatives. Despite this small difference, a significant underestimation of the water footprint was noted for animal products. This discrepancy suggests that consumers are not fully aware of the substantial blue, green, and grey WF associated with animal product production. Animal products require significant water for irrigation of feed crops (blue water), rain-fed pastures (green water), and to dilute pollutants from fertilizers, pesticides, and livestock waste (grey water). Going more into detail, this study also provide the two products belonging to the respectively category with the highest RMSE, that are olive oil for crops and derivates (0.386) and sheep meat for animal products and derivates (0.364).

These findings highlight a critical need to enhance consumer perception about the AWF of both crops and animal products. Effective awareness campaigns are essential to improve consumer knowledge, promoting more informed and sustainable consumption choices, ultimately leading to better water resource management in Italy. These campaigns should focus on providing clear and accurate information about the water requirements of different agrifood products, emphasizing the hidden water costs in the production processes, especially for animal-derived products. Such initiatives will not help consumers make more sustainable choices but also encourage producers to adopt more water-efficient practices.

The main limitation of this study is that the results derive from a non-targeted consumer sample. This approach may not accurately evaluate the specific perceptions and behaviour of different consumer segments in Italy. Future research efforts should aim to target sample by demographical, regional, and socioeconomical segments, leading to more precise and actionable insights into consumer awareness and attitudes towards the water footprint of agrifood products.

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Evaluating Circular Economy Good Practices in Agri-Food Sector using Multi Criteria Decision Analysis Approach

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Abstract

This study explores the transition from a linear to a circular economy, emphasizing the potential benefits and challenges associated with implementing Circular Economy Good Practices (CEGPs). The linear economy's "take, make, and dispose" model is unsustainable, relying on finite resources and generating significant waste. In contrast, the circular economy promotes resource efficiency, waste reduction, and sustainable development by viewing waste as a resource. This model not only reduces environmental strain but also offers substantial economic benefits, such as cost savings, job creation, and enhanced competitiveness. The evaluation of CEGPs poses a complex Multiple Criteria Decision Analysis (MCDA) problem due to the numerous indicators different in nature contributing to assess CEGPs. Traditional methods like the weighted sum approach are limited by their compensatory nature and subjective weight assignment. The study integrates two advanced MCDA methods, PROMETHEE and Stochastic Multicriteria Acceptability Analysis (SMAA), to overcome these limitations. The combined SMAA-PROMETHEE approach provides a robust framework for assessing and ranking CEGPs, considering environmental, social, and economic performance. Applied to fifty CEGPs, this method highlights the importance of a balanced approach to sustainability. The findings demonstrate the feasibility and benefits of transitioning to a circular economy, guiding organizations in adopting sustainable practices that contribute to long-term environmental, social, and economic goals.

Keywords: MCDA – Good Practices – Circular Economy – Indicators – Agri-food sector

Introduction

From linear to Circular Economy Good Practices (CEGPs)

Circular Economy (CE) strategies have the potential to reduce organizational risk exposure, manage costs and resources more effectively, and prevent supply chain disruptions by minimizing physical exchanges between economic systems and the environment (Van Opstal W. and Borms L., 2023).

Although the Linear Economy (LE), characterized by the "take, make, and dispose" paradigm and driven by a "bigger-better-faster-safer" mentality, has brought significant prosperity to many nations since the Industrial Revolution, its long-term sustainability is questionable (Stahel W. R, 2016). The linear production model neglects the natural limits on energy and raw material availability and erroneously assumes the environment's infinite capacity to absorb pollution and waste. Economists Kenneth E. Boulding and Barry Commoner challenged this linear model in their seminal works of 1966 and 1971, respectively, proposing a perspective that views Earth as a closed system where one industry's byproducts become another's raw materials, i.e., circular thinking. Despite the existence of 114 definitions for the CE (Kirchherr et al., 2017), they universally aim to reduce the strain on natural resources and advocate for the efficient use of minerals, fossil fuels, and forests to achieve sustainable development, offering a cyclical flow model for economic systems (Ellen MacArthur Foundation, 2015). Hence, in LE, resources are used once and then discarded, while in CE, resources are kept in use for as long as possible, extracting maximum value from them while in use, then recovering and regenerating products and materials at the end of each service life, extracting maximum value from them while in use, then recovering and regenerating products and materials at the end of each service life. From this logic, companies may exploit long term financial value creation and, at the same time, improving current environmental and social conditions.

As highlighted in the report "Growth Within: A Circular Economy Vision for a Competitive Europe", this model, which emphasizes continuous resource reuse and minimal waste, could result in substantial cost and resource savings amounting to €1.8 billion annually by 2030. This transition would also contribute to GDP growth and higher employment levels (Ellen MacArthur Foundation, 2015).

Several economic organizations have realized the potential of encompassing CE approaches within their business model and are experimenting with more or less innovative Circular Economy Good Practices (CEGPs) to implement across various business areas. CEGPs refer to strategies, actions, or initiatives that effectively contribute to the transition from linear economy to circular economy. For instance, eco-design (e.g., designing products that can be easily disassembled and refurbished), industrial symbiosis (where waste from one industry becomes a resource for another), material recovery (collecting old garments for recycling into new fabric) or circular supply chains (implementing closed-loop recycling processes for its products).

The National Agency for New Technologies, Energy, and Sustainable Economic Development (ENEA) has established the Italian Circular Economy Stakeholder Platform (ICESP) to collect and promote these innovative practices. To date, ICESP has gathered about 240 CEGPs from various sectors and business areas, aiming to quantify their environmental, social, and economic impacts and evaluate their replicability to encourage adoption by other companies. Organizations in the agri-food industries have generated 44 CEGPs with respect to five areas of application: production, consumption, waste management, row material procurement, and innovation and investment.

CEGP performance's evaluation: a multi criterion problem

Working Group 6 (WG6) from ICESP has elaborated a model to analyze the replicability of CEGPs and quantify the environmental, economic, and social impact on a national scale. The objective of the model is therefore to evaluate each CEGP by a single score to support the decision-making process of organizations intending to adopt those practices. To this end, WG6 developed an indicator-based model to capture the impacts on environmental, economic and social dimensions led by the CEGP implementation. Taken into consideration the whole set of indicators, is switching from linear to circular models convenient?

To answer, it is needed a single score that embraces all aspects (i.e., environmental, economic and social) summarizing the practice's performance. A common method used to aggregate parameters is the weighted sum, i.e., the sum of the products of each indicator's performance for its weight attached by the Decision Maker (DM) in accordance with its degree of importance.

Unfortunately, this method faces two crucial limitations when dealing with metrics that are different in nature and with trade-off problems caused by conflicting/interacting objectives connected to the three dimensions (e.g., improving environmental and social aspects may entail a worsening of economic performances).

The first limitation is compensation that allows to a negatively impacting variation to be offset by another positive variations (e.g., in the final score, an increase in pollution would be compensated by an increase in revenue).

The second limitation is represented by the meaning attached to the weights of criteria which have to be interpreted as tradeoffs (how much one has to improve the performance on a criterion to compensate the loss of one unit in another one) and not as importance coefficients of the considered criteria.

For all these reasons, some more suitable Multiple Criteria Decision Analysis (MCDA; Greco, Ehrgott, Figueira, 2016) approaches should be used. The most adopted MCDA methods in this sector include:

- Analytic Hierarchy Process (AHP) (Saaty, 1977);
- VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) (Yu, 1973);
- Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Hwang and Yoon, 1981);
- Grey Relational Analysis (GRA) (JuLong, 1982);
- ELimination Et Choix Traduisant la REalité (ELECTRE) (Roy, 1991);
- Stochastic Multicriteria Acceptability Analysis (SMAA) (Lahdelma, Hokkanen, & Salminen, 1998)
- Preference Ranking Organization METHod for Enrichment of Evaluations (PROMETHEE) (Brans & Vincke, 1986)
- Data Envelopment Analysis (DEA) (Charnes et al., 1978);
- Dominance-based Rough Set Approach (DRSA) (Greco et al., 2002; and others.

Among these methods, PROMETHEE is a non-compensatory aggregating method which, therefore, overcomes the problem of compensation between indicators. Indeed, it aggregates preference information of a DM through by defining a global preference function for each ordered pair of alternatives. In particular, for each criterion g_j, PROMETHEE defines a partial preference function $P_j(x, y)$ representing the degree of preference of x over y on g_j,.

The SMAA methodology, instead, avoids the arbitrary choice of the weights attached to the criteria by exploring the whole set of parameters compatible with some preference information provided by the DM. It is an MCDA method that takes into account imprecision or lack of data considering probability distributions on the space of criteria weights. SMAA has also been applied to dependent uncertainties (Lahdelma & Salminen, 2002; Lahdelma, Makkonen, & Salminen, 2006) and to preference with interacting criteria (Angilella et al., 2015).

Data and Methods

Indicators from ICESP (criteria)

Circular economy indicators typically measure input/output (e.g., energy, water, material, components, emission, waste, product, service) deriving from circularity approaches as percentage of total input/output. For instance, the voluntary regulation UNI/TS 11820:2022, issued by the Italian Technical Commission, introduced 71 key indicators for evaluating the degree of circularity of an individual business or clusters of organizations. However, in this case the objective is to evaluate the environmental, economic and social performance of a newly adoptable CEGP to support the decision on whether or not to implement it. It is therefore necessary to calculate indicators that capture the variations between pre and post CEGP implementation to assess its convenience with respect the three different dimensions.

To this end, the Working Group 6 (WG6) from ICESP has elaborated 19 metrics (see Table 1) based on the following characteristics:

- standardizing information;
- allowing comparison between different territories or sectors;
- enabling the analysis of trends and developments over time;
- simplifying the communication process through which information is provided to the user.

Table 1. *ICESP indicators for performance measurement.*

Macro-criteria	Critera		Measurement	Preference direction
Economics	Cost reduction	Design costs	quantitative	↓
		Procurement costs	quantitative	↓
		Production costs	quantitative	↓
		Distribution costs	quantitative	↓

		End-of-life costs	quantitative	↓
	Revenue increase	New products	quantitative	↑
		Expansion of existing product markets	quantitative	↑
		Premium price of the product	quantitative	↑
Environmental	Reduction in the consumption of virgin raw materials		quantitative	↓
	Reduction in energy consumption		quantitative	↓
	Reduction in water withdrawal		quantitative	↓
	Reduction in CO2 and greenhouse gas emissions		quantitative	↓
	Reduction in plastic consumption		quantitative	↓
	Reduction in waste production		quantitative	↓
	Reduction in water footprint		quantitative	↓
Social	Increase in eco-friendly consumers		quantitative	↑
	Creation of new jobs		quantitative	↑
	Reduction in accidents at work		quantitative	↓
	Increase in hours of education and communication on sustainability		quantitative	↑

Since this study aims at proposing a method to correctly and efficiently aggregate different indicators and evaluate alternative sustainability practices, the value of the indicators is randomly generated. To do that, it is used the rand() function on Excel for each metric by imposing the constraint of upper and lower bound, respectively 100% and -100%.

In MCDA terms, the whole set of indicators becomes criteria useful to evaluate each single alternative, represented by CEGPs, in accordance with preference function shape, weights of criteria, indifference and preference thresholds required by the implemented approach.

PROMETHEE

In this MCDA problem it is consider a set of alternatives A assessed with respect to a set of criteria $G = \{g_1, \ldots, g_n\}$, where $g_i\colon A \longrightarrow \mathbb{R}, j \in \mathcal{J} = \{1, \ldots, n\}$ and $|A| = m$. In the following, for the sake of simplicity and without loss of generality we assume that all criteria have an increasing direction of preference, that is, the greater $g_j(x)$, the better is x on g_j. For each criterion g_j, this method constructs a function $P_j(x, y)$ depicting the degree of preference of x over y on g_j. Six different types of preference functions can be used in practice (Brans and Vincke, 1986) each asking the definition of at least one threshold. In this case, since the data have been built in a random way and, therefore, it is not meaningful defining any threshold, we use the following partial preference function for each criterion g_j

$$P_j(x, y) = \begin{cases} 0 \; se \; d_j(x, y) \leq 0, \\ 1 \; se \; d_j(x, y) > 0, \end{cases}$$

where $d_j(x,y) = g_j(x) - g_j(y)$ is the difference of performances of x and y on g_j.

As previously stated, the PROMETHEE application involves the definition of a weight w_j for each criterion g_j such that $w_j \geq 0$ for all $g_j \in G$ and $\sum_{j=1}^{n} w_j = 1$. Then, for each ordered pair of alternatives $(x,y) \in A \times A$, PROMETHEE methods compute the global preference function

$$\pi(x,y) = \sum_{j=1}^{n} w_j p_j(x,y)$$

measuring how much alternative x is preferred to alternative y based on the whole set of criteria. $\pi(x,y)$ ranges between 0 and 1, the greater its value, the greater the preference of x over y. While $\pi(x,y)$ permits to compare pairs of alternatives each time, the positive $\phi^+(x)$ and the negative $\phi^-(x)$ flows are defined by PROMETHEE methods for each alternative x to compare it with all the other alternatives in A. Formally,

$$\phi^-(x) = \frac{1}{m-1} \sum_{z \in \mathrm{A} \setminus \{x\}} \pi(z,y) \quad \text{and} \quad \phi^+(x) = \frac{1}{m-1} \sum_{z \in \mathrm{A} \setminus \{x\}} \pi(x,y).$$

On the one hand, $\phi^-(x)$ measures how much the alternatives from $\mathrm{A} \setminus \{x\}$ are, in average, preferred to x while, on the other hand, $\phi^+(x)$ measures how much, on average, x is preferred to the alternatives from $\mathrm{A} \setminus \{x\}$. Of course, the greater $\phi^+(x)$ and the lower $\phi^-(x)$, the better is x. Finally, to have a unique measure of the goodness of x taking into account both the positive and the negative flows, PROMETHEE II builds the net flow $\phi(x) = \phi^+(x) - \phi^-(x)$. The greater $\phi(x)$, the better is x. On the basis of the net flow, the PROMETHEE II methods defines a preference (P^{II}), and an indifference (I^{II}) relation on the set of alternatives A such that $xP^{II}y$ iff $\phi(x) > \phi(y)$, while $xI^{II}y$ iff $\phi(x) = \phi(y)$.

SMAA-PROMETHEE (Corrente et al., 2014)

As already explained in the previous section, without any preference given by the DM, the weight vectors belong to the space $W = \{\boldsymbol{w} = (w_1, \ldots, w_n) \in \mathbb{R}^n : w_j \geq 0, \forall j = 1, \ldots, n, and \sum_{j=1}^{n} w_j = 1\}$. However, the DM could provide some preference on the considered criteria such as criterion g_j is more important than criterion g_k or criteria g_j and g_k are equally important, constraints that once translated into inequalities ($w_j > w_k$ in the first case and $w_j = w_k$) reduce the space of weight vectors compatible with the DM's preferences defining a new space $W^{DM} \subseteq W$. For each $\boldsymbol{w} \in W^{DM}$ and for each $x \in A$ one can compute $\phi(x)$ and, therefore, rank order all alternatives in A from the best to the worst. SMAA therefore explores the variety of rankings obtained varying the weight vectors $\boldsymbol{w} \in W^{DM}$. Because W^{DM} is formally defined by an infinity of weight vectors, SMAA results are computed on a well-distributed sampling of weight vectors in W^{DM} that we shall denote by S^{DM}.

For descriptive reasons, in the following, we shall use $\phi(x, \boldsymbol{w})$ in place of $\phi(x)$ just to underline the dependence of the net flow on the vector $\boldsymbol{w} \in S^{DM}$.

At first, SMAA defines a rank function $rank(x, \boldsymbol{w})$ giving the position of x in the ranking obtained considering the weights vector $\boldsymbol{w} \in S^{DM}$. Formally, it is equal to

$$rank(x, \boldsymbol{w}) = 1 + \sum_{z \in A \setminus \{x\}} \rho(\phi(z, \boldsymbol{w}) > \phi(x, \boldsymbol{w}))$$

where $\rho(true) = 1$ and $\rho(false) = 0$. Therefore, for each $x \in A$ and for each $r = 1, \ldots, n$, SMAA defines the subset of weight vectors in S^{DM}

$$S_r^{DM}(x) = \{\boldsymbol{w} \in S^{DM}: rank(x, \boldsymbol{w}) = r\}$$

that give position r to alternative x. This means that applying PROMETHEE II considering a weights vector $\boldsymbol{w}$ in $S_r^{DM}(x)$, x takes the $r-th$ position in the ranking. Analogously, for each ordered pair of alternatives $(x, y) \in A \times A$, the subset of S^{DM} placing x in a better position than y, is defined:

$$S^{DM}(x, y) = \{\boldsymbol{w} \in S^{DM}: rank(x, \boldsymbol{w}) < rank(z, \boldsymbol{w})\}.$$

On the basis of such sets, SMAA computes the following indices:

- the Rank Acceptability Index (RAI) $b^r(x)$: it is the frequency with which, considering all rankings obtained varying the weight vectors in S^{DM}, x takes position $r = 1, \ldots, n$. Formally,

$$b^r(x) = \frac{|S_r^{DM}(x)|}{|S^{DM}|}.$$

  $b^r(x) \in [0,1]$ and the best alternatives are those having $b^r(x)$ close to one for the first rank positions;

- the Pairwise Winning Index (PWI) $p(x, y)$: it is the frequency with which, considering all rankings obtained varying the weight vectors in S^{DM}, x is preferred to y. Formally,

$$p(x, y) = \frac{|S^{DM}(x, y)|}{|S^{DM}|}.$$

Also in this case, $p(x, y) \in [0,1]$ and, the greater $p(x, y)$, the more x is preferred to y.

Even if both RAIs give information in statistical terms considering the rankings obtained by using a sample of weight vectors compatible with few preferences given by the DM, in real world applications, one needs a unique ranking being representative of all possible ones. For such a reason, Kadzinski and Michalski (2016), define several procedures aiming to summarize the RAIs (for a similar recent procedure developed to summarize the PWIs, see Arcidiacono et al. 2023). In this paper, to summarize the RAIs, we compute the expected ranking of each alternative $x \in A$

$$ER(x) = -\sum_{r=1}^{|A|} r \cdot b^r(x)$$

that, from a mathematical point of view is a weighted sum of all RAIs. The greater $ER(x)$, the better x is on the considered problem.

Results and Discussion

In this section we shall apply SMAA to the classical PROMETHEE methods to deal with a multiple criteria decision making problem in which a DM has to choose among fifty different circular economy good practices to integrate within a certain business model, based on the simulated criteria of Table 1. With respect to the considered problem, we assume that the DM states that Environmental criteria are more important than social criteria that on their hand, are more important than economic ones. Moreover, in order to avoid those economic aspects are completely neglected, we assume that the DM states that economic criteria weight is at least equal to 10% of the total of criteria weights.

According to Tervonen and Lahdelma (2007), in order to achieve error limits of 0.01 for $b^r(x)$, we sampled 10,000 weight vectors from the space defined by the constraints translating the preference information provided by the DM. Therefore, following the previous description, $|S^{DM}| = 10{,}000$.

Since the DM is interested in obtaining a general overview of the fifty good practices in order to choose which one is the best, the results by applying SMAA to the PROMETHEE II method are presented considering environmental, social and economic aspects separately as well as the global level. To better appreciate the application of the proposed framework, in Table 2 we report the expected ranking of each good practice at partial and global level.

It is evident that by looking only at environmental criteria, good practice thirty-seven (GP37) is the best since it has the greatest value (-295.19). For the social dimension the good practice to choose is the twenty-six (GP26) with a value of -316.04. While considering only economic aspects the best good practice is again the twenty-six (GP26) with a value of -577.99.

However, the global ranking (i.e., including all aspects simultaneously) supports the decision on the good practices already suggested by the environmental macro criteria, that is, GP37.

Table 2. *Expected ranking results obtained by applying SMAA to the PROMETHEE II method*

	Environmental		Social		Economic		Global ranking
	Rank position	Value	Rank position	Value	Rank position	Value	
GP1	50	-4668.41	26	-2597.7	39	-3631.15	**50**

GP2	2	-517.07	17	-1852.42	47	-4334.34	**8**
GP3	18	-2210.58	28	-2815.92	34	-3211.21	**25**
GP4	12	-1354.86	9	-1099.57	10	-1394.79	**5**
GP5	23	-2569.71	2	-643.72	45	-4097.04	**17**
GP6	45	-4122.04	45	-4183.65	6	-900.84	**46**
GP7	38	-3360.18	27	-2650.99	31	-2802.62	**32**
GP8	4	-820.96	41	-3714.96	37	-3479.5	**19**
GP9	34	-3217.46	35	-3364.9	27	-2581.88	**38**
GP10	16	-2067.39	36	-3445.12	8	-1234.81	**20**
GP11	47	-4456.11	46	-4266	7	-1199.88	**49**
GP12	3	-710.42	19	-2031.37	24	-2357.42	**6**
GP13	48	-4473.38	33	-3223.07	11	-1569.37	**43**
GP14	11	-1248.26	13	-1699.84	28	-2641.07	**7**
GP15	26	-2642.44	20	-2108.16	33	-2991	**21**
GP16	21	-2301.4	6	-875.01	19	-1882.79	**9**
GP17	35	-3228.13	10	-1222.01	38	-3518.2	**23**
GP18	15	-2064.96	11	-1228.46	22	-2272.82	**11**
GP19	13	-1615.47	49	-4685.95	12	-1584.3	**31**
GP20	8	-1015.8	43	-3958.08	49	-4603.11	**34**
GP21	44	-4019.92	29	-2839.92	46	-4195.97	**47**
GP22	14	-1887.59	38	-3585.74	20	-2044.93	**22**
GP23	39	-3412.26	30	-2860.32	50	-4625.99	**45**
GP24	36	-3234.97	15	-1827.21	41	-3782.62	**29**
GP25	32	-2972.43	22	-2331.45	43	-3965.33	**33**
GP26	25	-2595.65	1	-316.04	1	-577.99	**4**
GP27	43	-3850.21	32	-2966.27	16	-1806.08	**37**
GP28	5	-886.96	47	-4443.27	36	-3469.49	**30**
GP29	37	-3350.69	37	-3534.49	35	-3425.54	**41**
GP30	10	-1181.89	3	-669.25	13	-1613.33	**3**
GP31	6	-931.45	44	-4133.86	14	-1677.47	**18**
GP32	9	-1043.13	12	-1231.12	2	-756.8	**2**
GP33	41	-3521.67	23	-2362.44	48	-4521.57	**44**
GP34	27	-2645.25	24	-2481.01	32	-2865.72	**24**
GP35	40	-3456.73	5	-826.35	9	-1289.37	**14**

GP36	7	-945.51	40	-3650.35	40	-3694.55	**26**
GP37	1	-295.19	16	-1845.45	5	-897.35	**1**
GP38	20	-2288.99	50	-4772.34	42	-3955.03	**48**
GP39	19	-2285.39	42	-3841.19	17	-1856.95	**28**
GP40	22	-2512.15	8	-994.62	29	-2718.38	**13**
GP41	49	-4559.63	4	-756.83	21	-2171.01	**27**
GP42	33	-3179.68	48	-4449.24	15	-1740.66	**42**
GP43	42	-3714.71	34	-3345.88	26	-2577.75	**40**
GP44	17	-2158.49	18	-1859.28	23	-2333.86	**15**
GP45	28	-2668.39	7	-969.93	18	-1872.94	**10**
GP46	31	-2811.67	21	-2182.99	3	-780.65	**16**
GP47	29	-2759.2	39	-3605.64	30	-2748.37	**36**
GP48	24	-2572.4	31	-2898.15	44	-3976.22	**35**
GP49	30	-2783.53	14	-1769.65	4	-794.82	**12**
GP50	46	-4309.24	25	-2482.82	25	-2475.11	**39**

Figure 1 represents the RAIs for the considered good practices which explain the frequency with which an alternative takes a certain position. Each bar indeed represents the probability that a certain good practice falls into a given position. For example, the best global good practice (GP37), colored in light blue, takes the 1st position in 35.7% of the cases, and it is the greatest frequency in absolute among each position.

Figure 1. *The Rank Acceptability Index (RAI)*

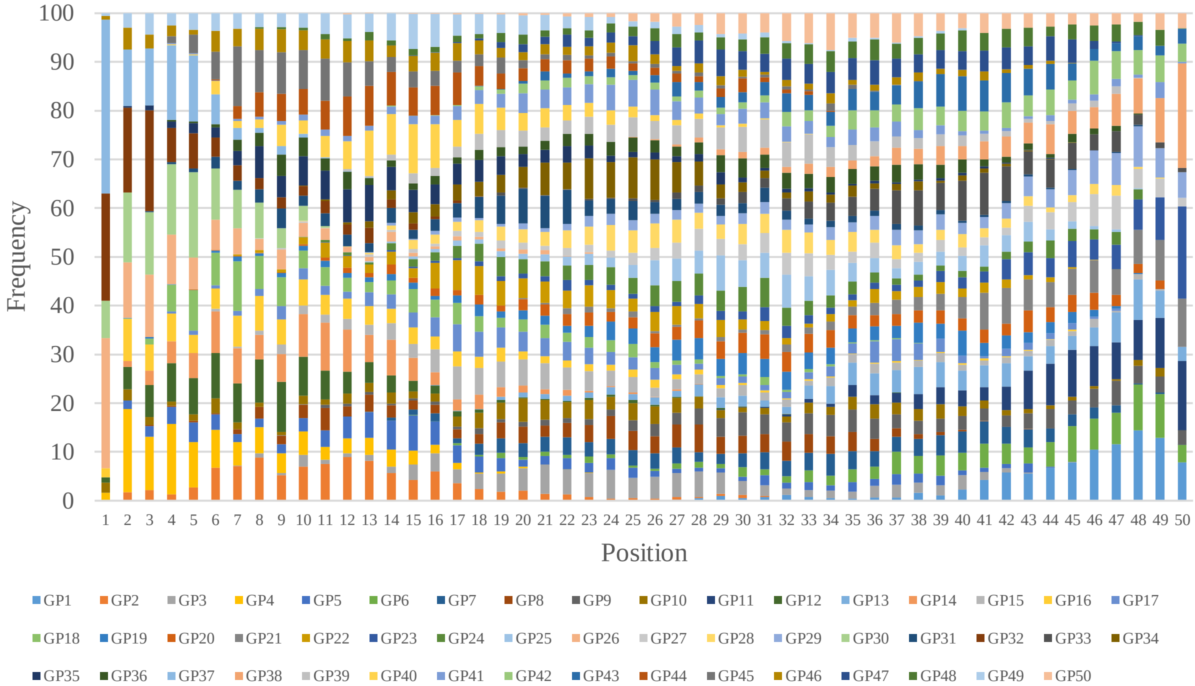

Table 3 shows the PWIs among good practices, that is the frequency with which an alternative (on the row) is preferred to another alternative (in the column). The table assumes a matrix shape which allows the DM to assess more in detail how much a certain good practice is preferred to another, considering all aspects. Pay attention that a similar table can be built also considering singularly environmental, social and economic aspects.

In particular, the best good practice chosen above (GP37) is preferred to thirty-five other good practices in at least 99% of the cases and only one time it is preferred to good practice twenty-six (GP26) in 51% of cases. While in all other cases it is anyway preferred in at least 70% of cases.

Summarizing, we can state that the RAIs and PWIs further enhance the decision-making process by providing detailed insights into the relative performance of different practices. These indices offer valuable information on the likelihood of a practice being the best option and its comparative advantage over others, respectively.

Table 3. Pairwise Winning Indices (PWIs) among good practices

	GP1	GP2	GP3	GP4	GP5	GP6	GP7	GP8	GP9	GP10	GP11	GP12	GP13	GP14	GP15	GP16	GP17	GP18	GP19	GP20	GP21	GP22	GP23	GP24	GP25
Good Pract	0	0.12	1.78	0	0.32	35.97	5.74	0.05	20.42	4.66	48.3	0.01	22.5	0	5.71	2.98	1.72	0.2	7.28	15.5	34.3	2.16	40.9	3.73	6.04
GP2	99.88	0	94.7	20.14	72.67	100	98.8	83.6	98.39	81.7	100	30.4	100	43.2	84.49	47.7	81.7	52	91.7	98.3	100	95.3	99.3	93.2	96.7
GP3	98.22	5.3	0	0	36.45	94.25	69.4	45.8	79.24	44	99.7	5.17	82.6	4.63	39.74	18.5	45	19.9	66.6	68.6	90.8	46.6	94.1	64.9	81.8
GP4	100	79.86	100	0	82.9	100	100	95	99.54	85.1	100	71.2	100	78.7	94.3	69.5	94.9	80.7	98.9	99.2	100	99.2	100	99.9	99.8
GP5	99.68	27.33	63.55	17.1	0	95.39	84.9	64.5	81.43	68.7	94.7	9.49	98.4	33.2	65.86	30.9	63.1	26.5	78.2	78.1	99.3	74.9	82.5	71.1	77.6
GP6	64.03	0	5.75	0	4.61	0	17.2	10.9	33.76	19	67.2	0.05	44.4	0	16.74	1.98	5.09	0.09	10.7	23.8	58.7	6.89	61.1	18.2	14.4
GP7	94.26	1.22	30.6	0	15.1	82.8	0	29.6	56.39	34.4	88.9	0.77	69.2	3.19	28.26	3.87	27.2	4.93	42.4	57.6	87.1	20.4	70.2	46	50.5
GP8	99.95	16.41	54.19	5	35.51	89.15	70.4	0	88.89	52.2	99.2	12	84.1	12.3	46.88	20.8	48.8	23	68.9	66.8	90.6	49.4	95.3	71.1	79
GP9	79.58	1.61	20.76	0.46	18.57	66.24	43.6	11.1	0	16.8	85.1	2.3	58	1.26	18.67	6.22	29.8	8.05	38	39.6	69.6	22.8	65.5	35.2	42.4
GP10	95.34	18.28	55.98	14.95	31.32	81.02	65.6	47.8	83.21	0	94.2	15.2	80	17.7	50.82	24.1	51.3	24.5	63.5	65.3	84	47.3	84.9	64	68.5
GP11	51.73	0	0.35	0	5.27	32.81	11.2	0.78	14.91	5.76	0	0	34.9	0	6.8	0.41	2.84	0	4.8	6.48	36.6	6.04	39.5	1.14	3.3
GP12	99.99	69.64	94.83	28.83	90.51	99.95	99.2	88	97.7	84.8	100	0	100	62.1	93.95	57.1	88.7	67.9	97.8	98.3	100	95	99.1	95.6	97.8
GP13	77.53	0	17.44	0	1.56	55.59	30.8	15.9	42.05	20	65.1	0	0	1.22	6.69	0.01	20.5	0.32	29.1	40.5	68.4	8.12	57.6	29.4	28.9
GP14	100	56.76	95.37	21.28	66.81	100	96.8	87.8	98.74	82.3	100	37.9	98.8	0	91.92	52.2	95.7	52.7	97.6	98.1	100	93.9	100	98.2	100
GP15	94.29	15.51	60.26	5.7	34.14	83.26	71.7	53.1	81.33	49.2	93.2	6.05	93.3	8.08	0	14.7	45.5	20.1	63.1	70.3	90.3	51.1	79.4	62.5	69.9
GP16	97.02	52.29	81.5	30.51	69.09	98.02	96.1	79.2	93.78	76	99.6	42.9	100	47.8	85.32	0	86.5	55.6	91.1	91.5	100	82.3	92.9	90.6	93.9
GP17	98.28	18.33	55.02	5.08	36.9	94.91	72.9	51.2	70.21	48.7	97.2	11.3	79.5	4.29	54.51	13.5	0	28.2	70	79.9	95.6	45.1	92.9	73.7	77.9
GP18	99.8	47.97	80.07	19.27	73.5	99.91	95.1	77	91.95	75.5	100	32.1	99.7	47.3	79.9	44.4	71.8	0	83.5	85.9	100	85.8	94.9	84.7	92.3
GP19	92.72	8.31	33.43	1.13	21.81	89.26	57.6	31.1	62.02	36.5	95.2	2.21	71	2.41	36.9	8.94	30	16.5	0	58.6	81.7	25.8	84.6	52.2	58.4
GP20	84.48	1.7	31.4	0.78	21.87	76.2	42.4	33.2	60.43	34.7	93.5	1.69	59.5	1.91	29.71	8.49	20.1	14.1	41.4	0	74.7	24.7	81.6	44.9	49.6
GP21	65.74	0	9.19	0	0.68	41.31	13	9.39	30.37	16.1	63.4	0	31.6	0	9.74	0	4.45	0	18.3	25.3	0	2.52	53.3	19.2	22.5
GP22	97.84	4.68	53.36	0.8	25.07	93.11	79.6	50.6	77.23	52.7	94	4.96	91.9	6.1	48.92	17.7	54.9	14.2	74.2	75.4	97.5	0	78.3	59.3	72
GP23	59.06	0.74	5.89	0	17.52	38.91	29.8	4.71	34.54	15.2	60.5	0.88	42.4	0	20.56	7.06	7.15	5.12	15.4	18.4	46.7	21.7	0	12.9	16.9
GP24	96.27	6.83	35.06	0.13	28.89	81.84	54	28.9	64.81	36	98.9	4.4	70.6	1.78	37.49	9.4	26.4	15.3	47.8	55.1	80.8	40.7	87.1	0	58.2
GP25	93.96	3.27	18.16	0.21	22.38	85.65	49.5	21	57.56	31.5	96.7	2.22	71.1	0	30.06	6.15	22.2	7.68	41.6	50.4	77.5	28	83.2	41.8	0
GP26	100	83.46	99.41	57.41	94.57	100	100	96.7	99.93	87.9	100	77.3	100	82.1	94.12	73.2	93.4	86.7	93.3	96	100	100	100	100	100
GP27	79.17	0.35	21.6	0	9.59	66.06	44.3	15.5	54.71	19.4	76.1	2.76	61.4	2.47	19.49	6.79	29.9	2.47	42.5	44.2	71	15.9	65.8	37	42.2
GP28	90.03	1.27	31.96	0.89	22.67	81.77	56.9	42.7	67.94	37.8	91.3	1.32	81.2	2.71	27.45	7.91	37.6	7.23	51.1	51.7	90.1	31.9	80.1	46.4	59.5
GP29	70.73	0	21.23	0.56	0	52.47	27.1	20.6	48.84	21.8	62.1	0	50.8	0.04	13.76	6.08	22.5	0	30.4	32.7	63.2	9.53	51.4	27	30.6
GP30	100	92.06	100	60.69	87.39	100	100	99.3	100	92.8	100	71.1	100	96	99.9	76.3	99.6	80.5	99.8	100	100	100	100	100	100
GP31	96.59	16.96	66.91	9.99	29.03	91.52	71.8	64.2	89	65.5	96.5	9.17	90.7	12	62.06	27.1	54.7	26.2	74.2	80.9	93	51.1	93.2	73.2	82.3
GP32	100	83.63	100	83.54	87.6	100	100	98.6	99.77	90.4	100	79	100	87.3	97.58	80.4	96.3	89.8	98.8	98.9	100	100	100	100	100
GP33	78.59	0	9.87	0	9.04	62.34	31.9	1.62	38.45	7.53	76.5	0.05	54.2	0	13.26	2.88	21.3	1.5	23	30.7	67.9	9.94	62.2	23.8	23.5
GP34	100	10.29	51.87	0.34	32.55	88.07	71.9	47.5	85.01	42.1	97.1	4.07	94.8	1.85	42.73	10.1	43.4	17.1	63.2	71.9	93.4	45.2	92.1	65.4	76.8
GP35	96.49	40.69	77	12.15	58.35	97.61	93.7	75.5	90.02	69.5	99.7	17.9	99.9	32	71.84	19.6	80.7	35.3	88.3	86	100	75.6	90.6	87.7	91.9
GP36	96.74	20.52	56.29	5.9	32.5	82.68	61.3	43.9	78.16	39	92.2	14.5	78.8	4.8	43.79	20.3	48.9	29.7	59.6	69.7	85.7	41.7	88.6	64.8	71.1
GP37	**100**	**99.86**	**99.92**	**70.06**	**96.35**	**100**	**100**	**97.7**	**100**	**96.9**	**100**	**89.6**	**100**	**91.9**	**100**	**95.8**	**99.4**	**96.7**	**100**	**100**	**100**	**99.9**	**100**	**100**	**100**
GP38	46.63	0	1.44	0	11.86	45.03	23	0.86	21.08	0.71	53.5	0	28.6	0	1.57	1.73	1.54	1.91	8.85	16.7	40.5	14.1	46.3	9.68	10.2
GP39	90.77	0.8	31.52	0.04	21.37	84.04	60.3	40	71.39	41.1	94.4	0.5	87.7	2.66	29.16	2.81	41.1	5.17	52.5	62.1	90.3	33.1	79.6	52	59.1
GP40	99.87	29.63	81.99	13.93	50.43	98.57	93.7	79.6	93.16	71.2	100	13.5	99.9	28.6	78.19	27.7	72.5	27.5	85.9	86.3	100	79.6	93.6	90	94.9
GP41	93.78	10.21	47.27	0.44	31.13	84.66	67.7	42.6	69.32	39.2	91.4	5.61	77.7	4.28	35.73	9.95	36.3	15.1	60	70.2	89.1	40.8	83.3	60.6	69.6
GP42	74.64	0.07	5.26	0	9.64	62.38	33.5	5.45	40.48	19.3	65.9	0.05	51	0.61	19.99	6.73	22.8	1.62	30	34.3	62	9.53	62	24	28.8
GP43	77.88	0.21	15.08	0	8.69	61.44	29.2	12	44.58	14.3	80.7	0.12	55.9	0	12.65	1.43	21.2	1.15	30.1	36.5	71.6	14.3	60.9	28.4	31.9
GP44	97.68	30.81	81.1	12.74	54.18	100	95.1	72.7	89.81	71.6	100	9.02	99.8	24.2	73.5	27.7	72.5	34.2	90.5	91.8	100	78.6	91.6	82.4	89.2
GP45	99.99	53.07	88.14	18.66	74.96	99.66	99.2	78.3	91.12	74.9	99.7	30.2	100	52.5	81.26	43.3	78.7	47.9	88.1	89.9	100	92.5	94	89.5	91
GP46	98.21	38.97	71.97	12.79	56.77	95.82	84.7	66.1	86.47	67.2	93.9	21	95.9	34.7	63.97	34	65.4	32	73.5	75.9	99	73.5	89.4	76.3	81.3
GP47	87.26	0	22.74	0	3.32	70.08	41.1	21.4	61.17	25.4	87.5	0	72	0.82	20.1	4.12	32.6	0.1	39.5	45.4	80.8	13.9	70.9	30.5	42.7
GP48	87.19	1.14	26.32	0.02	18.94	66.1	32.9	20.3	57.88	34.7	98.5	2.44	58.1	2.55	26.23	9.77	23.7	11.1	34.5	45.5	67.5	29.3	75.3	34.6	40.6
GP49	99.76	33.78	80.49	22.23	48.62	93.08	86.4	82.9	99.31	80.5	100	25	95.9	36.2	76.24	38.4	77	35.9	81.6	86.6	94.6	73.4	99.3	89.6	91.5
GP50	83.93	3.04	21.05	0.25	9.76	69.29	39.6	13.5	45.94	16.2	78	1.01	61.6	0	14.38	0.6	25	2.31	34.3	40.1	75.4	14.2	69.8	32.7	39.9

	GP26	GP27	GP28	GP29	GP30	GP31	GP32	GP33	GP34	GP35	GP36	GP37	GP38	GP39	GP40	GP41	GP42	GP43	GP44	GP45	GP46	GP47	GP48	GP49	GP50
Good Pract	0	20.8	9.97	29.3	0	3.41	0	21.4	0	3.51	3.26	0	53.4	9.23	0.13	6.22	25.4	22.1	2.32	0.01	1.79	12.74	12.81	0.24	16.07
GP2	16.5	99.7	98.7	100	7.94	83	16.4	100	89.7	59.3	79.5	0.14	100	99.2	70.4	89.8	99.9	99.8	69.2	46.9	61.03	100	98.86	66.22	96.96
GP3	0.59	78.4	68	78.8	0	33.1	0	90.1	48.1	23	43.7	0.08	98.6	68.5	18	52.7	94.7	84.9	18.9	11.9	28.03	77.26	73.68	19.51	78.95
GP4	42.6	100	99.1	99.4	39.3	90	16.5	100	99.7	87.9	94.1	29.9	100	100	86.1	99.6	100	100	87.3	81.3	87.21	100	99.98	77.77	99.75
GP5	5.43	90.4	77.3	100	12.6	71	12.4	91	67.5	41.7	67.5	3.65	88.1	78.6	49.6	68.9	90.4	91.3	45.8	25	43.23	96.68	81.06	51.38	90.24
GP6	0	33.9	18.2	47.5	0	8.48	0	37.7	11.9	2.39	17.3	0	55	16	1.43	15.3	37.6	38.6	0	0.34	4.18	29.92	33.9	6.92	30.71
GP7	0	55.7	43.2	72.9	0	28.2	0	68.1	28.1	6.35	38.7	0	77	39.8	6.35	32.3	66.5	70.8	4.9	0.78	15.32	58.95	67.15	13.58	60.41
GP8	3.3	84.5	57.3	79.4	0.75	35.8	1.42	98.4	52.5	24.5	56.1	2.28	99.1	60	20.4	57.4	94.6	88	27.3	21.7	33.92	78.58	79.7	17.06	86.5
GP9	0.07	45.3	32.1	51.2	0	11	0.23	61.6	15	9.98	21.8	0	78.9	28.6	6.84	30.7	59.5	55.4	10.2	8.88	13.53	38.83	42.12	0.69	54.06
GP10	12.1	80.6	62.2	78.2	7.2	34.5	9.59	92.5	57.9	30.5	61	3.06	99.3	59	28.8	60.8	80.7	85.7	28.4	25.1	32.81	74.57	65.35	19.51	83.78
GP11	0	23.9	8.72	37.9	0	3.55	0	23.5	2.89	0.31	7.76	0	46.5	5.64	0	8.56	34.2	19.3	0.02	0.26	6.15	12.54	1.53	0	21.99
GP12	22.7	97.2	98.7	100	28.9	90.8	21	100	95.9	82.1	85.5	10.4	100	99.5	86.5	94.4	100	99.9	91	69.8	78.98	100	97.56	75	98.99
GP13	0	38.7	18.8	49.2	0	9.28	0	45.8	5.25	0.14	21.2	0	71.4	12.3	0.06	22.3	49	44.1	0.21	0	4.13	28.02	41.88	4.13	38.37
GP14	17.9	97.5	97.3	100	4.04	88.1	12.7	100	98.2	68	95.2	8.12	100	97.3	71.4	95.7	99.4	100	75.8	47.5	65.32	99.18	97.45	63.83	100
GP15	5.88	80.5	72.6	86.2	0.1	37.9	2.42	86.7	57.3	28.2	56.2	0	98.4	70.8	21.8	64.3	80	87.4	26.5	18.7	36.03	79.9	73.77	23.76	85.62
GP16	26.8	93.2	92.1	93.9	23.7	72.9	19.6	97.1	89.9	80.4	79.7	4.16	98.3	97.2	72.4	90.1	93.3	98.6	72.3	56.7	65.99	95.88	90.23	61.61	99.4
GP17	6.63	70.1	62.4	77.5	0.4	45.3	3.67	78.7	56.6	19.3	51.1	0.57	98.5	58.9	27.5	63.8	77.2	78.8	27.5	21.3	34.57	67.38	76.33	23.04	74.99
GP18	13.3	97.5	92.8	100	19.5	73.8	10.2	98.5	82.9	64.7	70.3	3.3	98.1	94.8	72.5	84.9	98.4	98.9	65.8	52.1	67.97	99.9	88.95	64.12	97.69
GP19	6.73	57.5	49	69.6	0.24	25.9	1.24	77	36.8	11.7	40.4	0	91.2	47.5	14.1	40	70	69.9	9.47	11.9	26.49	60.55	65.51	18.36	65.7
GP20	4.05	55.8	48.3	67.3	0	19.1	1.1	69.3	28.1	14	30.3	0	83.3	37.9	13.8	29.8	65.7	63.5	8.25	10.1	24.1	54.63	54.55	13.44	59.9
GP21	0	29	9.93	36.8	0	7	0	32.1	6.61	0	14.3	0	59.5	9.7	0	10.9	38	28.4	0	0	0.98	19.18	32.54	5.36	24.56
GP22	0	84.1	68.1	90.5	0	48.9	0.01	90.1	54.8	24.4	58.3	0.09	85.9	66.9	20.4	59.3	90.5	85.7	21.4	7.49	26.48	86.12	70.66	26.57	85.76
GP23	0	34.2	19.9	48.6	0	6.78	0	37.9	7.94	9.38	11.5	0	53.7	20.4	6.39	16.7	38	39.1	8.42	5.97	10.58	29.12	24.71	0.69	30.22
GP24	0	63	53.6	73	0	26.8	0	76.2	34.6	12.3	35.2	0.03	90.3	48	10	39.4	76.1	71.6	17.6	10.5	23.7	69.54	65.38	10.4	67.3
GP25	0.01	57.8	40.5	69.4	0	17.7	0	76.5	23.2	8.1	28.9	0	89.8	40.9	5.07	30.4	71.2	68.1	10.9	9.05	18.68	57.28	59.42	8.46	60.14
GP26	0	100	100	100	59.9	89.8	45.2	100	99.6	91.3	89.9	48.9	100	99.8	95.7	98.2	100	100	94.6	89.8	97.64	100	98.28	88.62	100
GP27	0	0	29	49.7	0	11.2	0	62.2	21	8.24	29.1	0	73.4	34.8	3.67	32.3	66.3	54.7	8.69	2.71	10.49	40.55	46.33	1.33	51.33
GP28	0.04	71	0	77.3	0	21	0.19	82.3	36.5	12.4	44.4	0	87.6	51.1	6.91	41.8	85.1	75	3.62	3.87	19.04	64.86	61.72	9.45	78.46
GP29	0	50.3	22.7	0	0	4.99	0.12	50.4	13.1	6.49	29.4	0	67	18.6	1.82	25.1	46.2	47	0	0	0.09	26.21	31.61	3.63	42.09
GP30	40.1	100	100	100	0	99.8	42.8	100	100	94.1	99.2	29.6	100	100	98.7	99.8	100	100	99.2	91.7	88.73	100	100	93.67	100
GP31	10.2	88.8	79	95	0.23	0	8.76	94.8	65.4	31.6	74.3	0	99.9	74.2	29.9	63.2	89.7	90	27.4	21.4	33.22	83.32	82.42	31.42	92.38
GP32	54.8	100	99.8	99.9	57.2	91.2	0	100	99.5	93	98.4	43	100	100	94.1	99.1	100	100	89.5	89.5	89.8	100	100	83.47	100
GP33	0	37.9	17.7	49.6	0	5.16	0	0	4.12	3.15	12.5	0	73.2	17.2	0	22	56.3	45.9	2.44	2.94	7.64	27.73	32.95	0	36.33
GP34	0.37	79	63.5	86.9	0	34.6	0.46	95.9	0	16.3	58.8	0.09	100	64.3	12	62.9	84	91.5	21.9	12.4	31.31	78.61	75.35	9.02	85.9
GP35	8.74	91.8	87.6	93.5	5.87	68.4	6.96	96.9	83.7	0	77.2	0.96	97.2	88	55.5	86.3	91.8	98.4	52.7	34.1	53.82	93.07	86.57	47.27	100
GP36	10.1	70.9	55.6	70.6	0.85	25.7	1.64	87.5	41.2	22.8	0	1.84	100	55.7	23.4	55.1	81.6	78.6	27.7	26.4	30.5	60.69	70.61	14.43	73.23
GP37	**51.1**	**100**	**100**	**100**	**70.4**	**100**	**57.1**	**100**	**99.9**	**99**	**98.2**	**0**	**100**	**100**	**100**	**99.9**	**100**	**100**	**99.9**	**98.6**	**89.36**	**100**	**100**	**92.33**	**100**
GP38	0	26.6	12.4	33	0	0.06	0	26.8	0.01	2.83	0	0	0	11.8	0	3.67	31.8	27	0.05	2.44	7.91	21.98	21.19	0	22.89
GP39	0.21	65.2	49	81.4	0	25.8	0	82.8	35.7	12	44.3	0	88.2	0	9.82	45.3	77.8	78.6	7.08	3.81	21.96	71.23	68.29	13.78	80.64
GP40	4.34	96.3	93.1	98.2	1.31	70.1	5.89	100	88	44.5	76.6	0	100	90.2	0	85.2	95.2	100	45.6	28.2	49.52	99.68	88.66	48.1	100
GP41	1.78	67.7	58.2	74.9	0.19	36.8	0.93	78	37.1	13.7	44.9	0.07	96.3	54.7	14.8	0	76.3	74.2	18.8	11.5	30.43	63.29	71.59	16.27	71.1
GP42	0	33.7	14.9	53.8	0	10.3	0	43.7	16	8.16	18.4	0	68.2	22.2	4.85	23.7	0	42.5	6.87	2.66	2.92	32.57	33.8	0.67	37.74
GP43	0	45.3	25.1	53	0	9.97	0	54.1	8.52	1.58	21.4	0	73	21.4	0	25.8	57.5	0	1.12	0.98	5.21	34.76	38.1	1.76	46.7
GP44	5.38	91.3	96.4	100	0.77	72.6	10.5	97.6	78.1	47.3	72.3	0.12	100	92.9	54.4	81.2	93.1	98.9	0	25.8	50.22	97.56	87.42	49.83	96.77
GP45	10.2	97.3	96.1	100	8.35	78.6	10.5	97.1	87.6	65.9	73.6	1.41	97.6	96.2	71.9	88.6	97.3	99	74.2	0	69.86	99.12	91.66	64.04	99.18
GP46	2.36	89.5	81	99.9	11.3	66.8	10.2	92.4	68.7	46.2	69.5	10.6	92.1	78	50.5	69.6	97.1	94.8	49.8	30.1	0	94.78	81.44	50.32	89.63
GP47	0	59.5	35.1	73.8	0	16.7	0	72.3	21.4	6.93	39.3	0	78	28.8	0.32	36.7	67.4	65.2	2.44	0.88	5.22	0	45.55	0.39	62.72
GP48	1.72	53.7	38.3	68.4	0	17.6	0	67.1	24.7	13.4	29.4	0	78.8	31.7	11.3	28.4	66.2	61.9	12.6	8.34	18.56	54.45	0	3.8	53.86
GP49	11.4	98.7	90.6	96.4	6.33	68.6	16.5	100	91	52.7	85.6	7.67	100	86.2	51.9	83.7	99.3	98.2	50.2	36	49.68	99.61	96.2	0	98.08
GP50	0	48.7	21.5	57.9	0	7.62	0	63.7	14.1	0	26.8	0	77.1	19.4	0	28.9	62.3	53.3	3.23	0.82	10.37	37.28	46.14	1.92	0

The findings also underscore the importance of considering all dimensions of sustainability, environmental, social, and economic, when evaluating CEGPs. While certain practices may excel in one area, a holistic approach ensures that the chosen practices contribute positively to all aspects of sustainability. This balance is crucial for achieving long-term sustainable development goals.

Conclusions

The transition from a linear to a circular economy represents a paradigm shift in how businesses and societies approach resource utilization, waste management, and sustainable development. This transformation is essential for mitigating the adverse environmental impacts of the linear economy, characterized by its "take, make, and dispose" model, and for fostering a more sustainable and resilient economic system. The linear economy, which has been the dominant economic model since the Industrial Revolution, is inherently unsustainable due to its reliance on the continuous extraction of finite resources and its tendency to generate significant amounts of waste and pollution. The works of economists such as Kenneth E. Boulding and Barry Commoner have highlighted the limitations of this model, advocating instead for a circular approach where waste from one process becomes the input for another, thus creating a closed-loop system.

The Circular Economy (CE) aims to decouple economic growth from resource consumption by promoting the efficient use and recycling of materials, reducing waste, and minimizing environmental impacts. This model not only has the potential to alleviate the strain on natural resources but also offers significant economic benefits, including cost savings, job creation, and enhanced competitiveness. For example, the Ellen MacArthur Foundation (2015) estimates that adopting CE practices could save Europe up to €1.8 billion annually by 2030 while boosting GDP and employment levels.

A key component of the transition to a circular economy is the implementation of Circular Economy Good Practices (CEGPs). These practices encompass a wide range of strategies, including eco-design, industrial symbiosis, material recovery, and circular supply chains. Organizations worldwide are increasingly recognizing the value of these practices and integrating them into their business models to achieve long-term sustainability and profitability.

The evaluation and adoption of CEGPs pose a complex Multiple Criteria Decision Analysis (MCDA) problem. Traditional evaluation methods, such as the weighted sum approach, face limitations due to the compensatory nature of the method and the arbitrariness in assigning weights to different criteria. To address these challenges, a more sophisticated integration between MCDA methods, like PROMETHEE II and SMAA, has been applied here.

The PROMETHEE II method is particularly effective in dealing with the compensatory issues inherent in traditional MCDA approaches. It constructs a preference function for each criterion, allowing for a more nuanced aggregation of preference information. On the other hand, the SMAA method addresses the uncertainty and imprecision in decision-making by considering a range of possible parameters and evaluating their impact on the ranking of alternatives.

The integration of SMAA and PROMETHEE methods, known as SMAA-PROMETHEE, provides a robust framework for evaluating and ranking CEGPs. This combined approach leverages the strengths of both methods, enabling decision-makers to account for a wide range of factors and uncertainties in their evaluations. In this study, we have shown how the SMAA-PROMETHEE method could be applied in practice to evaluate fifty different CEGPs based on simulated criteria that capture environmental, social, and economic performance. The results demonstrated the effectiveness of this approach in providing a comprehensive and balanced assessment of each practice. For instance, the best global good practice (GP37) was identified based on its overall performance across all criteria, highlighting its strong environmental benefits and acceptable social and economic impacts.

The findings also underscore the importance of considering all dimensions of sustainability (environmental, social, and economic) when evaluating CEGPs. While certain practices may excel in one area, a holistic approach ensures that the chosen practices contribute positively to all aspects of sustainability. This balance is crucial for achieving long-term sustainable development goals.

The Rank Acceptability Indices (RAIs) and Pairwise Winning Indices (PWIs) further enhance the decision-making process by providing detailed insights into the relative performance of different practices. These indices offer valuable information on the likelihood of a practice being the best option and its comparative advantage over others, respectively.

In conclusion, the transition to a circular economy is not only feasible but also highly beneficial from both an environmental and economic perspective. The adoption of CEGPs, supported by advanced MCDA methods like SMAA-PROMETHEE, can significantly enhance the sustainability of business operations and contribute to broader societal goals. As organizations and policymakers increasingly recognize the value of the circular economy, the continued development and application of robust evaluation frameworks will be essential in guiding the transition towards a more sustainable future.

Acknowledgements

"This study was funded under the National Recovery and Resilience Plan (NRRP), Mission 4 Component 2 Investment 1.3—Call for proposals No. 341 of 15 March 2022 of Italian Ministry of University and Research funded by the European Union—NextGenerationEU, Award Number: Project code PE00000003, Concession Decree No. 1550 of 11 October 2022 adopted by the Italian Ministry of University and Research, CUP E63C22002060006, Project title "ON Foods—Research and innovation network on food and nutrition Sustainability, Safety and Security—Working ON Foods". Moreover, with respect to Salvatore Corrente research, this study was also funded by the European Union - NextGenerationEU, in the framework of the GRINS -Growing Resilient, INclusive and Sustainable project (GRINS PE00000018 – CUP E63C22002120006).

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Sustainable Water Practices: Understanding Water Consumption Behaviors Across Age Groups. Insights into Effective Strategies for Promoting Sustainable Water Use

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Abstract

Today, humanity finds itself having to jointly manage multiple crisis situations linked to political and social factors, as well as to the climate and the environment. Within the latter, there are pressing issues involving air, land, and water. Water plays a key role in the survival of man and the Earth and is a necessary requirement for the social and economic development of societies. In this work, the issues relating to this last resource were analyzed, investigating how much individual citizens know about the resource and its conditions and whether they implement behaviors that aim to prevent water waste. The survey was carried out by administering a questionnaire on the main social media as well as through channels such as e-mail, Teams and WhatsApp. Data collection took place in May and June 2023. A sample of 263 respondents have participated to the survey. The results show that, despite a low frequency in the introduction of water rationing measures or suspension of supply in the places where one lives, the knowledge of the problem of scarcity, as well as the experimentation of extreme climatic phenomena appear to be medium-high and, many of them believe it is appropriate to increase the dissemination of information about the problem. Furthermore, it was possible to observe that there is a poor attitude among individuals to change their eating habits in exchange for greater water sustainability, while the results linked to behaviors regarding personal hygiene are positive. Regarding the cleaning of the environments, however, it was observed that there is no real tendency towards virtuous or harmful behavior on the part of the subjects, but the degree of implementation proved to be high depending on the activity mentioned.

Keywords: Water Management, Environmental Management, Sustainable Practices, Consumer Behaviour.

Relevant Topic: Sustainable consumption and consumer

Introduction

Water is one of the natural resources essential for maintaining the balance of our planet and sustaining life and economic development. Historically, its availability has been considered unlimited. However, demographic and socioeconomic development, along with improvements in quality of life and lifespan, have increased the demand for water and led to its mismanagement (Vörösmarty et al., 2010). Although water is crucial for life, its extreme vulnerability to ongoing environmental and climate change, pollution, and waste is making it an increasingly scarce resource and a source of social tensions. Major water crises are exacerbated by phenomena such as droughts, rising temperatures, and extreme weather events, which impact vulnerable aquifers and outdated infrastructure and networks (Musie and Gonfa, 2023).

In recent decades, the growth in water demand has doubled that of population growth. It is projected that global water demand will reach 4,350 billion cubic meters in terms of withdrawals by 2050, while a vast number of people worldwide still lack access to drinking water sources and improved sanitation services. Efforts to provide safe water access to these population groups would likely increase domestic water demand (Wang, 2019). None of the Sustainable Development Goal (SDG) 6 targets appear to be on track. As of 2022, 2.2 billion people were without access to safely managed drinking water, with four out of five of these people living in rural areas. The situation with respect to safely managed sanitation is dire, with 3.5 billion people lacking access to such services. Cities and municipalities have been unable to keep up with the accelerating growth of their urban populations (Koncagül et al., 2024).

Water scarcity is a pressing global issue, concerning the inadequate availability of safe and clean water resources sufficient to meet human and ecological needs. By 2025, more than one billion people living in arid regions will experience a complete lack of water supply (Hasan et al., 2019). Even with highly efficient irrigation practices, these regions will not have sufficient water resources to meet the basic needs of households, industries, agriculture, and the environment. Projections suggest that around 1.8 billion people worldwide will face moderate water stress by 2050, with 80 percent of them residing in developing countries. Consequently, people in these areas will need to reduce their overall water consumption, leading to decreased local food production and increased reliance on food imports (Adaawen, 2021).

Furthermore, water scarcity has become a significant impediment to economic progress, leading to intense competition among different sectors reliant on limited water resources (Pérez et al., 2020). As water resources become scarce, conservation of water has become a high priority globally, making water management and conservation an important research area (Yang et al., 2017). Effective water management strategies are essential to address this problem and ensure sustainable water resources for future generations. Society faces technological and economic challenges in implementing an optimal system that allows all economic entities, including consumers, to be fully involved in rational water resource management. This involvement is reflected in their consumption patterns. Due to the relationship between water-saving behaviors and consumers' daily lives, changes in infrastructure, products, business models, and policies will not succeed without considering consumers' acceptance and adaptation (Jeffrey and Gearey, 2006).

While agriculture accounts for roughly 70% of freshwater withdrawals, industrial (≈20%) and domestic (≈10%) uses are the main drivers of increasing water demand. As economies industrialize, populations urbanize, and water supply and sanitation systems expand, the consumer assumes an increasingly important role in the use and rationalization of water resources. Domestic use includes drinking and non-potable water that households obtain through public supply or self-supply from sources such as wells and cisterns. Civil uses of water include food preparation and consumption, personal hygiene, and maintenance of domestic and public environments (Paul and Lama, 2019). Anna Jakubczak (2020) reports that household water consumption behavior depends on demographic characteristics such as age and gender. Variables describing the decision-making context of water consumers include place of residence and country of origin.

This study aims to understand how much Italian consumers know about the water resource, its current condition, and whether they implement behaviors to prevent water waste.

The paper is structured as follow: section 2 describes the methodology used for the quantitative research developed, section 3 describes the results obtained and discusses them while section 4 draws the main conclusions defining limitations and future research directions.

Methods

A quantitative approach was taken to understand the behavior of Italian consumers toward the water resource. Data were obtained through an online questionnaire developed with Computer Assisted Web Interviewing (CAWI) methodology and distributed from May to June 2023. This survey method represents an efficient technique to collect complex information quickly and cheaply, while ensuring anonymity and wide geographical coverage (Wright, 2005; Rice et al., 2017). Participants were reached via social networks (e.g. Instagram, Facebook, LinkedIn), instant messaging applications (e.g. WhatsApp), and email. A convenient non-random sampling method was used, as it allows people to be approached quickly and easily (Taherdoost, 2016). The final sample includes 263 respondents.

The questionnaire consists of closed-ended questions - single, multiple, or 5-point Likert scale - divided into three sections. The first investigates the socio-demographic features of the sample. The second section is focused on the cognitive aspect of the subject, with particular attention to the consumption and qualitative-quantitative conditions of the resource.

Finally, in the third section, we focused on the behavioural aspect of the subjects, analysing any harmful or virtuous attitudes toward the resource.

Data analysis involves descriptive statistics such as mean and standard deviation computation.

Results and Discussion

Respondents' Profile and Knowledge about Water Resource

Of the research participants, 68.8% identified as female and 31.2% as male. The majority (57.4%) were aged between 18 and 25, followed by 27.4% aged 26 to 35. Smaller percentages were from other age groups: 7.6% were 46 to 55, 3.0% were 36 to 45 and 56 to 65, and only 1.5% were over 65. Geographically, the sample was diverse, with participants from 17 Italian regions. The highest representation came from Puglia (25.5%), Sicily (15.6%), and Marche (11.8%), with lower percentages from Veneto (7.6%), Campania (6.8%), Emilia-Romagna (6.5%), Basilicata (6.5%), Lombardy (5.7%), and Lazio (4.2%). Regarding education, 47.9% had a bachelor's degree, 26.6% had a high school diploma, and 15.2% had a master's degree. Employment status showed 30.4% were students, 26.2% were both studying and working, 28.1% were employees, and 8.0% were freelancers. The sample also included 3.0% unemployed, 1.5% homemakers, and 1.1% retirees.

The second section of the research focused on understanding awareness of water resource usage. It began by analysing individuals' awareness of their water consumption and their perception of society's awareness. A notable discrepancy emerged between individual and collective knowledge. Respondents generally viewed society as poorly informed about water use, with an average rating of 2.17 on a five-point Likert scale. Conversely, respondents believed their personal awareness was higher, averaging 3.28. However, individual knowledge levels varied significantly, as indicated by the wide data dispersion. These results clearly show that the goal of increasing awareness to better manage water consumption has not yet been achieved. After reviewing various proposals from literature, including those by Laboratorio REF Ricerche (2020) and Ochoa-García (2021), aimed at enhancing citizen knowledge and improving water management, these proposals were presented to the sample to gauge their preferences. The proposals included: making the water bill clearer and simpler, implementing digital consumption monitoring (e.g., via apps) for each household, increasing informational and educational campaigns, and receiving consumption reports at specific intervals (e.g., monthly, quarterly, semi-annually). The last proposal, receiving regular consumption reports, was the most favoured by the respondents. The analysis further examined whether there was a correlation between age group and preferred option. Preferences varied among subjects. Younger age groups (18-25 and 26-35) tended to favor more "technological" options, such as digital consumption monitoring for households, likely due to their familiarity with new technologies. In contrast, older age groups (56-65 and over 65) preferred traditional options like clearer billing and increased informational and educational campaigns. The research also explored the issue of water scarcity. After extensively covering it in the initial part of the study, respondents were asked about their awareness of the problem. The questionnaire results showed an average awareness score of 3.36 with a dispersion of 1.03. To gauge the importance of this issue to respondents, they were asked whether they agreed on the need to disseminate more information about water scarcity or considered it secondary to other issues. The results indicated a high level of agreement on the importance of spreading information about water scarcity, with a mean score of 4.16 and a standard deviation of 0.94.

High awareness of water issues and the importance attributed to them are linked to factors such as climate change, which, as noted by ISTAT (2019) and Tricarico et al. (2017), is increasingly affecting Italian cities. When asked about their experiences with phenomena like intense rainfall alternating with droughts, temperature increases, and fewer cold days, 53.2% (140 respondents) reported frequent encounters. Another reason for high awareness of water scarcity is initiatives like Agenda 2030, aimed at raising sensitivity to such issues. Respondents were asked if they had heard of Agenda 2030 and its 17 sustainable development goals. Results showed that 54% (142 respondents) were aware, 16.3% (43) had partial knowledge, and 29.7% (78) were unaware. These findings highlight the need for more actions to increase sustainability awareness. After introducing Agenda 2030, the perceived urgency of issues related to Goals 6 and 14 in Italy was analyzed. According to ISTAT (2019), Goal 6 aims to ensure sustainable water and sanitation management for all. As shown in Table 1, the most urgent factors identified by respondents are reducing pollution, stopping uncontrolled water discharge, and restoring water-related ecosystems. Slightly less urgent were increasing water use efficiency across all economic sectors (4.10), enhancing community involvement in managing water and sewage systems (4.02), and ensuring universal access to safe and affordable drinking water (3.97). Interestingly, the least urgent aspect perceived was ensuring universal access to drinking water, a target initially set for 2020. However, no country has adequately managed this issue, and in Italy, as noted by the ASviS report (2022), no policies have been implemented to address the delays in achieving this target.

Table 1. *Degree of urgency perceived by the subjects in reference to the targets of Goal 6.*

	Mean	St. Deviation (SD)
Guarantee universal access to drinking water, safe and affordable for all	3.97	1.16
Reduce pollution and completely stop uncontrolled discharge practices into waters	4.35	0.91
Increase water use efficiency in all sectors	4.10	0.97
Involve the community more in trying to better manage the water and sewerage network	4.02	1.08
Restore the state of ecosystems connected to water (e.g. mountains, forests, rivers and aquifers)	4.21	1.00

For Goal 14 (see Table 2), which focuses on preserving water sources crucial for planetary protection, respondents were asked about the perceived urgency of various issues in Italy. Results showed diverse opinions, but reducing marine pollution from land activities was seen as most urgent, with the highest average score (4.35) and the lowest standard deviation (0.93), indicating strong consensus. Other urgent issues included restoring marine ecosystems for healthy waters, eliminating subsidies that promote intensive or illegal fishing, and protecting at least 10% of coastal and marine areas. Slightly less urgent were regulating fishing to restore fish stocks (3.97), promoting scientific research and marine technology transfer (3.95), enforcing international law to improve marine conservation (3.94), and increasing economic benefits from sustainable marine resource use (3.92). The least urgent issue was ensuring market access and resources for small-scale fishers (3.61). This aligns with the latest ASviS report (2022), which highlights limited progress in Italy towards Goal 14, confirming the high urgency expressed by respondents.

Table 2. *Degree of urgency perceived by the subjects in reference to the targets of Goal 14.*

	Mean	St. Deviation (SD)
Reduce marine pollution from land-based activities	4.35	0.93
Regulate fishing to encourage the restoration of fish stocks	3.97	1.06
Protect at least 10% of coastal and marine areas	4.10	1.01
Eliminate and ban subsidies that favour intensive or illegal fishing	4.15	1.03
Guarantee the ability to restore marine ecosystems to have healthy waters	4.18	0.99
Ensure access to marine markets and resources for small-scale fishermen	3.61	1.24
Apply international law to improve the conservation of the seas and their resources	3.94	1.11
Increase the economic benefits deriving from the sustainable use of marine resources	3.92	1.06
Promote the development of scientific knowledge and research and transfer of marine technology	3.95	1.09

The final topic in this section addressed water rationing or supply suspension. Respondents were asked how often their usual place of residence experienced these measures. Results showed that 34.2% never experiencing water rationing or suspension, 30.8% rarely, 24.3% occasionally, and only 10.6% often (9.5%) or always (1.1%). The study also assessed the perceived quality of tap water at home, asking respondents to rate it on a scale from 1 (not at all) to 5 (very). The average rating was 2.89. These findings align with CeVI et al. (2019), indicating that water quality deterioration is not limited to less developed areas but is also an issue at the European and national levels.

Behavioural Tendencies Regarding Water Resources

The final section of the survey focused on individuals' attitudes towards water resources. The goal was to determine whether daily behaviours are sustainable or if water-related issues remain theoretical. First, respondents were asked if water conservation should be a daily consideration. An overwhelming 96.58% said "yes," while 2.28% were unsure, and 1.14% said "no". Next, respondents rated the sustainability of their water consumption on a scale from 1 to 5, with an average score of 3.32, indicating moderate self-assessed sustainability.

Breaking it down by age group, the most sustainable practices were reported by those aged 36-45 (mean 3.63), 55-65 (mean 3.38), and 46-55 (mean 3.35). Less responsible behaviours were noted among those aged 26-35 and over 65. The 18-25 age group aligned with the overall average at 3.31. This contrasts with the findings of Laboratorio REF Ricerche (2020), which suggested that younger individuals are more proactive in sustainable practices.

To analyze respondents' daily sustainable practices, a series of activities were proposed, highlighting actions that reduce water footprint, as emphasized by WWAP (2021) and Legambiente (2017). These activities focused on common domestic uses such as nutrition, personal hygiene, and household cleaning. Table 3 shows the results considering also differences among different age consumers. Regarding nutrition, respondents showed a low tendency to change dietary habits to reduce water impact, such as avoiding red meat, sugars, and processed foods. This was reflected in the lowest average score (2.65). However, using reusable bottles for water was more common, with an average score of 3.59, despite high data dispersion (1.30). According to CeVI et al. (2019), personal hygiene activities contribute significantly to domestic water consumption. The two key activities highlighted are turning off the tap while brushing teeth (4.19) and while soaping (3.78). Adjusting the water heater, although not among the least adopted practices, has a lower average score (3.02) compared to the others. In household cleaning and management, practices like using rainwater for watering plants and only running dishwashers and washing machines when full were assessed. Watering plants with rainwater scored low (2.91), and using basins for washing dishes and clothes by hand was the least common practice (2.89). Avoiding pre-rinsing dishes before using the dishwasher had an average score of 3.08, while using appliances only when full was a well-adopted habit (4.09). These findings highlight the need for increased awareness and adoption of sustainable water practices in daily life.

The goal of assessing generational sustainability led to dividing the sample into age groups and analyzing their propensity to adopt sustainable behaviors. Table 3 shows that, regarding dietary habits, only the 18-25 and 56-65 age groups scored above the general average of 2.65 in avoiding red meat, sugars, and processed foods. Younger respondents (18-25) were also the most likely to use reusable water bottles (3.72), while a declining trend was observed in other age groups, except those over 65 (3.25).

In personal hygiene, the most practiced behavior was turning off the tap while brushing teeth (4.19), with the 18-25 age group leading (4.31). The 26-35, 36-45, and 56-65 age groups also frequently adopted this practice. However, those aged 46-55 and over 65 scored lower. Turning off the tap while soaping was common among the 46-55 (3.80), 56-65 (4.13), and 26-35 (3.79) age groups. Adjusting the water heater before bathing was less practiced by the younger groups (18-25 and 26-35).

For household cleaning, sustainable practices like using rainwater for plants increased with age, with the 56-65 group scoring highest (3.38). Using appliances with full loads was common, especially among the 18-25 (4.19) and 56-65 (4.38) groups. Pre-rinsing dishes and using basins for washing dishes and clothes were less popular overall.

In summary, while the oldest age group (>65) was the least likely to adopt sustainable practices, the 56-65 and 18-25 age groups showed the most positive results (see Table 3).

Table 3. *Habits of virtuous use of water by age group*

Items/Ages	***18-25***		***26-35***		***36-45***		***46-55***		***56-65***		***>65***	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Avoid the consumption of red meat, sugars, and processed foods because their production involves greater water consumption	2.72	1.25	2.50	1.23	2.63	1.19	2.45	1.15	3.25	0.89	2.50	1.91
Store water in glass bottles or water bottles	3.72	1.23	3.56	1.39	3.25	1.04	3.10	1.29	3.00	1.51	3.25	1.71
Water the plants/garden with rain or reused water	2.97	1.44	2.74	1.45	2.50	1.31	3.10	1.41	3.38	1.69	3.00	1.41
Only run washing machines and dishwashers with full loads	4.19	1.08	3.96	1.11	3.75	1.16	3.80	1.15	4.38	0.52	4.00	0.82

Adjust the water heater/boiler before taking a bath	2.93	1.51	3.00	1.41	3.38	1.60	3.30	1.38	3.75	1.04	3.25	1.71
Turn off the tap when brushing your teeth	4.31	1.13	4.10	1.24	4.13	1.13	3.85	1.42	4.00	1.20	3.75	0.96
Turn off the tap when soaping	3.75	1.42	3.79	1.42	3.75	1.28	3.80	1.32	4.13	1.13	3.75	1.50
Don't wash dishes before putting them in the dishwasher	3.13	1.59	3.10	1.52	3.13	1.81	2.75	1.41	2.88	1.64	2.75	1.71
Use a basin of water when washing dishes or clothes by hand	2.79	1.55	3.00	1.56	3.25	1.75	2.80	1.44	3.25	1.39	3.25	1.71

In the previous section, key tools to promote water consumption awareness, such as clearer billing have been examined. Here, it has been a focus on individuals' personal efforts to promote water conservation. When asked, "How much do you try to raise awareness about water conservation among those close to you?" half of the respondents reported actively doing so, indicating room for improvement in personal proactivity.

Next, the use of water dispensers due to their numerous benefits, such as reducing water waste, plastic use, transportation pollution, and CO_2 emissions (CeVI et al., 2019) has been analyzed. Only 11.4% of respondents noted frequent presence of water dispensers in their usual places (e.g., gyms, offices, public spaces), while 24.7% saw them "often" and 27.8% "sometimes." Conversely, 16.7% rarely saw them, and 19.4% never did. This highlights the need for more dispensers in frequented places.

Regarding the willingness to use water from dispensers, the overall trend was positive, with an average score of 3.75. Age-wise, older groups (56-65 and over 65) were less inclined to use dispensers (averages of 2.63 and 2.50, respectively), while the 36-45 group showed a higher propensity.

When asked about the quality of dispenser water, respondents, especially those aged 36-45, agreed it has the same hygienic standards as bottled water. This is encouraging, considering that fear of poor water quality is a major reason for buying bottled water (The European House Ambrosetti, 2021). Younger respondents (18-25 and 26-35) were more skeptical, while the older group (46-55 and over 65) showed the highest trust in dispenser water quality. Opinions on the taste and odor of dispenser water were mixed, with an average score of 3.06, indicating uncertainty. This uncertainty was particularly notable among those aged 26-35 (2.81), 36-45 (2.63), and 56-65 (2.75). This aspect is significant as taste and odor greatly influence water choice (The European House Ambrosetti, 2021).

Conclusions

The study provides a comprehensive overview of water consumption awareness and behaviors among different age groups in Italy. The results indicate a general awareness of water scarcity and the importance of sustainable water practices, yet highlight significant discrepancies in individual versus collective knowledge. Younger respondents tend to favor technological solutions, while older groups prefer traditional methods. The study also underscores the need for more proactive measures and educational campaigns to enhance water conservation practices across all demographics.

Theoretical and Practical Implications

The results of this study have important theoretical and practical implications. Theoretically, the findings contribute to the literature on environmental awareness and behavioral economics by demonstrating the variance in sustainability practices across different age groups. This variance highlights how generational differences influence the adoption of sustainable behaviors, providing valuable insights into how age-related factors impact environmental practices. Additionally, the study offers insights into the effectiveness of various educational and informational strategies in promoting sustainable water consumption, suggesting that tailored approaches may be necessary to address the unique preferences and behaviors of different age groups.

Practically, the study suggests several actionable insights. The preference for digital monitoring among younger respondents implies that integrating technology into water conservation efforts could be particularly effective for this demographic. This could involve the development of apps and digital tools that provide real-time feedback on water usage, thereby encouraging more mindful consumption. Furthermore, the widespread agreement on the importance of disseminating information about water scarcity underscores the need for enhanced public awareness campaigns. These campaigns should focus on making water conservation information more accessible and engaging, thus fostering a culture of sustainability. Moreover, the study highlights the necessity of increasing the presence of water dispensers in public spaces. Doing so could significantly reduce plastic use and promote sustainable water practices, aligning with broader environmental goals.

Limitations and Future Research Directions

Despite its contributions, this study has several limitations that have to be taken into consideration. One major limitation is that, although the sample is geographically diverse, it may not be fully representative of the broader population. Similar considerations apply to the age distribution, which is not homogeneous. This potential lack of representativeness could limit the generalizability of the findings. Additionally, the reliance on self-reported data for assessing water usage and conservation behaviors introduces the possibility of bias, as respondents might overestimate their sustainable practices. Furthermore, the study primarily focuses on perceived knowledge and behaviors, which may not accurately reflect actual water consumption patterns.

To address these limitations, future research should aim to include a larger and more representative sample, thus enhancing the validity of the findings. Longitudinal studies would also be beneficial, providing deeper insights into how water conservation behaviors evolve over time and identifying long-term trends. Experimental research could further assess the impact of specific interventions, such as educational programs or technological tools, on actual water usage. Such studies would help in determining the most effective strategies for promoting sustainable practices. Additionally, investigating the barriers to adopting sustainable water practices, particularly among older age groups, could inform more targeted and effective strategies. Understanding these barriers would enable the development of interventions tailored to overcome specific challenges faced by different demographics.

In conclusion, by addressing these limitations and exploring new avenues of research, future studies can build on the findings of this study to further investigate water conservation behaviors. This, in turn, will aid in developing more effective strategies for promoting sustainability, ensuring that water resources are managed more efficiently and responsibly.

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Circular economy metrics in the agri-food sector: an applicative study in the olive oil industry

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Abstract

The circular economy (CE) has received attention as a model based on an efficient use of resources and less waste production. The olive oil industry detains relevant resources in terms of biomass but is also considerably polluting. The lack of a recognized set of metrics to assess CE limits its adoption, hampering the sector's path to sustainability. Thus, the present study evaluates the complementary use of Life Cycle Assessment (LCA) with a set of selected CE indicators (C-indicators) to support the monitoring of CE in the olive oil industry. To do so, it performs an empirical analysis applying LCA analysis and selected C-indicators to two hypothetical scenarios in the olive oil sector (i.e., composting and anaerobic digestion and combined heat and power generation). Results show lights and shadows of adopting both assessment metrics in a unique approach to support circularity assessment for the olive oil industry. Criticalities emerge, e.g., for the difficulty in identifying indicators able to compare CE scenarios, or for methodological LCA choices which severally impact assessment outcomes, making a complementary vision challenging. However, some limitations arise, e.g., due to the modelling choice of the hypothetical scenarios in LCA, while future studies may entail such challenges to design an assessment framework able to guide companies of the olive oil industry to CE assessment. This contribution is part of the research project "Towards circular and sustainable agri-food systems: metrics for assessment (CIRCULAGRIS)", CUP J53D23009360006 – code. 2022JNNJJX, founded by Ministero dell'Università e della Ricerca (MUR).

Keywords: Agri-food; Circular economy; Assessment metrics; Olive oil

Relevant Topic:

Introduction

The agri-food sector (AFS) has increasingly moved away from natural cycles with the advent of industrialisation. Today, the sector faces significant challenges due to the overexploitation of resources. This will be exacerbated by the expected population increase, which will reach 9.7 billion by 2050, according to the United Nations (United Nations, 2022). Within the sector, the olive oil industry plays a central role in the Mediterranean diet but is, at the same time, responsible for severe air and water emissions (Ncube et al., 2022). In this context, the Circular Economy (CE) model received attention as an alternative to the linear take-use-waste model that can redirect the sector towards sustainable development. However, CE does not always lead to lower sustainability impacts; for example, it can cause rebound effects (Poponi et al., 2022). Thus, it is crucial to measure the circularity of the scenarios implemented by the companies, monitoring their effectiveness and alignment with sustainability. Although ISO 59020, which provides an assessment system for CE, is now published (ISO, 2024), AFS needs specific attention. The sector is based on biological flows - according to the terminology of the so-called butterfly diagram designed by the Ellen McArthur Foundation - underlying biological flows is the concept of regeneration, i.e. the return of nutrients to the earth and building natural capital (EMAF, 2022). Therefore, food flows follow different logic from technical ones and need specific metrics to measure their circularity and sustainability. In recent years, several studies have collected metrics to measure circularity in the AFS (Poponi et al., 2022; Silvestri et al., 2022; Kounani et al., 2023); a relevant fragmentation level has emerged, which makes it difficult for practitioners and policymakers to navigate through many available metrics. This generates risks of burden shifting, where impacts are shifted upstream or downstream in the production process (Poponi et al., 2022) or cherry-picking by companies, which select indicators based on a higher valorisation of their current activities, without a real focus on CE (Roos Lindgreen et al., 2022). Furthermore, while C-indicators provide information regarding the level of circularity of a process or strategy, they are often punctual and risk losing the overall view and the sustainability trade-offs (Samani, 2023). At the same time, assessment methodologies such as LCA can define the environmental profile of a circular scenarios but without assessing its circularity in a strict sense (Roos Lindgreen et al., 2021; Niero and Kalbar 2019). In the face of these critical issues, several authors have proposed combined measurement approaches, i.e. consisting of measurement methodologies such as LCA or Material Flow Analysis and combining them with CE indicators for AFS (Rufi-Salis et al., 2021; Amicarelli et al., 2021).

The application of LCA with indicators has received particular attention, e.g., Niero and Kalbar (2019) associate LCA-based indicators with Material Circularity-based Indicators (MCI) in the beverage industry, and Gallo et al., (2023) associate LCA with modified MCI, which is modified to enhance biological flows and applied in different food supply chains, (Roos Lindgreen et al., 2021). In this context, several studies explore CE metrics used in agribusiness, but only one recent review focus on CE indicators in the olive oil industry (Kounani et al., 2023). Thus, the present study aims to evaluate and discuss the joint application of LCA with CE indicators to assess their contribution to measuring CE in the olive oil industry. To do so, the present preliminary study conducts an empirical analysis using data from enterprises in the Calabrian territory and from the ILCIDAF database (ILCIDAF Portal - Italian Life Cycle Inventory Database of Agrifoods, 2024) that combines the LCA method with circularity indicators identified in the literature and calibrated for the olive oil sector. The study is part of the project "Towards Circular and Sustainable Agri-food Systems: Metrics for Assessment" (CIRCULAGRIS) CUP J53D23009360006 - code 2022JNNJJX, financed by the Ministry of University and Research (MUR). The project aims to define circular and sustainable metrics for the Italian wine, olive oil and cereal (i.e. wheat and pasta) supply chain. This will allow decision-makers to be guided towards efficient and effective circular practices, in line with sustainable development goals.

Methods

To assess the potential of combining LCA and C-indicators to support the measurement of CE, this study proposes their application to an analysis context. The LCA method is a standardized tool able to measure the environmental impact related to the production of a product, process, or service along its life cycle (ISO 14040, 2020; ISO 14044, 2020)). The environmental profile and circularity related to two scenarios of treatment for olive oil supply chain's waste produced in two companies located in Calabria region (Italy), was assessed by the combined use of the LCA method and a selection of C-indicators. Data are sourced from existing scientific literature and databases. Specifically, most of the data were gathered from the Research Project of National Interest (PRIN 2017) ILCIDAF - N. 2017EC9WF2, sector ERC SH2, Linea C – funded by the Ministry of University and Research (MUR). The project aimed to create Life Cycle Inventory datasets of the Italian olive oil supply chain, analysing the agricultural and the olive mill phases.

The present preliminary analysis aims to assess the environmental profile related to two Scenarios (S) based on circularity principles: S-Composting and S-Anaerobic Digestion and Combined Heat & Power unit (AD-CHP). The present LCA analysis is conducted according to the ISO standards 14040 and 14044 (ISO 14040, 2020; ISO 14044, 2020). The study aims to compare the environmental burdens of different systems, evaluated on equivalent functions. The system boundaries of the analysis follow a cradle to grave approach, specifically including: i) agricultural cultivation, ii) olive oil production and iii) olive oil mill waste treatment. In analysing an entire supply chain (including waste treatment), it is crucial to identify a common factor in choosing the Functional Unit (FU) (Salomone and Ioppolo, 2012). Therefore, the chosen FU to compare the different scenarios is 1000 kg of olives. In addition, the system boundaries of the analysis include the avoided production of some energy and material sources. This implies that the scenarios based on circular principles allow for avoiding the production of conventional products and the related negative environmental impacts. One, operating in the agricultural phase, adopting an integrated cultivation technique. The other, operating in the olive mill phase, adopts a two-stage extraction model. Moreover, given the relevance of aerobic and anaerobic treatment processes in the olive oil sector, outlined by many studies on the topic (Bouhia et al., 2023; Galliou et al., 2018; Bovina et al., 2021), composting and AD-CHP treatment were assumed as hypothetical scenarios. Data referred to the hypothetical composting and AD-CHP treatment processes were extracted from the previous LCA study of Mondello et al. (2017). The main inputs and output data are presented per functional unit in Table 1.

Table 1. Main input and output data related to the functional unit of 1000 kg of olives.

		Scenario	
	Unit	**Composting**	**AD-CHP**
Input			
Transport	tkm	1.99E+01	19.10
Electricity	kwh	1.45E+02	8.90E+01
Diesel	l	5.00E-01	
Auxiliary materials	t		1.00E-01
Output			
Electricity	kWh		2.20E+02
Compost	kg	2.10E+02	
Biogas	Nm^3		8.50E+01

In the Composting scenario, olive mill waste is processed in a composting plant to produce compost which can be used in the agricultural phase as organic fertilizer. Data related to electricity and diesel emissions are considered. In the AD-CHP scenario, olive mill waste is sent to anaerobic digestion to produce biogas and compost. The biogas produced is then transformed into electricity by a combined heat and power generation plant. Data related to electricity and auxiliary materials emissions are considered. Moreover, all the scenarios depicted generate valuable nutrients and energy output, avoiding the production of similar conventional products. Specifically, the production and application of mineral fertiliser are avoided using compost and digestate as organic fertilisers. At the same time, the electricity produced because of the biogas produced in the AD-CHP scenarios avoids the production of electricity from conventional sources.

The SimaPro 8 software (PreConsultant, 2010) is used to conduct the analysis. The Environmental Footprint 3.0 method (European Commission, 2018) was adopted to carry out the Life Cycle Impact Assessment (LCIA) phase. The EF includes 16 impact categories: Climate Change; Ozone Depletion; Photochemical Ozone Formation; Ionizing Radiation; Particulate Matter; Human Toxicity Cancer; Acidification terrestrial and freshwater; Eutrophication Freshwater; Human Toxicity Non-Cancer; Eutrophication Marine; Eutrophication Terrestrial; Land Use; Ecotoxicity Freshwater; Water Use; Resource Use, Fossil; Resource Use, Mineral and Metals.

To evaluate the circularity of the system under analysis, some circularity indicators were selected. The most appropriate indicators were identified in the literature, among studies presenting micro-level circularity assessment adapted or adaptable to the agri-food context and specifically to the olive oil supply chain. In this sense, a recent study (Kounani et al. 2023), highlighted the current absence of a definitive set of indicators specific to the olive sector, making urgent the need to select studies targeting the AFS to assess its applicability to the olive oil supply chain. Considering the indicators identified in the literature and the specific characteristics of the analysed system, the following indicators were selected and modified to be adapted to the present study context, as shown in Table 2.

Table 2. Main characteristics of the indicators selected.

Indicators	Formula	Description	Reference
Nitrogen circularity indicator	kg N (delivered through recycling)/kg N (food waste at source)	Ratio between the amount of N produced after recycling in a process and the amount of N present in the waste stream (kg)	Poponi et al., (2022) Feiz et al., (2020)
Biogas recovery from waste efficiency	$I_{b,t} = {Q_b}/{m_t}$	Ratio between the amount of energy produced by waste per year amount of waste generated in the same year	Mancini and Raggi (2021)

Results and Discussion

The LCA analysis allowed us to identify the environmental profile of the two assumed circular scenarios. Furthermore, Table 3 shows how including or not including avoided products within the analysis enables a considerable reduction in the potential environmental impacts associated with the two scenarios. Specifically, more environmental credits are linked to the AD-CHP scenario. The AD-CHP system allows electricity produced from conventional sources to be replaced by electricity produced from the biogas produced at the plant, as well as the production of digestate to replace the use of generic mineral fertiliser. Specifically, the most relevant savings margins are seen in Ozone Depletion, and Resource use, fossils. Positive differential margins are also present, as in the case of Climate change and Acidification. The Composting scenario also shows a positive differential for Ozon depletions and Water use. However, the most relevant credit is recorded instead for Resource use, fossils.

Instead, indicators present in the literature and adapted to the study context are used to assess the level of circularity of the two scenarios. The hypothesised scenarios follow the principles of circularity, specifically through nutrient recycling given the production of organic fertiliser from olive mill waste and energy recovery from olive mill waste, which avoids the production of electricity from conventional sources.

For the assessment of nutrient recycling, the focus is on the nitrogen component, as the macronutrient of reference for crop growth, in line with Feiz et al., (2020). The indicator is calculated as the ratio between the nitrogen content in the solid digestate or compost and the nitrogen content of the olive mill waste considered. The calculations for the indicator are shown in Table 4.

Table 3. *Characterisation results related to the FU of 1000kg of olives, with and without avoided products (AvPr).*

		Scenario_AD-CHP			**Scenario_Composting**		
Impact category	**Unit**	**AvP**	**WAvP**	**%**	**AvP**	**WAvP**	**%**
Climate change	kg CO2 eq	6.80E+02	7.47E+02	8.96%	4.88E+02	4.93E+02	0.88%
Ozone depletion	kg CFC11 eq	7.36E-05	7.83E-05	6.11%	7.18E-05	7.27E-05	1.24%
Ionising radiation	kBq U-235 eq	1.24E+01	2.38E+01	48.05%	2.18E+01	2.19E+01	0.42%

Photochemical ozone formation	kg NMVOC eq	3.16E+00	3.30E+00	4.20%	2.48E+00	2.49E+00	0.33%
Particulate matter	disease inc.	4.18E-05	4.28E-05	2.30%	3.13E-05	3.14E-05	0.47%
Human toxicity, non-cancer	CTUh	2.82E-05	2.86E-05	1.63%	2.76E-05	2.77E-05	0.04%
Human toxicity, cancer	CTUh	2.22E-07	2.33E-07	4.53%	1.64E-07	1.64E-07	0.34%
Acidification	mol H+ eq	4.07E+00	4.42E+00	7.77%	2.93E+00	2.95E+00	0.62%
Eutrophication, freshwater	kg P eq	1.62E-01	1.68E-01	3.71%	1.64E-01	1.64E-01	0.02%
Eutrophication, marine	kg N eq	3.78E+00	3.83E+00	1.17%	2.89E+00	2.90E+00	0.09%
Eutrophication, terrestrial	mol N eq	1.94E+01	2.00E+01	2.76%	1.54E+01	1.55E+01	0.31%
Ecotoxicity, freshwater	CTUe	2.13E+06	2.13E+06	0.02%	2.13E+06	2.13E+06	0.00%
Land use	Pt	8.44E+05	8.44E+05	0.02%	8.44E+05	8.44E+05	0.00%
Water use	m3 depriv.	7.70E+02	8.09E+02	4.76%	6.84E+02	6.95E+02	1.59%
Resource use, fossils	MJ	1.04E+04	1.19E+04	12.45%	6.56E+03	6.67E+03	1.63%
Resource use, minerals and metals	kg Sb eq	1.00E-02	1.01E-02	0.07%	9.81E-03	9.82E-03	0.02%

Table 4. Calculations for the Nitrogen recycling indicator.

Nitrogen recycling potential			
	Amount	Unit	Reference
Olive mill waste	8.68E+02	kg	ILCIDAF
N % in olive pomace	8.70E-01	%	Leone et al., 2021
N content in mill waste	7.55E+00	kg	Calculated data
Scenario Composting			
Compost	1.82E-01	kg	Calculated data
Urea	9.00E+00	kg	Mondello et al., 2017
N content in compost	3.59E+00	kg	Calculated data
Nitrogen recycling potential	4.76E+01	%	
Scenario AD-CHP			
Solid digestate	1.91E-01	kg	Mondello et al., 2017
Urea	9.40E+00	kg	Mondello et al., 2017
N content in solid digestate	4.32E+00	kg	Calculated data
Nitrogen recycling potential	5.73E+01	%	

In the Composting scenario, 47.6% of the nitrogen produced by the composting process is 'recycled' from the mill waste, while in the AD-CHP scenario, 57.3% of the nitrogen generated via the AD-CHP plant is recirculated. Thus, comparing the two scenarios, the AD-CHP plant seems able to recirculate more nitrogen through solid digestate production than composting, entailing a better performance in terms of the circularity of nutrients.

Considering the energy recovery profile of the system under analysis, the Energy recovery from waste efficiency is considered (Table 5). The indicator enables the assessment of the efficiency of the treatment system by evaluating how much waste is used to produce a given amount of generic energy. The indicator is adapted from the study of Poponi et al (2022) and Mancini and Raggi (2021), where the latter was originally focused on biogas efficiency.

Table 5. Calculations for the Energy recovery from waste efficiency indicator.

Energy recovery from waste efficiency			
S-Composting			
	Amount	Unit	Reference
Biogas produced	0	Nm^3	
Waste produced	8.68E+02	kg	ILCIDAF, 2024
Energy recovery from waste efficiency	NA	kWh/kg	
S-AD-CHP			
Biogas produced	7.38+02	Nm^3	
Waste produced	8,68E+02	kg	ILCIDAF, 2024
Energy recovery from waste efficiency	8.5-02	Nm^3/kg	

In this case, the AD-CHP scenario produces 8.5-02Nm^3/kg per every kilogram of waste that the olive mill system produces, while Composting scenario does not entail energy recovery. Thus, the AD-CHP scenario presents a better circular performance in energy recovery efficiency.

The LCA analysis made it possible to assess the environmental profile of the circular scenarios of the system under consideration. The study considered the positive contribution of avoided products such as electricity produced from conventional sources and mineral fertiliser production. The AD-CHP scenario was the least impactful in almost all the impact categories analysed, due to the production of electricity and digestate because of the anaerobic digestion activity and the combined heat and power plant activity. In terms of circularity, the two selected indicators (aimed at assessing nutrient recycling and energy recovery efficiency through the various waste treatment systems proposed) gave answers in line with what emerged from the LCA analysis. So, in this case, sustainability seems to be moving in the same direction as circularity. This is far from obvious since one does not necessarily imply the other (Rigamonti and Mancini, 2021). Combining LCA with the CE assessment allow to highlight potential environmental impacts for implementing circular scenarios, which is crucial, since CE application may generate trade-offs which may affect the selection of appropriate scenarios of intervention (Shevchenko et al., 2024). At the same time, LCA alone may not provide information on the circularity of a process but only monitor the potential environmental impacts of implementing a circular practice (Peña et al., 2021). Moreover, LCA deals with multifunctionality, namely allocating the environmental impacts to different products which belong to the same process, which is particularly relevant in the AFS context given its complexity. There are several strategies to mitigate this aspect, such as system expansion, substitution or allocation. In this case a substitution approach was chosen, evaluating the environmental credits due to the avoided production and use of conventional product. This may additionally challenge the comparison with C-indicators, since substitution evaluations consider a life cycle perspective, while indicators usually do assess single aspects of a product (Møller et al., 2023).

On the other hand, several CE indicators are present in the literature for the AFS, however, not all of them conform to the specificities of the olive oil industry. In this regard, some indicators proposed in the literature for the AFS were tested here to measure CE in the olive oil industry. Several points of reflection emerge; first, the punctuality of the indicators proposed in the literature, makes it possible to focus on specific aspects, making it necessary to consider several indicators even concerning the same strategy. Further complexity derives from the general lack of benchmarks, which makes it difficult for practitioners to orient themselves in the evaluation of their work unless a comparative analysis is made. Furthermore, it is challenging to find indicators suited to compare scenarios which have similar goals, such as composting and AD-CHP, which are both waste treatment scenarios and among the most frequent in the olive oil industry. According to this preliminary analysis, C-indicators seem often focused on assessing the final output of CE processes, thus it would be relevant to identify "upstream" indicators able to compare systems with similar goal but different outputs.

LCA analysis and C-indicators show different but complementary information. A concrete example is the Nitrogen recycling potential, which makes enrich the information provided by impact categories such as Terrestrial eutrophication by giving insights into the circularity profile of the analysed system in terms of nitrogen (Møller et al., 2023). However, in the evaluation it is necessary to remember that the two metrics use different analysis perspectives to avoid under-optimising the system; the LCA potentially focuses on the entire life cycle of a product or process, while the indicators focus on specific aspects of it (Møller et al., 2023). In conclusion, the complementarity of LCA and CE indicators makes them a potential tool for measuring and monitoring CE for the olive sector, but cautions is needed in their use. Indeed, as evidenced by Kounani et al (2023), it is challenging to define a best set of C-indicators for the olive oil sector due to its complexity. To guide practitioners towards CE measurement in the olive oil context, it is first necessary to define ex-ante the specific objective of the analysis and modelling the overall assessment accordingly. Moreover, C-indicators should be selected not only focusing on the final outcomes of a circular scenario but also along different life cycle stages of the product to foster comparison mechanisms. These suggestions should be considered when designing a future framework for guiding companies in selecting appropriate CE metrics.

Conclusions

This preliminary study aims to evaluate the complementary use of the LCA method with unconstrained C-indicators and to test its applicability to the olive oil industry through an empirical analysis. Specifically, the study designed two circular scenarios, i.e., composting and AD-CHP. The LCA was used to assess the potential environmental burden associated with the two proposed scenarios, while C-indicators measured their level of circularity. The analysis confirmed a better environmental and circularity performance for the AD-CHP scenario, which envisages the production of electricity to replace electricity produced from conventional sources and digestate, used as a substitute for mineral fertiliser. To benchmark the two scenarios against the CE, Nitrogen recycling content and Energy recovery from waste were selected as indicators. The analysis showed that LCA and selected C-indicators can be used in separate but complementary ways. However, it is necessary to consider the different system boundaries, with the LCA evaluating the entire product life cycle while the indicators focus on specific aspects.

The critical issues that emerged during the analysis suggest the impossibility of defining a standardised set of metrics for the olive oil industry but also the need to guide the companies firstly by identifying the objective of the analysis and only then to the modelling of the LCA and the selection of the indicators, to avoid cases of cherry picking, greenwashing or simple overlapping of information, generating bias in the analysis. Several assumptions were made in the modelling phase, which could have impacted the result of the study, such as the decision to focus only on the nitrogen recycling rate, (neglecting the presence of potassium and phosphorous, which are also macronutrients present in organic fertilisers such as digestate) or the few C-indicators identified in the analysis to compare the two scenarios. However, the study aimed to address the methodological challenges in measuring CE in the olive oil industry. Future studies could explore the presence of C-indicators able to compare CE strategies at different level than output or define a framework for the olive oil context that could guide companies towards measurement based on their measurement and reporting objectives.

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Circular Economy Indicators in Agrifood: A Continuously Evolving Scenario

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Keywords: Agri-food, Indicators, Circular Economy, Sustainability, Model

Relevant Topic: Sustainability in Agri-Food

Introduction

Indicators are essential tools for evaluating and monitoring the effectiveness of policies and practices related to the Circular Economy (CE) in the agri-food sector. They provide a clear and measurable picture of environmental, social, and economic performance, allowing for interventions to improve organizational performance and assess the impact of policies in specific areas for improvement.

Despite the growing interest in the circular economy within the agri-food sector, the literature still highlights a lack of specific indicators capable of comprehensively and accurately assessing the circularity of companies and productions (Poponi et al., 2022). Recently, there has been an increase in studies aimed at defining measurement systems and metrics to evaluate circularity, articulated into three main areas: scientific literature, certification standards, and grey literature.

The scientific literature has significantly contributed to defining models and measurement tools to support the transition to CE (Elia et al. 2017, Saidani et al., 2019) , assisting policymakers in developing strategies and identifying critical issues and strengths for investments (Cristóbal et al., 2018, Peña et al., 2021, Tadesse et al., 2019). However, the variety of methodologies and perspectives used makes it difficult to systematically integrate the tools (Di Maio et al., 2017; Franklin-Johnson et al., 2016). Among the prevalent methodologies, life cycle thinking (Corona et al., 2019; Pauliuk, 2018) and particularly Life Cycle Assessment (LCA) (Gallo et al. 2023, Ghisellini et al. 2023) are frequently applied.

Some studies focus on single aspects, not fully reflecting the environmental and circular benefits generated (Haupt & Hellweg, 2019; Helander et al., 2019). However, integrating different indicators helps overcome these limitations, though there remains a need for adequate and easy-to-apply measurement tools (Pena et al. 2021, Rigamonti & Mancini, 2021).

New models are emerging from recent literature. Kumar et al. (2022) proposed a framework to monitor the agri-food supply chain with 16 key performance indicators (KPIs). Other authors have examined the most commonly used tools to measure circularity in the agri-food sector, highlighting strengths and weaknesses (Fassio & Chiarelli, 2023) (Rodino et al., 2023).

In parallel, certification standards for CE have been developed. BS 8001:2017, the first standard published in this area, provides guidelines for adopting circular practices, although it does not include specific measurement indicators. In France, the XP X30-901 standard (2018) proposes a project management system to improve environmental, economic, and social performance using a circular approach.

In Italy, the UNI/TS 11820:2022 standard was developed to measure and assess circularity performance, including 71 indicators divided into seven reference categories necessary to verify the effectiveness of company strategies.

At the European level, the new Common Agricultural Policy (CAP) of 2023 integrates circularity and sustainability into agricultural production with specific indicators for achieving climate-environmental and circular bioeconomy objectives monitored by Eurostat (2022). The latest published standard is ISO 59020 Circular economy - Measuring and assessing circularity performance, which "specifies requirements and provides guidance to organizations for measuring and assessing a defined economic system to determine their circularity performance at a specific time."

Given the diversity of approaches to developing indicators and the lack of effective integration, there is a significant gap in the shared methodology for collecting and analyzing these tools. In response to these challenges, the study by (Poponi et al., 2022) contributed to systematizing CE indicators in a dashboard, allowing for a more comprehensive analysis.

This study aims to update the systematization of indicators considering the changes in the literature and the new research needs emerging in the agri-food sector.

Materials and Methods

Building on the previous study (Poponi et al., 2022), a systematic literature review was undertaken to update and refine the understanding of the indicators used in the agri-food sector to measure circularity. The research focused on analyzing the Scopus database, known for its wide coverage of high-quality scientific articles. The investigation was conducted on articles published up to February 2024 with a query specifically constructed to identify relevant research that integrated the terms "circular economy," "agri-food," and "indicator."

From the initial results, which included 30 articles, 17 were excluded as they belonged to the literature review category. Although these articles provided a useful overview of the field, they did not fully meet the study's objective of extracting and directly analyzing the indicators applied in concrete contexts in the agri-food sector. Therefore, the analysis focused on the remaining 13 articles, which were analyzed in detail through a complete reading of the texts.

From the analysis of the 13 articles, a total of 123 indicators were extracted. These indicators were subsequently subjected to a harmonization process to avoid redundancies and ensure consistency in their application. This process reduced the number of indicators to 89, which were classified according to the model proposed by (Poponi et al., 2022). This model provides for a division into eight main areas (scope), including air, water, soil, energy, waste, value and cost productivity, equality, and innovation, organized into three spatial dimensions (macro, meso, micro) and three sustainability areas (economic, social, environmental).

An additional classification was introduced to distinguish the indicators based on their applicability at the product or organization level (Poponi et al., 2023), a crucial analysis for understanding the differences in the practical application of circularity across different operational scales and business contexts. This approach provided a systematic and multidimensional view of the use of indicators in the agri-food sector, offering a detailed framework that facilitates the comparison and integration of existing tools.

The analysis revealed that indicators are present in all identified areas, except for the "Knowledge and Innovation" scope, which showed a lack of specific tools. This result suggests the need for further research to develop and integrate indicators that can effectively measure innovation and knowledge management in the context of circularity in the agri-food sector.

Results

The following describes the main indicators used to monitor environmental and economic sustainability in the agricultural and agri-food sectors. The indicators, divided into various areas (Air, Water, Soil, Energy, Waste, Cost, Value and Productivity, Equality), measure efficiency, environmental impact, and equity in agricultural practices with applications at different operational levels.

Air Scope includes three indicators related to emissions from the food industries and ammonia (NH_3) in agricultural and livestock activities. The "Total Air Pollutant Emission (TAPE)" indicator measures the eco-efficiency of production processes by comparing output with the emissions generated. The other two indicators specifically monitor NH3 emissions, one of the main causes of PM 2.5 pollution in Europe, responsible for serious respiratory diseases. These indicators, applicable at both the macro and micro levels, focus on environmental sustainability. The indicator "Subsidized farms to reduce their NH3 footprint" is cross-linked to the "Cost, Value, and Productivity" scope. (Wyer et al. 2022).

Water Scope includes two indicators: one measures the corporate water footprint using a life cycle-based approach (LC-based), while the other focuses on efficiency in water resource management through incentives (Davis et al. 2017, Rosa et al., 2020). Both indicators, applicable at both macro and micro levels, monitor environmental sustainability. The indicator "Agricultural area subsidized to improve their water efficiency" is cross-linked to the "Cost, Value, and Productivity" scope.

Soil Scope includes fourteen indicators that monitor nutrient efficiency, biodiversity, and soil quality (Perez-Mercado et al. 2022, Castillo-Diaz et al 2023, Vingerhoets et al. 2023). Indicators such as "Circularity" and "Nutrient use efficiency" measure the reintegration of nutrients into the soil and the efficiency of agricultural supply. Other indicators evaluate crop diversification and agricultural area management. Four of these indicators are applicable at both macro and micro levels, while the others are only applicable at the macro level. Three indicators also monitor the economic aspect and are cross-linked to the "Cost, Value, and Productivity" scope.

Energy Scope includes two indicators: one monitors the calorific potential of biomass, and the other the fuel price used in agricultural practices (Poponi et al. 2023, Castillo-Diaz et al. 2023). One indicator is cross-linked and applicable at both the product and organization levels, while the other is limited to the macro dimension. Both monitor environmental sustainability, with one also having an economic application. The indicators are cross-linked to the "Waste" and "Cost, Value, and Productivity" scopes.

Waste Scope includes eight indicators focused on agricultural waste management, particularly on recycling packaging and efficiency in nutrient reuse (Amicarelli et al. 2021, Castillo-Diaz et al. 2023, Vingerhoets et al. 2023). Indicators such as "Material Use Efficiency (MUE)" and "Material Circularity Indicator (MCI)" promote sustainability by reducing the consumption of virgin raw materials. Most of the indicators are applicable at the macro level, with three also at the micro level, and one cross-linked. All monitor environmental sustainability.

Cost, Value, and Productivity Scope includes thirty-four indicators that evaluate resource costs, energy efficiency, and resource productivity (Amicarelli et al. 2021, Sillero 2023, Castillo-Diaz et al. 2023). Indicators such as "Direct Material Input (DMI)" and "Resource Productivity (RP)" measure the efficiency of the agri-food sector. The indicators apply at both macro and micro levels and monitor both environmental and economic sustainability. Five indicators are cross-linked to the "Energy," "Soil," and "Water" scopes.

Equality Scope includes twenty-six indicators that monitor inclusivity and equity in the sector, focusing on funding for small farmers and young entrepreneurs. Other indicators evaluate employment and poverty in rural areas. Twenty indicators are applicable at the macro level, five at both the macro and micro levels, and one at the meso and micro levels. Nineteen indicators are cross-linked to the "Cost, Value, and Productivity" scope.

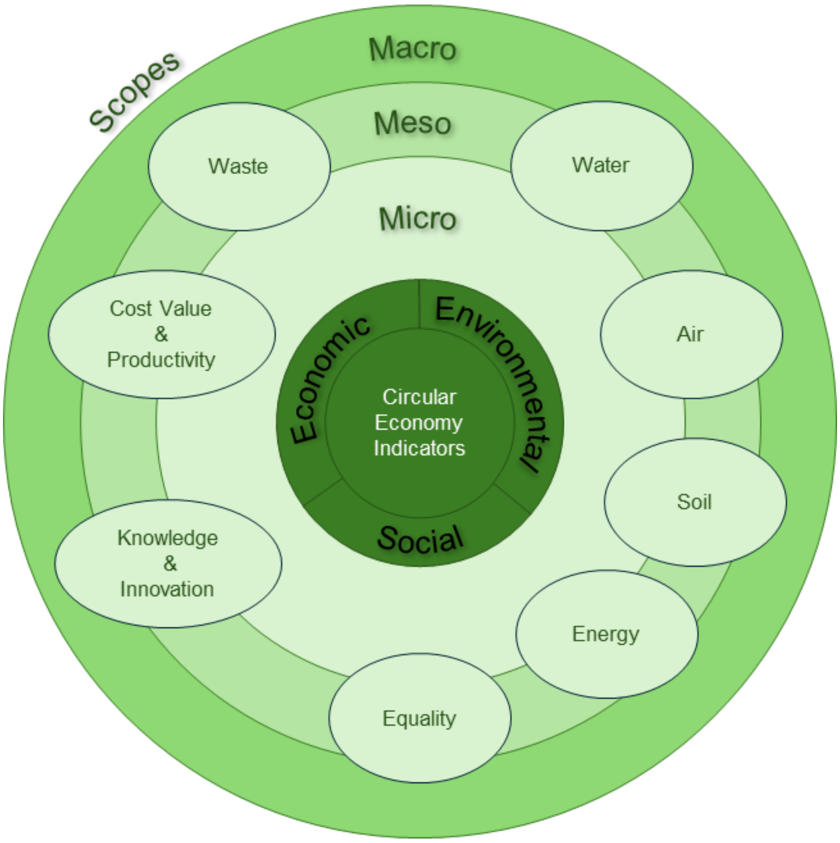

Fig. 1 – Indicator Model

The figure shows the structure of the indicators distributed across the eight main areas (Air, Water, Soil, Energy, Waste, Cost, Value and Productivity, Equality, Knowledge, and Innovation), each linked to three spatial dimensions (macro, meso, micro) and three sustainability areas (economic, social, environmental).

This multidimensional approach allows us to visualize how the indicators are distributed and interact across different levels and areas, offering a comprehensive representation of circularity in the agri-food sector, highlighting the interaction between various factors.

Conclusions

The results of this study highlight the importance of defining a framework of circular indicators aimed at gaining an in-depth understanding of the dynamics in the agri-food sector. These indicators allow for monitoring the trends of the main economic, environmental, and social variables, also providing a solid basis for evaluating public policies and business strategies in the agri-food context.

In particular, the application of these indicators has made it possible to identify critical intervention areas and opportunities for improvement. The ability of these tools to promptly detect changes in the economic and environmental context makes the indicators an indispensable support for strategic management in the sector. Moreover, the multidimensionality (cross-sectional and cross-linked) of the employed indicators contributes to a holistic vision that integrates economic, social, and environmental aspects, thereby promoting a more sustainable approach.

From the results obtained in the analysis of the various "Scopes," we can derive a multiple understanding of the conditions and dynamics of the agri-food sector, emphasizing the need for an integrated approach to managing and improving the circular economy. Each "Scope" provides an essential contribution to describing the application of indicators in specific contexts.

Finally, the results show how circular economy indicators in the agri-food sector have recently developed, especially in economic and social areas. This aspect also stems from policy directions, particularly the Common Agricultural Policy (CAP). Indeed, there has been a considerable presence of indicators used in the CAP for sustainability and circular economy in recent times. This indicates a strengthening of the EU agricultural management policies increasingly oriented towards greater integration of sustainability and circular economy principles.

Implications

From a research perspective, this study contributes to the existing literature by demonstrating the effectiveness of using an integrated set of indicators to evaluate the circularity of the agri-food sector. This study opens new areas of analysis for exploring more complex and integrated evaluation models, encouraging further empirical studies to test and refine the proposed indicators. The possibility of extending this methodology to other sectors or adapting it to specific local needs could also stimulate greater interdisciplinarity in research, involving experts from various fields and promoting a more holistic and sustainable vision of sectoral development.

The practical implications of this study have an impact both for policymakers and sector operators. Integrating these indicators into monitoring and evaluation practices can improve the ability to respond to sector challenges, facilitating strategic planning and the formulation of more targeted policies. In particular, the systematic vision of these indicators could positively influence agri-food policies at the national and international levels, promoting greater coherence and coordination among the actors involved in the sector.

For companies, adopting these indicators can optimize management decisions, improve operational efficiency, and promote sustainable practices. In future research steps, the indicators should be classified according to circular economy principles to have a more user-friendly tool.

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Track 5: Sustainability

A Sustainability Opportunity Study: the case of Swedish Building

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Abstract

The building value chain from cradle to grave is a complex system where it could be difficult to agree on how quality and sustainability should be understood, defined, and measured. Based on results from earlier studies sustainable building could be defined as at least affordable and carbon neutral. However, this does not seem to be the common understanding. Both international and national strategies focus on working with the carbon footprint with little or no focus on the value created and on costs incurred. This indicates a limited understanding of building sustainability. The industry solution for solving the carbon emission problem is to use Carbon Capture and Storage (CCS). However, CCS is an expensive end of the pipe solution and seems to assume that current cement and concrete production already are at best performance levels. The purpose of this paper is to further develop the Sustainability Opportunity Study to a sensemaking roadmap. The method is to apply the proposed SOS on Swedish building sustainability and further on concrete and cement sustainability. Publicly available documents and data are analysed in terms of understanding, defining, and measuring building sustainability. Results indicate a common lack of understanding building sustainability in Sweden. Building sustainability is largely interpreted as the carbon footprint. The indicated improvement potential is at least 30% of carbon savings. The proposed building sustainability roadmap, which uses basic quality principles, seems to provide a way of sensemaking.

Keywords: Cement, Concrete, Sustainability, Sustainable Development, Sustainability Opportunity Study.

Relevant Topic: Integration between quality and sustainability

Introduction

The Quality Movement seems to have had its peak towards mid 1990s beginning of 2000. Total Quality Management (TQM), which these days frequently is called Quality Management (QM) is still practised in some of the Swedish universities. The change from TQM to QM has been organic and there is no commonly agreed understanding of what the difference is, if there is any. Sweden as a country is struggling with multiple quality problems with examples being such as public transport and trains performing poorly and with health care and schools having serious performance problems without any apparent solution in sight. When discussing solutions, it seems that QM does not seem to have any significant role to play.

The Quality Wave is today the Sustainability Wave and there have been many efforts to link quality and sustainability, without this leading to any apparent common understanding. Still, when going back to basic principles and seeing systemic quality as the process that produces the right thing in the right way over time there are two clear roles in Quality four Sustainability (Q4R) which are sensemaking of the right thing and providing the programs, principles, practices, and tools for doing the thing right. QM seems mostly to have worked with doing the thing right and less with identifying the right thing. QM has a 100-year history of process-based improvement and could support sustainability, provided there is an understanding of the What, the output to improve. This is where the problem lies. We do not seem to have a common understanding of what sustainability is, neither on the global level nor on a subsystem level. Sustainable development and sustainability are mostly presented as a list of problems. There is little theory coming from the sustainability field that supports change management. The commonly cited Brundtland Commission Definition of Sustainable Development - *sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs* - needs substantial work before it can be understood, defined, and measured in any context. Essentially it points out People now and in the future as the main stakeholders. For future generations to be able to satisfy their needs we also need focus on Planet. This makes Profit to an enabler which means that the frequently used Triple Bottom Line for People, Planet and Profit could be a problem and that the Eco Efficiency of value per harm could be a better model (Isaksson et al. 2015). In any system the challenge is to identify the vital few sustainability impacts with focus on People and Planet needs. Profit is needed and the license to operate goes to the company that provides the most stakeholder needs value for the lowest stakeholder harm (Isaksson, 2021).

Globally, the building value chain, from raw material extraction and the actual construction phase to building use and eventually reuse or disposal, accounts for about 40% of manmade CO_2 emissions. This makes climate impact (Planet) to a vital few issue which needs to be included in a sustainability definition. The global cement and concrete industry have embraced this, and carbon reduction is in focus. Carbon Capture and Storage (CCS) is proposed as the main strategy. CCS is very costly and could more than double cement prices. The main strategies do not include influence on price. Another thing missing is the user value of buildings, concrete, and cement. Essentially focus is only on the carbon footprint (Planet). Globally, about 50% of building is residential building. With shelter being a human right, we could see affordability as a vital few issue. This leads to the definition of sustainable building being at least affordable and carbon neutral (Isaksson et al. 2023). Eco Efficiency of value per harm for buildings becomes harm per value for practical reasons. When procuring apartments in Sweden we refer to the cost per m^2 which we can be seen as the affordability indicator. The climate indicator in harm per value terms could be, kg CO_2/m2. The building value could be further broken down into concrete and cement value. Cement is the glue in concrete. The main purpose of cement is to bind together sand and aggregates with the help of water. The stronger the cement is the more concrete of the same strength can be produced by a competent concrete producer. This means that we could see sustainable cement and concrete as satisfying building needs to the lowest prices and to the lowest carbon footprint. This is very close to the value-based quality approach - the value we get for the price (Garvin, 1984). Price could be seen as People harm and the carbon footprint as Planet harm.

QM and its programs, practices and tools seem to be dedicated for simple and complicated problems and maybe not for complex ones. Rosvall (2024) proposes the matrix Space of Challenges (SOC) as a way of understanding different types of change situations. The proposed three by three matrix describes the difficulty of the change in terms of simple, complicated, and complex and problems, issues and dilemmas. An interpretation of this is that Quality Management might only be relevant for simple and complicated problems, where there is an agreement of what the output is. In In a complex problem the output is unknown. An example of this is that we do not seem to be agreeing on what building sustainability is and therefore cannot measure the output. This most probably is a generic problem as indicated in Isaksson et al. (2023) that describe the Sustainability Opportunity Study. We can do an Opportunity Study when have an agreed process output with goals. The three steps of doing an Opportunity Study are: Diagnosing, Analysing and Solving (Isaksson, 2015). The common sense logic starts with Diagnosing the improvement potential as the difference between target and current performance. Analysing studies, the different causes using mainly qualitative methods. The identified causes are then analysed and in Solving converted into proposed solutions. A sufficient improvement potential with causes that can be understood and viable solutions is an Opportunity which can be presented to the management that decides if an improvement project will be started or not. The Opportunity Study can be done by researchers, consultants or students provided the access to sufficient data.

When there is no agreed output indicator, as seemingly there is not for sustainable building, sustainable concrete and sustainable cement, we need to do a Sustainability Opportunity Study (SOS). The SOS starts with Understanding, Defining and Measuring the step of Diagnosing. For Swedish building there is a proposal for an SOS with focus on harm per value indicators as described above with sustainable building being measured in terms of price and carbon footprint per m^2 living space (Isaksson et al. 2023). The main gaps in the work are that it is not clear how building, concrete and cement sustainability are currently measured in Sweden and consequently how the performance is. The proposed SOS does not provide the order of things to be done - the roadmap. Further there is limited theoretical help for Understanding Analysing and for Understanding Solving. The Space of Challenges (SOC) theory could possibly be used in strengthening the parts of the SOS logic.

The purpose of this paper is to present a complete and revised SOS for Swedish building sustainability and a roadmap with focus on the part of materials and notable cement and concrete. The overall purpose is to demonstrate that Quality Management can become Sustainable Development by going from customer focus to stakeholder needs focus. The research questions are:

RQ1: How is current building, concrete and cement sustainability being understood, defined, and measured in Sweden?

RQ2: How could the SOS be improved to support sensemaking of building, concrete, and cement sustainability?

RQ3: How could the use of SOS and the practices and tools included be converted into a roadmap?

Methods

The RQ1 is answered by searching for definitions on sustainable building internationally and for Sweden using Google and Google Scholar and by reviewing global and national strategies for building, concrete, and cement. The data collected is analysed using the value per harm logic including the review of relevant targets. The RQ2 is answered by reviewing previous version of the SOS and adding details into the different parts particularly using the SOC theory in the building value chain context. The RQ3 is based on reviewing the logical sequence from detecting a potential problem or opportunity and then converting it to a proposed opportunity for improvement that could be presented to the management of the studied system.

Results and Discussion

Building Sustainability internationally and in Sweden does not seem to have been defined. Previous work by Isaksson and Rosvall (2020) studying sustainability reports in the Swedish building value chain indicated that there were only a few definitions and that those mostly focused on the carbon footprint. A study of how leading building companies had defined sustainability resulted in similar results with focus on the carbon footprint only but without any clear definitions of what sustainable building could be (Isaksson et al. 2022). A quick search for definitions of sustainable housing does not provide any conclusive answers. A leading Swedish building company, Skanska, defined sustainable housing as: *The climate transition is one of the most important challenges facing our society. To meet the UN's global sustainability goals, changes in behaviour are required. Not least when it comes to how we live, considering that the home accounts for a fifth of a household's climate footprint*. The definition is of limited help with focus on climate only. The Swedish housing company Svea Fastigheter that provides apartments provides examples of how it measures building sustainability: *The number of initiatives to strengthen the local community in socio-economically weak areas; Number of properties that offer homes that complement existing housing stock with more ways of living; Number of* *neighbourhood joint activities.* This is not a clear definition, but list of activities at different levels. The observation is that main impacts of climate and affordability seem to have been identified, but separately by actors in different parts of the building value chain and not jointly. It has not been possible with a simple search to find the proposed indicators of kg CO_2 per m^2. There seems to be some limited information on the purchase price of apartments per m^2. This is however not explicitly the cost of a m^2/year, which would be needed as a comparison with the salary level to assess affordability. The indicative conclusion is that building sustainability has not been understood, defined, and measured in a coherent and relevant way to describe the level of sustainability. This means that the What of building sustainability is unclear which indicates that improvement might not be efficient since there is not an agreed direction. Lack of appropriate measurements could be seen as a barrier to sustainable building development.

Sustainability in Swedish cement and concrete is interpreted based on both international and Swedish work. Sustainable Building has been only reviewed briefly by search for any recent definitions for Sweden and internationally The European Cement Association - CEMBUREAU (https://www.cembureau.eu/) is the representative organisation of the cement industry in Europe and has a leading role in guiding cement sustainability. The Global Cement and Concrete Association (https://gccassociation.org/) represents 80% of the world's concrete industry outside of China. These organisations provide also input of how Sweden views cement and concrete sustainability. In Sweden, Cementa, belonging to Heidelberg Materials, is the only Swedish cement producer. Heidelberg is a leading global company and well connected with CEMBUREAU and the Global Cement and Concrete Association. The CemZero is a previous Cementa initiative for reaching carbon neutrality. The Swedish research institute Mistra has produced a Roadmap for Cement Industry Carbon Exit (Mistra 2020, Karlsson et al. 2021). In Table 1 there is a review of leading organisations for cement and concrete and their interpretation of how to work with cement sustainability or as it is expressed - work on cement carbon neutrality. The conclusions based on the brief analysis are that there is a limited understanding of cement and concrete sustainability as a footprint only. The value is only being mentioned in terms of tonnes. A tonne of cement could have varied strength depending on standards. The EN 197 standard specifies the strength classes 32.5, 42.5 and 52.5 with the figures indicating the minimum compressive strength in MPascals (MPa) at 28 days. Apart from this the cement industry could make specific agreements of producing stronger cements of up to at least 70 MPa using Ordinary Portland Cement clinker. This means that building value for a tonne of cement could vary with a factor two. This affects the strategies chosen. A focus on user value would highlight the importance of improving cement performance. This is not a strategy mentioned whereas improving concrete performance is included.

***Table 1**. Document analysis of leading organisations with focus on how cement and concrete sustainability is dealt with. CCS stands for Carbon Capture and Storage.*

Document	CCS	Alternative fuels	Alternative Materials	Reducing clinker coefficient	Improving cement	Supplementary cementitious	New cements	Improving concrete performance	KPI used

					performance	materials		(design and use)	
Cembureau	x	x	x	x		(x) implicit		x	Kg CO_2/tonne cement
Global Cement and Concrete Association	x	x	x	x		x	x	x	Total CO_2 emissions
Mistra Road Map Cement Carbon Exit	x	x		x		x (fly ash and slag)		x	Tonne CO_2/tonne clinker
CemZero Cementa Heidelberg Materials	x	x				x			Tonne CO_2/tonne clinker

Mistra (2020) suggests that there could be over consumption of cement in Sweden at the level of 30% or more. The Mistra reference is based on figures from a European report and comes with the comment that cement use in concrete measured as kg/m^3 might be higher due to focus on rapid building practices which require more cement. Cement, which is a cheap raw material, is used for speeding up the drying of concrete. Based on the review there does not seem to be relevant measurements for cement and concrete sustainability using the value per harm concept. With focus on value per harm, focusing on better cement performance and better cement performance in concrete it could be possible to produce the same user value with possibly more than a 30% reduction of the current carbon footprint. Reducing the carbon footprint could then reduce the investment of CCS and reduce the running costs of it. Lack of relevant measurements could severely hamper sustainable cement and concrete development.

The Sustainability Opportunity Study (SOS) matrix in Table 2 is adapted from Isaksson et al. (2023). If there is an output - a y-value then we can do a simple Opportunity Study (Isaksson, 2015). But, when the situation is complex, like with Swedish Building we need to start with understanding the system to define sustainability and sustainable development as a prerequisite for measuring output.

Table 2. *The Sustainable Opportunity Study (SOS) with relations to a roadmap starting in measuring and with links to the Space of Challenges (SOC) (Rosvall, 2024) and the Process Based System Model (PBSM) (Isaksson, 2019) which can be used for sensemaking. Adapted from Isaksson et al. (2023)*

	Understanding	Defining	Measuring
Diagnosing	Which are the vital few sustainability impacts in	Defining sustainability as a state using main impacts and	KPI for Sustainability

	the value chain?	sustainable development as change of the state with a defined minimum rate	(output)? SOC? Yes – do OS No – do SOS
Analysing	Which are the vital few causes based on a stakeholder needs analysis – PBSM, SOC?	Defining main causes Pareto?	KPI for main causes and priorities? (x-values)?
Solving	Which are the vital few solutions-SOC and Pareto?	Defining main solutions	Proposed S(OS) with improvement potential, actions and strategy

Table 3 has been designed with Table 2 as starting point for the Swedish building value chain.

Table 3. *The SOS for the Swedish building value chain interpreting Table 2 and including steps for the roadmap.*

	U	**D**	**M**
D	**Building value chain? See Figure 3.** Which are the vital few stakeholder needs? People in need of housing and an atmoshphere with too much CO_2? Main impacts? Housing value, carbon emissions and affordability.	**Sustainable Swedish building is:** "Satisfying building and construction user needs while being at least affordable and carbon neutral". **The goal is** to reach carbon neutrality latest by 2045. (Isaksson et al. 2024)	**What type of challenge do we have?** This could in the SOC be a complicated dilemma with known but marginalised interests (People and Planet) and unknown exercise of power and decision-making relations. Existing building sustainability KPI and targets? No – do SOS **Results for KPI and goals from SOS**: KPI: kg CO2 and cost/m2 and year of housing as sustainability **Goal: Sustainable housing** development as reaching 0 kg net CO2 by 2045 and reaching a cost equalling 30% of minimum Swedish net salary for an apartment according to housing norms by 2045. **Improvement potential** (indicative based on cement and concrete improvement): About 30% of current CO2 - emission from cement or about 500 000 tonnes of CO2 per year. Value based on 100 Euro/tonne in carbon credit trading - about 50MEuro/year.

	U	D	M
A	**Causes for identified improvement potential** - complex and complicated dilemmas (stakeholders and stakeholder interest) **PBSM with main Ms. See Figure 4.** Cement producers - Business model with focus on maximising tonnage sold of a commodity Standards - excessive regulations making change difficult - introducing new cements is very difficult Society - de facto cement monopoly reducing competition Customers - lack of understanding of what constitutes sustainability - lack of relevant measurements Research - value propositions of alternative binders and stronger cement not clear	**Defining main causes** to be worked with establishing relevant measurements to enable clear communication of opportunities within practice and research to act as a drivers for change	**Analysing of KPIs** Presenting output for building sustainability performance in more detail for building, concrete and cement sustainability. **Cement and Concrete value (**Adapted from Isaksson et al. 2024): Compressive strength (cement and concrete) times quantity/volume (LMPa*tonnes/m^3) - the L is a factor that combines average strength and variation based on a model from the cement standard EN 197 Harm/value: Price and CO_2/LMPa*tonnes Price and CO_2/LMPa*m^3 Price and CO_2/ m^2 wall Price and CO_2/m^2 floor Performance change over time (sustainability improvement)
S	**Solutions with focus on Measurements** Presenting sustainability measurements based on relative measurement of value/harm and harm per value for building, concrete, and cement as result of planned research. Potential role of SOC in finding solutions?	**Proposing a permanent follow up** based on the identified KPIs in the Swedish building value chain and for cement and concrete sustainability	**Presenting the opportunity** for improved measurements as an enabler for sustainable building. Time plan and budget for introducing cement, concrete and building sustainability and sustainability improvement measurements with identified sustainability targets and best change rate benchmarks.

The starting point in the Table 3 matrix is in Measuring Diagnosing in the upper right corner. The first observation is that there are no agreed KPIs for building sustainability neither on the overall level nor on the level of sub-processes. What exists are the Environmental Product Declarations (EPD) based on a Life Cycle Analysis which are used to track the main footprint, such as the carbon footprint. This moves the focus to Understanding Diagnosing which start with the value chain in Figure 1.

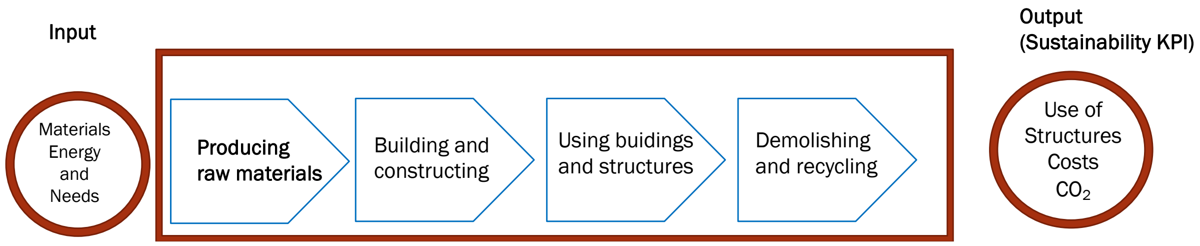

Figure 1. *Building value chain based on EN 15978:2011. The part of materials including cement and concrete production has been highlighted. The effects of decisions here on the entire building value chain have been studied.*

Focus, in this work has been on the subprocess of producing raw materials and particularly producing cement and concrete and the impact of this on building sustainability. The proposed definitions include two parts which are how to measure the level of sustainability and then how to measure the change of this level. When building sustainability changes quickly enough to reach the defined goal of carbon neutrality until the Swedish national goal of 2045, we could say that there is sustainable building development for climate sustainability. The requirement for cost and price reduction to achieve sustainable building development for affordability has not been studied. The indicated carbon and cost savings based on an initial review of indicated opportunities results in a yearly saving potential of 500 000 tonnes of CO_2 and a potential future cost saving of 50 MEuros per year when carbon taxes of about 100 Euro need to be paid. The calculations are based on the production of 2.8 Mtonnes of cement per year with a carbon footprint of 600 kg/t cement and saving 30% of the cement used. This means that it makes sense to proceed to Analysing. The overall analysis indicates that we probably have a complex dilemma. In Figure 2 the Swedish building system and its main elements is presented using the Process Based System Model (PBSM) (Isaksson, 2019). The main process in Figure 2 is the building value chain and its four sub-processes. Focus in the External and Internal 10 M analyses (Isaksson, 2024) is on producing cement and concrete as part of producing materials and the effect this has on overall building sustainability performance. Qualitative Analysing can be done using the 10M checklists. The analysis in Table 3 has not followed the 10Ms but is free format. The same main causes for the existing potential related to business model, measurements and standards are highlighted in the free format analysis and in the brief review in Figure 2.

The cement industry business model is in conflict with improving cement performance. This could be the reason for the international cement industry proposing CCS as a solution. Improving cement performance with the purpose of reducing its use would be logical in terms of value per harm. Using CCS is an end of the pipe solution that enables the cement industry to continue with business as usual. An alternative way forward would be to make it profitable for the cement industry to improve cement performance. This might reduce the size and investments needed for CCS. Standards complicate change and the use of new materials and cements. The cement industry is not in need of new standards. On the contrary complicated standards form a protection against competition. Discussing the best solution with different stakeholders is difficult since there is no agreed and relevant way of measuring building, concrete, and cement sustainability. We need fact-based decisions which could start with agreeing upon how to measure sustainability and sustainable development for buildings. Work could start with reviewing value per harm with using EPD for the environmental harm of a product and relating this to the value created. EPDs are generated based on data obtained through life cycle assessments (LCA) using Product Category Rules document (PCR) in line with the European standard EN 15804, ISO 14025, and other related international standards.

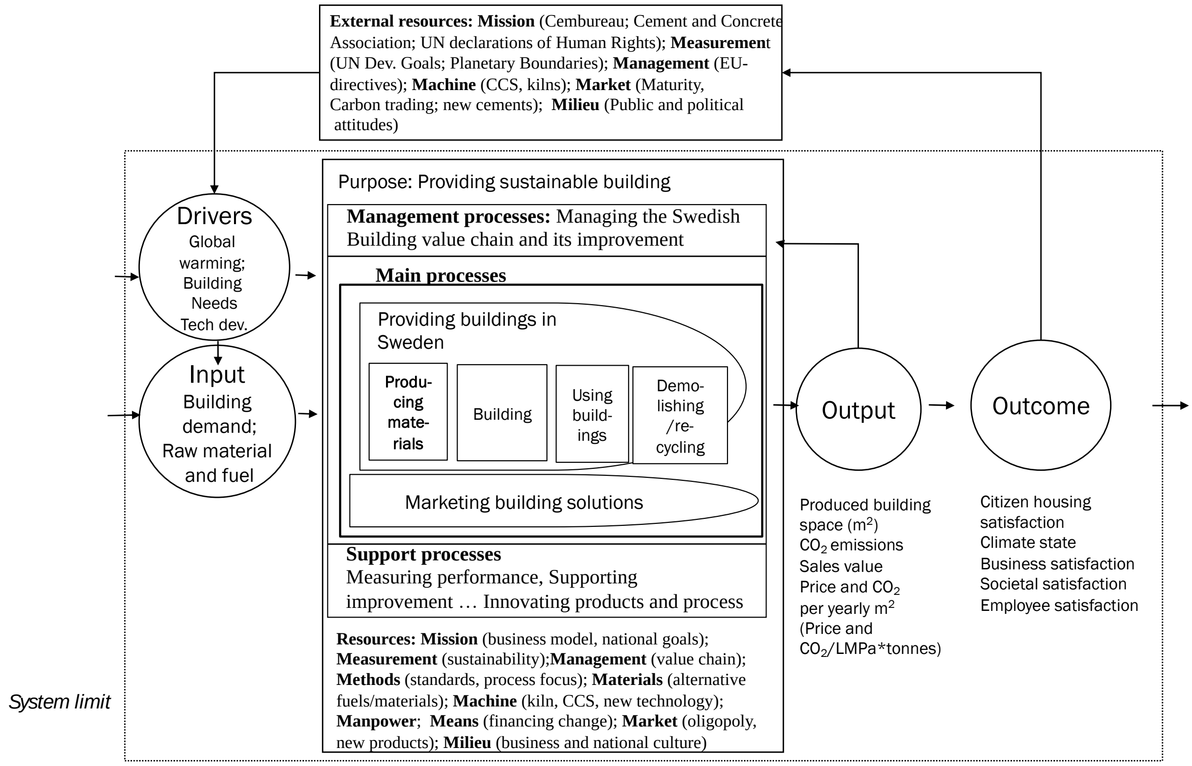

Figure 2. *Process Based System Model for Swedish building. Adapted from Isaksson (2019)*

The proposed solution is to start with finding an agreement for a common building sustainability definition which can be operationalised. This iteration of a Sustainability Opportunity Study (SOS) for Swedish building results in a proposal to proceed with a project that provides a proper taxonomy for the overall building sustainability and for the part of materials to start with.

Based on the work done a proposed roadmap for an SOS is presented in Table 4.

Table 4. *A proposed roadmap for a generic Sustainability Opportunity Study.*

Activity	Motivation	Comment
Define the overall system to be studied	A system with perceived problems or assumed improvement potential	The scope could be a local process or a global system
Check how sustainability	An agreed measurement with targets indicates a mature	There will always be some type of understanding. If there are no generally agreed indicators and results are difficult to

Activity	Motivation	Comment
performance is measured	understanding of sustainability	find without there being any clear targets, then most likely an SOS is needed. Use the Space of Challenges (SOC) logic to define which type of challenge the studied system is. With relevant KPIs (should be based on value per harm) and data with relevant targets (e.g., Science Based Targets) it will be possible to assess the improvement potential as the difference between current performance and target.
Understanding Diagnosing	Define value chain from cradle to grave Identify main stakeholders and their needs Apply the Pareto principle to identify main value and harm Always check climate, biodiversity, poverty, and effects on peace Use Planetary Boundaries and UN SDGs for further checks	Limit number of sustainability impacts to a vital few knowing that the definition will be: At least ... which leaves room for later changes. The Planetary Boundaries (Rockström et al. 2009) provide a good start for identifying Planet needs. The UN SDGs provide good support covering both People and Planet issues. Profit is a means to an end and is created by providing the best stakeholder needs value for the least harm.
Defining Diagnosing	Propose a definition which relates the value produced to main harms	Value is mostly People value in the form of goods and services but could also be Planet value in e.g., restoration of wetlands. Harms is both for People and Planet.
Measuring Diagnosing	Define sustainability as a level with chosen indicators and sustainable development as a change process with a specified rate	Sustainability could like quality be viewed as different levels and sustainable development could be seen as a sustainability development which is quick enough to achieve a state of sustainability while the system is still working, like achieving zero net carbon emissions until 2045.
Understanding Analysing	Use PBSM to describe system and use 10Ms as checklist. Use SOC to find out details of Mission, Management and Manpower Use Pareto to single out causes which can be actioned	In a complex system data will mostly be qualitative and implicit. Sensemaking needs to start with understanding the system and its elements including different stakeholders. Further research is needed on providing details for M-criteria and also how SOC can support in identifying power relations and interests (Rosvall, 2024).
Defining Analysing	Suggest main causes to be worked with	Further theory development needed
Measuring Analysing	Propose how to measure the main causes identified	Further theory development needed
Understanding Solving	What competency and agency	Further theory development needed

Activity	Motivation	Comment
	could be available for solving identified causes? Use SOC to find out relations among key stakeholders.	
Defining Solving	Suggest a solution which seems feasible for the system studied	Further theory development needed
Measuring Solving	Prepare a business case for the proposed change including time plan	Provided a realistic opportunity can be generated, proposed this to the system management Further theory development needed
From SOS to DASIAS	Provided management interest the proposed opportunity is converted into an improvement project, probably with some modifications	DASIAS (Isaksson, 2015) is a common-sense improvement model where Diagnosing-Analysing-Solving (DAS) describes both an Opportunity Study and the first steps in the improvement process which additionally has Improving-Anchoring-Studying. The SOS can be carried out by consultants whereas the DASIAS should be carried out by stakeholders in the system. This means that a new start including the full DASIAS is needed.

Conclusions

The indicative conclusions to the research questions are:

RQ1: How is current building, concrete and cement sustainability being understood, defined and measured in Sweden? Answer: The sustainability in the overall building value chain in Sweden and in the subprocess of producing materials (cement and concrete) are mainly described with the carbon footprint. For building sustainability there are some mentions relating to affordability. There seems to be no common understanding of sustainability in the Eco Efficiency value per harm terms.

RQ2: How could the SOS be improved to support sensemaking of building, concrete and cement sustainability? Answer: The SOS has been revised and applied for Swedish building and presented in Table 3 and in Figures 1 and 2. The Space of Challenges (SOC) has been included initially. Here, more research is needed.

RQ3: How could the use of SOS and the practices and tools included be converted into a roadmap? Answer: A proposed roadmap is presented in Table 4 which provides a logic from starting work with a system until a proposed Opportunity Study and how to proceed with an improvement process.

The overall conclusion is that Quality for Sustainability (Q4S) could be defined by modifying the quality principle, customer focus, to focus on stakeholder needs. Vital stakeholder needs can be defined starting from the main global stakeholders People and Planet in the studied system and then identifying the What of sustainability by identifying the main user value and main harm produced using the Pareto principle as a lens. The working definition based on "at least ..." enables a start that includes the vital few sustainability impacts. With a defined output the rest is basic QM - the How. With these minor changes Quality Management could become Sustainable Development.

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Monitoring of diffuse biogas emissions from landfills using drone- based technology

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Abstract

When managing a landfill, one must account for the environmental aspects concerning uncaptured landfill gas (LFG), since this gas contains methane which is a powerful GHG, and also one must account for economic aspects since uncaptured LFG represents a loss of earnings, since this gas can be used to produce electrical energy. It is thus essential to have effective emission monitoring systems to check the efficiency of the LFG capturing systems implemented in the landfill.

This paper illustrates the authors' current state of research concerning the use of drone (a.k.a. unmanned aerial vehicle) technology used together with specific sensors as a means of monitoring methane emissions deriving from uncaptured emissions of LFG. Specifically, the technology, setup and approaches used to measure methane concentrations on the landfill surface and methane flux are illustrated.

At present the research concerning methane concentration measurement via drone has reached a consolidated state and it has been extensively applied in landfills in Italy. The measurement of methane flux from a landfill surface represents ongoing research which needs to address in more detail aspects concerning the drone flight path, the type of sensors used for the monitoring and the wind measurements during the flight of the drone.

This innovative use of drones and of specific sensors has proved to be a very useful complementary tool for landfill managers as a means of identifying hot spots which can then be further investigated with more traditional systems such as flux-boxes and held measuring devices.

Keywords: Landfill gas, diffuse methane emission monitoring, drone, unmanned aerial vehicle

Introduction

Methane (CH_4) is a potent greenhouse gas, with a climate-altering effect 86 times greater than that of CO_2 over a period of 20 years and 30 times more impactful over 100 years (Friedlingstein et al., 2022). Landfills are currently one of the main anthropogenic sources of CH_4 emissions, which in 2020 accounted for 94% of total emissions attributable to the waste sector in Europe (EEA, 2022).

Monitoring can be carried out both to locate emission points on the landfill surface (hotspot mapping on the landfill surface) and to quantify the total flow from the site. Traditionally, the first objective is pursued through point measurements conducted with portable instruments. The FID (Flame Ionization Detector) and PID (Photo Ionization Detector) sensors are the two most commonly used types of sensors. The FID sensor uses an ionizing flame to detect organic compounds, while the PID sensor uses an ultraviolet lamp to ionize compounds present in the air. An operator walks the site and records points that exceed a pre-established concentration threshold. However, these techniques have limitations in terms of spatial coverage and temporal resolution.

The second objective is a complex exercise that presents different challenges. Among the methodologies developed to perform this difficult task, the accumulation chamber method is currently one of the most widely used (Lucernoni et al., 2016; Rachor et al., 2013; Abichou et al., 2011). The method was first applied by Pearson et al. (1965) to estimate radon-222 emissions into the atmosphere. Much of its diffusion in the landfill sector is due to an English technical standard issued in March 2003, "Guidance for Monitoring Landfill Gas Surface Emissions", which foresees the use of the accumulation chamber within a well-defined and structured protocol.

In Italy, Legislative Decree 36/2003 imposes on landfill operators the obligation to monitor surface CH_4 emissions but does not provide indications on the technique to be used to observe compliance. In the absence of provisions, the accumulation chamber has been particularly appreciated in the sector, both for its practicality and low costs and for the methodological support provided by the English guideline. The method involves measuring the rate of change in CH_4 concentrations inside a small chamber, placed in contact with the surface. Measurements are conducted on a grid of points distributed randomly or according to a regular mesh; the surface emission for the entire site is then derived as the average of the measured values or using geostatistical tools (Gonzalez-Valencia et al., 2016; Battaglini et al., 2013; Ishigaki et al., 2005). Several studies have highlighted how the method tends to underestimate the actual flow, considering the accumulation chambers unsuitable for estimating landfill emissions on a small scale (Borjesson et al., 2000; US EPA, 2018). The reliability of the results is often compromised by some operational and interpretative limits of the guideline, which can be summarized in the following three points: sampling density, survey duration, and the inability of accumulation chambers to quantify certain significant contributions. Several studies have emphasized the need to increase the number of monitoring points commonly used (Babilotte, 2011; Levy et al., 2012; Wong, 2018). In particular, Wong (2018) analysed the impact of the number of measured points on the reliability of the final data. It emerged that in order to estimate CH_4 emissions with a precision within 20% from a site of only 0.2 ha, 220 monitoring points were necessary on the landfill surface. Such a sampling density is hardly applicable in practice and represents the main limitation of the accumulation chamber methodology. The second limiting factor is the duration required by a monitoring campaign. Since meteorological conditions influence the emission rate and its temporal variability, it is essential to design the investigation to be as fast as possible. The temporal variability of emissions in a landfill is largely attributed to fluctuations in barometric pressure. Several authors highlight a negative correlation between emission rates and pressure (Czepiel et al., 2003; Borjesson et al., 2000). The accumulation chamber method requires hours or even days to complete landfill monitoring, making it unsuitable for capturing the temporal variability of the phenomenon. Finally, there are emission contributions in landfills that cannot be quantified using the method. Biogas extraction wells and similar infrastructures represent important contributions to CH_4 emissions from a landfill, as well as cracks and fissures on the site's sidewalls. The flux chamber cannot be used in such circumstances; therefore, the protocol assigns to the plant operator the task of quantifying or estimating these emissions with other methods and including them in the final monitoring results. They are rarely considered in the estimation of total emissions, contributing to a significant underestimation of the reported data.

Unmanned Aerial Vehicles (UAVs, also known as drones) for CH_4 monitoring offer new opportunities to estimate CH_4 flows from a landfill thanks to recent advances in sensor miniaturization that make these instruments increasingly light and suitable for equipping on a drone. In particular, they can overcome the three operational limitations just described for accumulation chambers. Sensors on board a UAV platform are able to acquire data at high frequencies (up to several tens of Hz), allowing for a higher sampling density. The drone's speeds also allow for significantly reducing survey times. Unlike accumulation chambers, they can conduct monitoring in a hazardous or inaccessible area to humans or the accumulation chamber itself (biogas extraction wells, cracks, and fissures on the sidewalls).

Another significant advantage of monitoring landfill methane emissions with drones is the reduction in operating costs. Compared to traditional methods involving the use of ground or manned aircraft operated by specialized personnel, the use of drones is more cost-effective and efficient. Drones require less human and material resources to operate and can cover large areas in a short amount of time, reducing overall monitoring costs. As already noted by Fosco et al., (2024), UAV-based applications aiming to quantify CH_4 flux in landfills are very limited and experimental in nature.

This paper aims to illustrate a new UAV-based approach for monitoring CH_4 emissions from landfill sites. In particular, an instrumental setup and operational procedures are described to locate emission points on the landfill site and estimate the emission flux from the site.

This paper is structured as follows. Section 2 describes the instrumental setup (type of drone and sensors used). Section 3 analyzes the individual phases that constitute the method: desk study (paragraph 3.1), flight planning (3.2), data acquisition (3.3), and data processing (3.4). The specific operations are then described depending on whether the monitoring is aimed at locating hotspots on the landfill site (section 4) or quantifying the flux from the site (section 5). Finally, paragraph 6 concludes this work with some indications on aspects to improve and potential lines of research.

System Design

The system consists of a UAV platform, a CH4 analyzer, and a weather station. The UAV platform used is a commercial quadcopter (Matrice 350, DJI), equipped with RTK (Real-Time Kinematic) system for precise positioning. The choice of a rotary wing drone is due to operational advantages compared to a fixed-wing counterpart. For example, rotary wing drones can fly in stationary mode over a predetermined point (hovering). They are also more manoeuvrable and do not require runways for take-off. Being able to fly at lower speeds, they can guarantee a high spatial resolution of the survey. Unlike fixed-wing drones, they cannot cover large areas, but the battery duration (with the proposed setting, approx. 30 min) is suitable for landfill monitoring.

The drone is equipped with an open-path tunable diode laser spectrometer (OP-TDLAS). The sensor (Laser Falcon methane detector, Pergam-Suisse AG) emits electromagnetic radiation at a selective wavelength for CH_4 (1.65 μm); this reaches a target (usually the ground) and returns to the sensor. The intensity of the return signal is proportional to the CH_4 concentration along the optical path. The instrument acquires data at a frequency of 10 Hz and provides a result expressed in ppm-m (range 0 - 50,000 ppm-m).

It has a radar altimeter that allows flight in "terrain following" mode. This is a very useful function in areas with variable terrain, characterized by complex topography. By adapting to the terrain, the drone can acquire data at a constant and accurate altitude, obtaining better quality results.

An onboard computer (SkyHub, UgCS) completes the instrumentation equipped on the drone with the purpose of recording georeferenced data measured by the altimeter and OP-TDLAS sensor. Meteorological parameters (wind speed and direction, temperature, atmospheric pressure) are acquired 2 m above the ground, using a weather station located at the site.

The instrumental setup is illustrated in figure 1.

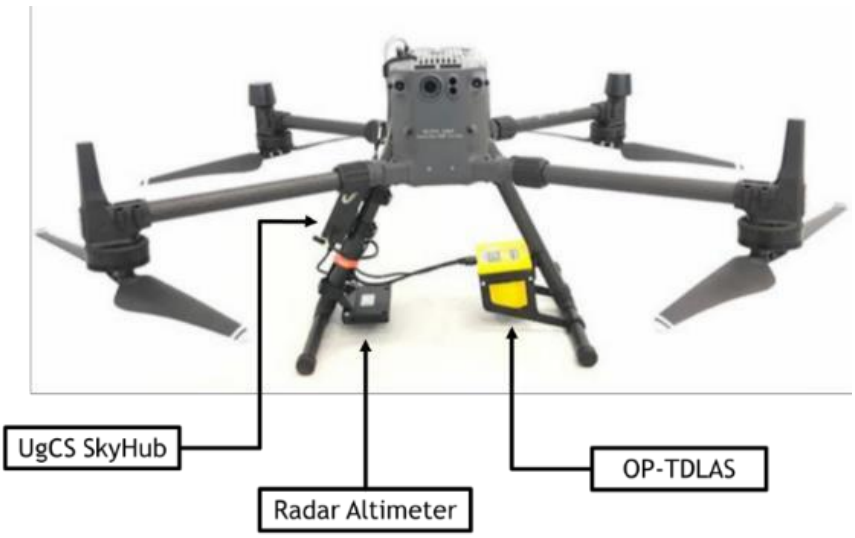

Figure 1. Hardware system architecture

Operations protocol

Site inspection

The first step of any measurement campaign is the site inspection. This consists of a "desk-study" phase and may require or be complemented by a preliminary on-site inspection before the flight. This is an essential step to identify feasible flight paths, avoiding any obstacles on the site (tall vegetation, suspended cables, pylons, buildings etc.). It is also important to identify the presence of potential sources of emissions external to the site. In this case, a downwind flight over the site is necessary to exclude these contributions and avoid overestimating the real emissions.

Fight plan

Flight design depends on the monitoring objective. If the survey is conducted to map hotspots on the landfill surface, it is necessary to ensure high spatial density and minimize background noise. To achieve these goals, the flight is conducted by tracing parallel transects orthogonal to the prevailing wind direction. The step between two consecutive transects is between 15 and 30 m, while the flight altitude varies between 10 and 20 m. It is important to note that the downwash from the propellers can alter the measurement, and flight altitude must be evaluated to minimize this distortion. The drone's speed is a parameter that affects the spatial representativeness of the data. Table 1 shows the spatial resolution of the acquisition as a function of the drone's cruising speed:

Table 1. Spatial resolution as a function of drone speed

Drone speed (m s^{-1})	Spatial resolution (point/m)
1	10
2	5
3	3.3
4	2.5
5	2

Flights conducted to map hotspots on the landfill surface are preferable to be carried out at low speeds (1 – 2 m s^{-1}), while those for flux can be carried out at 2 – 3 m s^{-1}. Higher speeds can be considered if the site is particularly extensive.

To facilitate the identification of emitting points on the landfill surface, flights are conducted at 10, 15, and 20 meters in height. The flight can be conducted in automatic or manual mode. In the first case, the drone follows pre-set trajectories by the pilot, which helps improve the overlap of the surveys. It is preferable for these reasons over manual flight, but can only be implemented if site-specific conditions ensure adequate safety for the operation.

To quantify CH4 emissions from a landfill, the flight design involves scanning a vertical plane downwind of the site. Horizontal transects are carried out at multiple heights; the extent of the downwind plane must be sufficient to capture the entire emission plume. The maximum height depends on the distance of the vertical plane from the site and the vertical dispersion of the plume and is usually in the order of tens of meters. Different authors (Allen et al., 2019; Yong et al., 2024) choose to exploit the maximum height allowed by regulations. Knudsen and De Rossi (2022) recommend checking the data collected after each flight to adjust the size of the plane in the next flight based on the results obtained. The distance between two horizontal transects should not exceed 5 meters, while the first transect can be conducted at 10 meters AGL. Flight patterns for hotspot localization (a) and flux quantification (b) are shown in Figure 2.

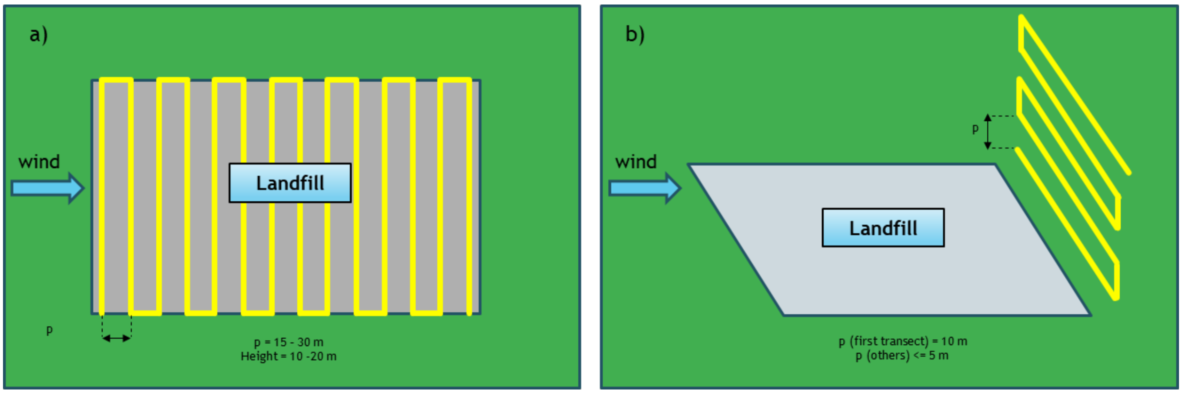

Figure 2. Flight patterns. Hotspot localization (a) and flow quantification (b).

Data collection

During each flight, the onboard computer (SkyHub, UgCS) records the following parameters:

- time.
- geographical coordinates and altitude (GPS).
- elevation above the ground.
- integrated CH_4 concentration.

These data can be viewed in real time at the Ground Station and are supplemented by measurements taken by the meteorological station (wind speed and direction, temperature, atmospheric pressure, data acquisition time).

Data processing

At the end of each flight, the data acquired by the drone is purified from the so-called "false positives." These are measurements that erroneously indicate the presence of CH_4 when this gas is actually absent or present in negligible quantities compared to the background environmental levels. This error can be caused by both external interferences and sensor malfunctions.

It is important to remove these corrupted data to ensure the real representativeness of the final result. The cleaned dataset is then used as input for the subsequent analysis phase, depending on the monitoring objective (hotspot localization or quantification of emission rates).

Localization of emission hotspots

Once the flight datasets are cleansed (at least three), the results are displayed and overlayed on a GIS platform. A threshold value is set depending on the flight altitude, emission profile of the site, and background noise. Indicatively, a threshold value of 100 ppm-m is set for a flight at 10m and 200 ppm- m for a flight at 20m.

However, this value may need adjustments based on the data measured by the drone.

The overlay is done to verify if it is indeed a hotspot and not a disturbance induced by turbulent transport. If three flights are conducted and the point is confirmed by at least two flights within a 5m radius, then the area is considered emissive. In the case where only one flight identifies the emissive point, this is verified on-site with a handheld instrument. One stands at the point and walks in a circle around it, increasing the distance gradually up to 5 meters from the potential emission point. If the handheld instrument detects values above 100 ppmv, the point is validated as emissive, otherwise, it is discarded.

An example of the above is shown in figure 3. From three surveys conducted at 10, 15, and 20 meters, 3 emissive areas were identified, confirmed by three flights (area n.4, 5, 7) and one confirmed by two flights (area n. 6). Areas n. 1, 2, and 3 were instead identified by a single flight and subsequent verification with a manual tool did not show potential emissions.

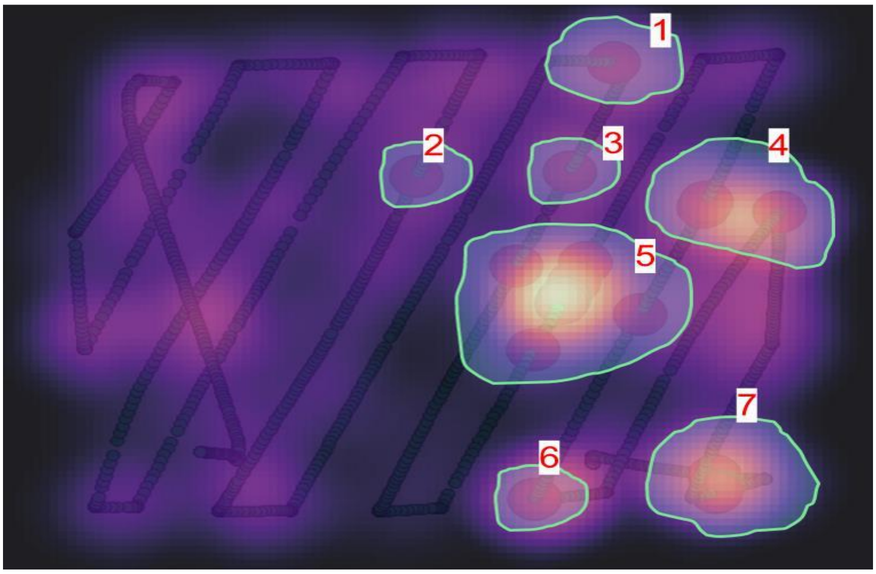

Figure 3. Concentration map with location of emission hotspots.

CH_4 flux quantification

The data acquired according to flight scheme b in figure 2, cleaned of false positives, are combined with wind data to estimate the emission flow through a mass balance. The drone performs transects at multiple heights and estimates the methane concentration between two successive traces. The background environmental level is estimated on a windward plane or derived from the flight itself; it is then subtracted from the drone measurements.

The increments above the background environmental level are then multiplied by the normal wind speed to the plane and interpolated, obtaining the flow between two successive transects. The sum of the contributions equals the total flow.

The following control parameters can be defined, which influence the final result and must be carefully considered:

- Flight time: the method requires quasi-stationary conditions with wind perpendicular to the plane. The shorter the duration of the survey, the lower the probability that the wind changes direction or that turbulent fluctuations affect the final data. The maximum acceptable time is around 20 minutes; however, it is always preferable to reduce it to around 10 minutes or even less (as long as spatial resolution is not lost).
- Downwind plane dimensions: the emission plume must be entirely captured. At the end of the first flight, it is good practice to check the data to see if it is necessary to widen the plane or increase the altitude for subsequent flights.
- Drone speed: the plume tends to disperse as one moves away from the emission point and mixes with the atmosphere. In the vicinity of the site (within a few tens of meters from the landfill edge), it is preferable to ensure a high density of points to capture the plume morphology. For this reason, it is recommended to fly at 1 - 2 m s-1. At greater distances, complete plume mixing allows for less dense sampling, and it is possible to fly at speeds > 2 m s-1. Note that the further one moves away from the source, the smaller the observable CH4 increment above the background environmental level. Therefore, flights should not be conducted more than 50 m from the landfill edge.

Figure 4 shows a flow map averaged for three flights conducted downwind of a landfill. The flights were conducted at a speed of 2 m s^{-1} and each lasted approximately 12 minutes. Transects were performed at 15 m, 20 m, and 25 m AGL. Significant contributions are highlighted between 19 and 23 m. In particular, two plumes are clearly visible at a height of around 21 m (circled areas in figure 4). The estimated flow was 8.12 g s^{-1}, in line with the results obtained from the gas chamber method (9 g s^{-1}).

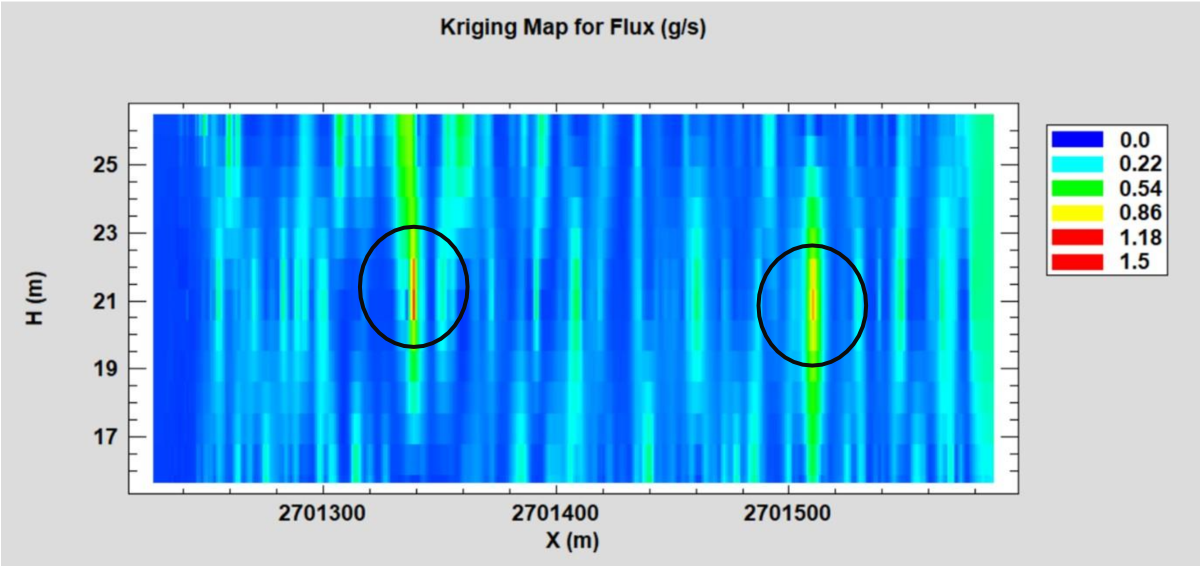

Figure 4. Mediated flow map of three flights to a landfill site. The circled areas highlight two emission plumes located approximately 21 meters away.

Conclusions

The results of this work show that the proposed UAV-based method is suitable for monitoring CH_4 emissions in landfills. In particular, operational protocols have been briefly described for locating hotspots on the landfill surface and quantifying the total flux from the site.

Despite the good agreement found for both objectives, the method has several aspects that can be further investigated and optimized.

Firstly, wind data acquired on the ground may not be representative in case of complex site topography or extensive measurement planes. To eliminate this source of uncertainty, wind measurements can be carried out directly on board the drone. There are various types of anemometers available on the market for this purpose. However, tests are needed to understand the minimum distance at which the sensor should be placed so as not to be influenced by the downwash from the propellers. Similarly, the OP- TDLAS sensor should be positioned so as not to be in the propellers' influence area.

There are also general aspects that depend on the specific characteristics of the drones and sensors chosen to apply the method. One of the main challenges is the calibration and validation of the sensors equipped on board the drone. It is essential to ensure that the collected data are accurate and reliable to enable quality assessment. Furthermore, standardized measurement methodologies and protocols are required to ensure the consistency and comparability of data collected by different UAVs and operators.

These protocols should define the conditions for surveys, speeds and heights based on the site and wind, the minimum number of flights to be carried out, and the dataset quality for usability.

Another challenge is the management and analysis of large volumes of data generated by UAVs during investigations, which can also be used to support atmospheric dispersion studies and provide flow estimates using other methods. This aspect is very interesting because it allows obtaining two flow data from the same survey with different techniques.

In conclusion, monitoring CH_4 emissions in landfills using UAVs has great potential, and the proposed method is just one example of it. However, further studies and research are needed to address the challenges mentioned above and current technological limitations.

Future research should focus on new monitoring methodologies, advanced sensor development, standardization of measurement protocols and data management, in order to maximize the potential of UAVs in monitoring CH_4 emissions in landfills and minimize their contribution to global warming.

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Sustainable business models: a literature review

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Abstract

This study investigates the integration of sustainable development into business strategy and management, addressing the lack of clarity and consistency in terms such as Sustainable Business Models (SBMs) and Business Model Innovation. Utilizing a narrative review based on PRISMA guidelines, the research examines 255 peer-reviewed scientific articles that include Sustainable Business Model-s in their titles. The findings elucidate theoretical definitions and practical applications of SBMs and track the evolution of the concept over time. Additionally, this work enhances the understanding of SBM innovation and its successful implementation in both academic and business contexts, addressing critical gaps in the literature.

Keywords: Sustainable Business Models, Business Models, Sustainability, Management, Key Word Analysis, Literature Review.

Relevant Topic: Sustainable Organization

Introduction

Business strategy and management disciplines are increasingly integrating sustainable development into their established assumptions and frameworks (Bonfanti et al., 2023; Guo et al., 2022; Oskam et al., 2021). However, there remains a lack of clarity, conceptual consensus and consistency in the usage of 'sustainable business models' (SBMs) (Chan et al., 2024; Ciulli et al., 2022). Based on the PRISMA methodology through a thorough key word analysis this work analyses all the 255 peer reviewed articles that formulated the contemporary bibliography of the SBM articles in the subject of Social sciences, Management and Business.

The aim of this review is to study the SBM literature from its very beginning, as well as all article types (studies, literature reviews and general articles), to represent the SBM concept holistically. This work aims to contribute to the understanding of the SBM concept and its innovations by adding recent bibliography to the debate and answering the following questions:

Q1. What are the main thematic areas and key focus areas of the Sustainable Business Models bibliography?

Q2. What are the pillars of impact in Sustainable Business Models?

Q3. What are the key innovations in Sustainable Business Models?

The paper is divided into four sections, Introduction, Methods, Results/Discussions and Conclusions. More specifically, Section 1 introduces the main research goals and questions of the study. Section 2 analyses the research methodology and design. Section 3 examines the results of the study. Finally, Section 4 presents the overall conclusions, limitations and avenues for future research.

Methods

This work attempts to review the evolution of the Sustainable Business Model-s. The methodological procedure is a key factor for the successful completion of a literature review article. The methodological procedure for the current article is based on the contemporary bibliography for literature review articles (Siddaway et al., 2019). The steps are briefly illustrated in Table 1.

Table 1. Methodology steps in conducting this Literature Review

Methodology Steps	
Investigation	Are there any relative papers?
Preparation	Define the search terms. Define the article types and time frame of the examined literature.
Searching	Choose the database. Choose the review guideline.

More specifically, regarding the investigation step, a thorough assessment was conducted to determine whether similar reviews had already been performed by others, with no such studies found. In the preparation step, potential variations in terminology were noted before researching the article databases to avoid excluding any valuable articles. No significant differences were found, so the following terms were included: Sustainable Business Model and Sustainable Business Models. The inclusion and exclusion criteria were formulated to restrict the search to relevant articles (Table 2). In the searching step, only published peer-reviewed articles written in English and indexed in Scopus and Web of Science were included. Using these databases, 255 articles were identified, published in scientific journals. The PRISMA checklist was chosen as a guideline for the review. Accordingly, the current review consists of the following sections: Title, Abstract, Introduction, Method, Results and Conclusions.

Table 2. Inclusion and exclusion criteria.

Inclusion Criteria	**Exclusion criteria**

Articles studying the SBM in Social Sciences, Business and Management.	-
Peer-reviewed articles from well-known databases: Scopus, Web of Science.	Non-academic databases.
Academic journals.	Gray literature (conference papers and reviews, book chapters, reports, etc.) and online sites.
Peer-reviewed articles published from the beginning of SBM research to July 2024.	Any publication written after July 2024.
Articles written in English.	Articles written in a language other than English.

Results and Discussion

Thematic analysis of SBMs literature

This chapter aims to enhance the understanding of the multifaceted nature of sustainability in business models by identifying the main thematic areas within the Sustainable Business Models bibliography through the categorization of keywords in the examined literature. Based on the keyword analysis, five thematic areas regarding SBM scientific bibliography are extracted (Geographic, Industry-specific, Conceptual Frameworks, Cross-cutting themes and Contextual), which are analyzed below.

Geographic: Keywords that pertain to particular nations or geographic zones serve to denote the spatial concentration found within the academic literature. For exemplification, the identification of nations such as Norway (Viciunaite, 2022; Høgevold et al., 2016; Høgevold et al., 2014; Høgevold, 2011), China (Chen, 2023; Lu et al., 2022; Li et al., 2020; Birkin et al., 2009), Taiwan (Wang et al., 2021; Lin et al., 2021; Lee & Chang, 2019), Germany (Kolasch & Mais, 2024; Dressler, 2023) and Brazil (Gomes et al., 2022; Hultman et al., 2012) denotes a worldwide engagement with the concept of sustainable business frameworks, wherein certain inquiries or comparative analyses illuminate regional regulations and industrial methodologies. This heterogeneity underscores the universal character of sustainability, accentuating the necessity for approaches that are tailored to specific contextual circumstances.

Industry-Specific: The literature reflects the application of sustainable business models across various sectors. In the wine industry (e.g., Mura et al., 2024; Dressler, 2023; Dressler & Paunović, 2020), agriculture (e.g., Barth et al., 2021; Ribeiro et al., 2018; Brehmer et al., 2018) and agri-food (e.g., Barth et al., 2021; Tiscini et al., 2020; Barth et al., 2017) sectors, there is a strong focus on sustainable farming practices, supply chain management and the development of organic product lines. The construction industry (e.g., Cerdá-Suárez et al., 2023; Hu et al., 2019), manufacturing (e.g., Kirst et al., 2023; Bonfanti et al., 2023; Al-Baghdadi et al., 2021; Burhan et al., 2021; Cardeal et al., 2020; Godina et al., 2020; Høgevold et al., 2016) and industrial and production engineering (e.g., Shakeel et al., 2020; Dembek et al., 2018; van Bommel, 2018; Dentchev et al., 2018; Joyce & Paquin, 2016; Marconatto et al., 2016) are characterized by innovations in materials, energy efficiency and the adoption of circular economy principles. The service industry (e.g., Battistella et al., 2018; Yip et al., 2018; Høgevold et al., 2015) emphasizes digital transformation and customer engagement strategies to promote sustainability. Lastly, the airline industry and air transportation sectors (e.g., Rotondo et al., 2019; Tiwari & Kainth, 2014; Heinz & O'Connell, 2013) are working on reducing carbon footprints, improving fuel efficiency and implementing sustainable business models in aviation.

Conceptual Frameworks: Several keywords emphasizing the theoretical/conceptual underpinnings of sustainable business models. Business model innovation (e.g., Chan et al., 2024; Coffay & Bocken, 2023; Dhir et al., 2023; Li et al., 2023; Schlüter et al., 2023; Utaminingsih et al., 2023; Ciulli et al., 2022) and the business model canvas (e.g., Goffetti et al., 2022; Basile et al., 2021; Pizzi et al., 2021; Cardeal et al., 2020; Hernández-Chea et al., 2020) serve as frameworks for designing adaptable and value-creating business models. The concept of a circular economy (e.g., Mura et al., 2024; Cerdá-Suárez et al., 2023; Reinecke et al., 2023; Macchion et al., 2023; Pedersen et al., 2023; Chuang et al., 2022; Boldrini & Antheaume, 2021; Ostermann et al., 2021; Pizzi et al., 2021; Fernandes et al., 2021; Cantele et al., 2020; Dentchev et al., 2018) emphasizes waste reduction and resource efficiency. The triple bottom line approach (e.g., Norris, 2024; Effendi et al., 2024; Kirst et al., 2023; Bonfanti et al., 2023; Alonso-Martinez et al., 2021; Peralta et al., 2019; Battistella et al., 2018; Gallo et al., 2018; Joyce & Paquin, 2016; Høgevold et al., 2014) balances economic, environmental and social impacts. Additionally, value proposition (e.g., Norris et al., 2023; Cano et al., 2023; Lagin et al., 2022; Hossain, 2021; Viciunaite & Alfnes, 2020; Morioka et al., 2017; Baldassarre et al., 2017) and value creation (e.g., Norris, 2024; Hausdorf & Timm, 2023; Norris et al., 2021; Okam et al., 2021; Hossain, 2021) focus on generating value for businesses and stakeholders while aligning with sustainable development goals.

Cross-Cutting Themes: The literature also emphasizes themes such as sustainable innovation (e.g, Peralta & Gismera, 2021; Baldassarre et al., 2020; Reinhardt et al., 2020; Rotondo et al., 2019; Laukkanen & Patala, 2014), open innovation (e.g., Szromek, 2021; Alvarez-Meaza et al., 2020; Roman et al., 2018) and technological development (e.g., Dhir et al., 2023; Del Giudice et al., 2022; Alvarez-Meaza et al., 2020; Godina et al., 2020), highlighting the role of innovation and technology in achieving sustainability goals. Corporate social responsibility (CSR) (e.g., Mura et al., 2024; Macchion et al., 2023; Basile et al., 2021; Paletta et al., 2021; Villalobos, 2020; Mattera et al., 2021; Voinea et al., 2019; Upward & Jones, 2016; Duran-Encalada & Paucar-Caceres, 2012) and corporate sustainability (e.g., Rathobei et al., 2024; Norris, 2024; Pieas & Schultz, 2023; Pimenowa et al., 2023; Morioka et al., 2022; Norris et al., 2021; Paletta et al., 2021; Lozano, 2018; Van Bommel, 2018; Dentchev et al., 2018; Morioka et al.,2017; Stubbs, 2017) are critical themes, focusing on integrating sustainability into business operations through corporate strategies and policies. Additionally, stakeholder engagement (e.g., Rathobei et al., 2024; Zgonari, 2024; Acciarini et al., 2022) is a significant theme, involving various stakeholders in the implementation and promotion of sustainable practices.

Contextual: Recent literature also addresses contextual factors such as the impacts of the COVID-19 pandemic on sustainable business models (e.g., Shan et al., 2023; Zheng et al., 2022; Csutora et al., 2022; Mattera et al., 2022; Lin et al., 2021; Cavicchi & Vagnoni, 2020; Mattera et al., 2021) and the necessary adaptations that businesses have made in response. Additionally, the broader environmental context, including climate change (e.g., Kolasch & Mais, 2024; Calandra et al., 2023; Guinot, 2020; Gray et al., 2018; Baldassarre et al., 2017) and its associated challenges (e.g, Ebrahimigharehbaghi et al.., 2022; Hultman et al., 2012; Jupesta et al., 2011), is a significant focus, underscoring the global challenges faced by sustainable business models in addressing environmental impacts.

Key focus areas of SBMs

Analyzing interrelated keywords and their variations helps in refining the focus areas of the literature on sustainable business models. The keywords analysis revealed eight main focus areas in the SBM bibliography (Focus areas: Sustainability/Sustainable, Business Models/Business Model, Innovation, Corporate/Organizational, Stakeholder/Stakeholders, Environmental, Circular Economy and Value). More extensively:

The keyword "*Sustainability/Sustainable*" appears with high frequency (e.g., Peralta & Gismera, 2021), scoring 435 mentions, indicating its central importance in the literature [Sustainability/Sustainable keywords: Sustainability, Sustainable Development, Sustainable Business Model, Sustainable Business, Sustainable Business Models, Sustainable Business Model Innovation, Sustainable Value Creation, Sustainable Innovation, Sustainable Development Goal, Sustainable Values, Sustainable Performance, Sustainable Entrepreneurship, Sustainable Business Model (SBM), Sustainability Innovation, Environmental Sustainability, Business Sustainability].

The terms "*Business Models/Business Model"* are also prominent (e.g., Schlüter et al., 2022), with 147 mentions, accentuating the focus on the conceptualization and innovation of business models [Business Models/Business Model keywords: Business Models, Business Model Innovation, Business Model, Business Modeling, Business Model Canvas, Business Model Innovation (BMI), Business Model For Sustainability, Business Model Design, Business Models For Sustainability, Circular Business Models, Circular Business Model].

"*Innovation*" scores 110 keywords (e.g., Dhir et al., 2023), emphasizing the critical role of innovation in achieving sustainability [Innovation keywords: Innovation, Business Model Innovation, Sustainable Business Model Innovation, Sustainable Innovation, Technological Development, Open Innovation].

Keywords related to corporate strategies and corporate social responsibility (CSR) are categorized under "*Corporate/Organizational*" with 42 mentions (e.g., Coffay & Bocken, 2023) [Corporate/Organizational keywords: Corporate Sustainability, Corporate Strategy, Corporate Social Responsibility (CSR), Organizational Framework].

Environmental concerns are reflected in keywords under "*Environmental*" with 27 mentions focusing on environmental impacts and management (e.g., Mura et al., 2024) [Environmental keywords: Environmental Economics, Environmental Impact, Environmental Management, Environmental Sustainability, Environmental Issue, Environmental And Social, Environment].

"*Stakeholder/Stakeholders*" appears 26 times (e.g., Rathobei et al., 2024), underscoring the importance of stakeholder engagement in sustainable practices [Stakeholder / Stakeholders keywords: Stakeholder, Stakeholders, Stakeholder Engagement, Multiple Stakeholders].

"*Value*" related keywords, scoring 24 mentions (e.g., Lagin et al., 2022), point to the importance of value creation and proposition in sustainable business models [Value keywords: Value Proposition, Value Creation, Sustainable Value Creation, Sustainable Values, Value Chain].

Lastly, the concept of the "*Circular Economy*" is highlighted with 16 keywords (e.g., Cerdá-Suárez et al., 2023), indicating a focus on circular economic principles [Circular Economy keywords: Circular Economy, Circular Business Models, Circular Business Model].

SBMs Pillars of impact

Categorizing keywords facilitates the extraction of information regarding the primary pillars of impact within the literature on sustainable business models. This process enables a more comprehensive understanding of the main impact areas, which encompass environmental, economic, social and cross-cutting impacts. Such an analysis helps discern how different facets of sustainability are incorporated into and influence business models across various contexts. More specifically, by analyzing the keywords, four main pillars are identified:

Environmental Impact: This pillar encompasses concepts such as sustainability, circular economy, climate change, environmental impact, greenhouse gas, carbon footprint, life cycle assessment (LCA) and environmental management. This category relates to sustainability practices that directly affect the environment.

Economic Impact: The literature of this pillar encompasses profitability, value proposition, economic and social effects, business model innovation, revenue streams and competitive advantage. This category focuses on economic performance and financial aspects.

Social Impact: This pillar involves corporate social responsibility (CSR), stakeholder engagement, social entrepreneurship, corporate sustainability, human rights and community development. It is associated with social responsibility and community engagement.

Cross-cutting Impact: This category covers innovation, stakeholder engagement, corporate strategy, sustainable business models, business model canvas, sustainable development goals and dynamic capabilities.

The concepts in this category are relevant across multiple impact areas and often represent overarching theories.

SBMs Innovation

Key innovations in the literature on sustainable business models often revolve around integrating sustainability into business strategies (Utaminingsih et al., 2023), processes and products (Coffay & Bocken, 2023). One of the most significant areas is business model innovation, where changes in how a business operates (Dhir et al., 2023), delivers value and generates revenue (Li et al., 2023) now often incorporate sustainability as a core component (Chan et al., 2024). This includes concepts like Business Model Innovation (BMI) and Sustainable Business Model Innovation, which illustrating the evolving nature of business frameworks to include sustainable practices.

The circular economy represents another groundbreaking innovation, shifting from the traditional linear economy of "make, use, dispose" to a model that emphasizes minimizing waste and maximizing resource use (Mura et al., 2024; Cerdá-Suárez et al., 2023). Circular business models and principles of the circular economy focus on creating closed-loop systems (Pizzi et al., 2021) where materials are reused, recycled and maintained within the economy for as long as possible (Ostermann et al., 2021).

Digital and technological innovations also play a crucial role in enhancing sustainability (Del Giudice et al., 2022). Industry 4.0, which integrates advanced technologies like Internet of Thinks (IoT), Artificial Intelligence (AI) and big data into manufacturing processes, improves efficiency and reduces waste (Godina et al., 2020). Blockchain technology ensures transparency and traceability in supply chains, which is essential for verifying sustainability claims (Tiscini et al., 2020). Open innovation fosters collaboration with external entities to develop sustainable technologies and practices, driving forward the agenda of sustainability (Szromek, 2021).

Product and service innovations are pivotal, focusing on creating new, more sustainable products and services. Product-service systems combine products and services to deliver more sustainable solutions, such as leasing instead of selling products, thus reducing waste and promoting reuse (Sousa-Zomer & Miguel, 2018). Design thinking applies creative strategies to develop environmentally friendly and sustainable products, emphasizing a user-centered approach to sustainability (Barth et al., 2021).

Sustainable innovation and development target broad goals aimed at achieving sustainable development (Oskam et al., 2021). This includes aligning business strategies with Sustainable Development Goals (SDGs) (Bonfanti et al., 2023), which provide a global framework for addressing sustainability challenges (Morioka et al., 2017). Sustainable innovation seeks to create new products, processes and services that contribute to sustainable development (Guo et al., 2022; Marconatto et al., 2016).

Value chain innovations improve sustainability throughout the supply chain (Bjartmarz & Bocken, 2024). This involves enhancing sustainability in production, logistics and sales processes and implementing sustainable practices in sourcing, production and distribution (Mutta et al., 2021). These innovations ensure that sustainability is embedded at every stage of the value chain (Kim wt al., 2004).

Strategic and organizational innovations involve changes in organizational strategies and structures to prioritize sustainability (Dressler, 2023). Corporate sustainability focuses on embedding sustainability into the core strategies of organizations, ensuring that it is a fundamental part of their mission and operations (Pimenowa et al., 2023). Corporate Social Responsibility (CSR) engages businesses in ethical practices that contribute to economic development while improving the quality of life for employees, their families, the local community and society at large (Mura et al., 2024).

Finally, sector-specific innovations address the unique challenges and opportunities within particular industries. In agriculture, construction and manufacturing, innovations focus on improving resource efficiency (Kirst et al., 2023), reducing environmental impacts (Burhan et al., 2021) and enhancing social responsibility (Gardeal et al., 2020). These sector-specific approaches ensure that sustainability is tailored to the specific needs and contexts of different industries, promoting a more comprehensive and effective implementation of sustainable business practices (e.g., Bonfanti et al., 2023; Godina et al., 2020).

Strategies and actions

Implementing innovations in sustainable business models involves strategic planning (Birhan et al., 2021), stakeholder engagement (Dembek et al., 2018) and integrating new practices (Peralta et al., 2019) and technologies (Barth et al., 2021). The subsequent analysis delves into the SBM innovation strategies and actions that have emerged from the examined literature.

Primarily, sustainability and sustainable practices require a multi-faceted approach (Peralta & Gismera, 2021). Businesses should start by assessing their current impact through an environmental and social impact assessment to understand their baseline (Utaminingsih et al., 2023). Setting clear goals aligned with global standards like the Sustainable Development Goals (SDGs) is crucial. Integrating sustainability into the core strategy of the company ensures that it becomes a fundamental part of decision-making (Chan et al., 2024). Educating and engaging employees on sustainability practices fosters a culture of environmental stewardship (Schlüter et al., 2023). Actions to adopt green technologies, use sustainable sourcing and develop circular economy practices can significantly reduce waste and promote a sustainable business model (Macchion et al., 2023; Fernandes et al., 2021).

Business model innovation is another critical area. Redefining the value proposition to focus on sustainable and ethical benefits is essential (Dhir et al., 2023). Exploring new revenue streams, such as subscription models, leasing, or service-based models, promotes product longevity and resource efficiency (Li et al., 2023; Schlüter et al., 2023). Leveraging digital transformation to optimize operations, improve transparency and engage customers in sustainability efforts can drive substantial improvements (Coffay & Bocken, 2023; Hernández-Chea et al., 2020). Businesses can use the Business Model Canvas to visualize, design and innovate their business models, integrating sustainability aspects (Goffetti et al., 2022; Basile et al., 2021). Starting with small-scale pilots to test new models and refine them based on feedback is a practical approach (Cardeal et al., 2020).

In terms of corporate and organizational innovations, developing a comprehensive Corporate Social Responsibility (CSR) strategy that aligns with company values and stakeholder expectations is fundamental (Macchion et al., 2023). Encouraging sustainable practices at all levels of the organization through leadership commitment and employee engagement is crucial (Mattera et al., 2021). Regularly reporting on sustainability performance using frameworks like the Global Reporting Initiative (GRI) or Sustainability Accounting Standards Board (SASB) ensures transparency (Paletta et al., 2021; Lozano, 2018). Setting up a sustainability committee to oversee initiatives (Pimenowa et al., 2023), track progress and ensure compliance (Morioka et al.,2017), along with engaging in community initiatives that align with the company's sustainability goals (Norris et al., 2021), can reinforce these efforts.

Stakeholder engagement involves mapping out all stakeholders, including customers, employees, suppliers and local communities (Acciarini et al., 2022). Engaging stakeholders early and often in the decision-making process, seeking their input and addressing their concerns is vital (Zgonari, 2024). Developing clear communication strategies to keep stakeholders informed about sustainability efforts and progress and partnering with Non-Governmental Organizations (NGOs), industry groups and other companies to promote sustainability standards and practices, can lead to more robust and inclusive sustainability efforts (Rathobei et al., 2024).

For environmental practices, businesses should focus on minimizing resource use by optimizing processes to reduce energy, water and material consumption (Calandra et al., 2023; Guinot, 2020). Implementing measures to cut greenhouse gas emissions and waste generation is also crucial (Kolasch & Mais, 2024). Environmental Management Systems (EMS), such as ISO 14001, can help systematically manage environmental responsibilities (Baldassarre et al., 2017). Investing in cleaner technologies that reduce environmental impact is a practical step towards sustainability (Gray et al., 2018).

Circular economy practices involve designing products for longevity (Pizzi et al., 2021) ensuring they can be easily repaired or upgraded and establishing systems for product take-back, recycling and reuse (Cerdá-Suárez et al., 2023; Dentchev et al., 2018). Transitioning to Product-as-a-Service (PaaS) models (Pedersen et al., 2023; Chuang et al., 2022), where customers access products without owning them, promotes reuse and refurbishment (Ostermann et al., 2021). Developing closed-loop supply chains that minimize waste (Mura et al., 2024; Cantele et al., 2020) and encourage the return of materials into the production cycle is another effective strategy (Reinecke et al., 2023; Fernandes et al., 2021).

In value creation, businesses should focus on delivering sustainable value to customers by addressing their environmental and social concerns (Hossain, 2021; Hausdorf & Timm, 2023). Ensuring transparency in the value chain, from raw materials to final product delivery, builds trust and accountability (Okam et al., 2021). Developing sustainable products that offer benefits like reduced carbon footprints or ethical sourcing and educating consumers about the sustainable attributes of products, can encourage responsible consumption (Norris, 2024).

Finally, innovation and technological development are pivotal. Investing in research and development for sustainable technologies and practices can drive long-term improvements (Dhir et al., 2023). Adopting emerging technologies like AI, IoT and blockchain can enhance sustainability efforts by improving efficiency and transparency (Del Giudice et al., 2022). Collaborating on open innovation with other companies, research institutions and startups fosters collective advancement (Godina et al., 2020). Implementing digital solutions for monitoring, reporting and enhancing sustainability performance ensures that businesses remain on track with their sustainability goals (Alvarez-Meaza et al., 2020).

According to the academics by following these strategies and actions, businesses can effectively integrate sustainability into their operations and drive meaningful, long-lasting change.

Conclusions

As mentioned in the main body of the article, Sustainable Business Models (SBMs) is a constantly developing concept. Consequently, new innovative and specialized viewpoints are emerging. This review set out to examine the evolution of SBMs both theoretically and practically. Specifically, by analyzing the SBM scientific literature in the Management/Business sector, this research highlights the thematic focus areas, pillars and innovations of SBMs.

Based on literature review analysis, five thematic areas in the SBM scientific bibliography are identified: Geographic, Industry-specific, Conceptual Frameworks, Cross-cutting Themes and Contextual. Additionally, the key focus areas of the SBM literature include Sustainability/Sustainable, Business Models/Business Model, Innovation, Corporate/Organizational, Stakeholder/Stakeholders, Environmental, Circular Economy and Value. Among these, the Sustainability/Sustainable area is the most examined (437 articles), while the Circular Economy is the least examined (16 articles). The main innovations in SBM managerial and business literature include business model innovation, circular economy innovation, digital and technological innovations, product and service innovations, sustainable innovation and development, value chain innovations, strategic and organizational innovations and sector-specific innovations (e.g., agriculture, construction, etc.).

While this review examines the entire existing literature up to July 2024 to present a holistic view of SBM development, with an emphasis on its contribution to management, future studies should examine more recent works to reach specific conclusions that will further enrich knowledge in relevant fields.

The findings of this study have several theoretical and practical implications. This review provides researchers with a summary of the SBM literature, highlighting the evolution and use of the term. An important practical implication is that this study consolidates all the strategies and actions related to achieving Sustainable Business Models.

Acknowledgments

The research project is implemented in the framework of H.F.R.I call "Basic research Financing (Horizontal support of all Sciences)" under the National Recovery and Resilience Plan "Greece 2.0" funded by the European Union – NextGenerationEU (H.F.R.I. Project Number: 016799).

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Integrating Sustainability into Total Quality Management: Analysis of the Deming Award Winning Companies

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Keywords: TQM definition, Sustainability, Deming Prize, Sustainability Report

Relevant Topic: Sustainable quality management, standards and certification

Extended Abstract

Companies must integrate sustainability into their quality management models in an era of intensified global competition to achieve lasting competitive advantages (Fasil and Osada, 2011). Total Quality Management (TQM) has evolved to include social and environmental responsibilities alongside traditional economic objectives. This study examines how the principles of TQM, defined in the new sustainability-oriented version proposed by Silvestri et al. (2024), are implemented by companies that won the Deming Prize in 2023 ("Deming Prize website", 2023).

Objectives of the Study

The main objective of this research is to analyse the implementation of sustainability-oriented TQM principles in companies that won the Deming Prize in 2023. The study focuses on four main themes of the new TQM definition: (1) management philosophy, (2) stakeholder satisfaction, (3) continuous improvement and (4) sustainable development.

Methodology

The study takes an exploratory qualitative approach by analysing the sustainability reports of three companies: a catalyst manufacturer (ACompany), an agro-industrial conglomerate (DCompany) and a construction machinery manufacturer (BCompany). Content analysis was used to identify how these topics are implemented in the companies' sustainability reports.

The analysis was conducted in two main phases. In the first phase, a manual content analysis was performed to classify the definitions of the different topics and their respective keywords. Subsequently, the results were compared with an automatic analysis using ChatGPT to ensure accuracy and reduce interpretation bias.

Results

The results show that all companies adopt a management philosophy emphasizing customer satisfaction, human resource management, and continuous improvement. They demonstrate a broad understanding of stakeholders and use various strategies to engage them effectively (Garvare and Johansson, 2010; Manresa et al., 2021; Navarro et al., 2021). Continuous improvement is central to all companies, using TQM tools such as the PDCA cycle and Kaizen to improve efficiency and reduce environmental impact.

ACompany: Uses TQM to continuously improve quality and efficiency, reducing environmental impact and promoting the use of environmentally friendly materials.

DCompany: employs TQM to optimise processes, involve stakeholders and adopt sustainable innovations, ensuring efficient use of resources and reduced environmental impact.

BCompany implements 'The BCompany Way', a TQM-based philosophy that promotes continuous improvement, process management, and technological innovation while reducing emissions and improving energy efficiency.

Managerial and Scientific Implications

Managerial implications suggest that managers integrate sustainability into their quality management practices, using TQM to achieve sustainable development goals. The scientific implications confirm that TQM, aligned with sustainability principles, can effectively support companies in achieving these goals.

The research significantly contributes to the existing literature on TQM and sustainability by providing empirical evidence on how companies can implement TQM principles to achieve sustainable development goals. The new definition of TQM proposed by Silvestri et al. (2024), which incorporates economic, social and environmental dimensions, was validated through the analysis of the sustainability reports of Deming Prize-winning companies, highlighting the effectiveness of this philosophical approach in corporate management.

Research Limits

The main limitation of the research concerns the limited sample of companies analysed. The study was based on a limited sample of companies, limiting the generalisability of the results. Another limitation concerns the manual analysis of the reports, which could introduce interpretative bias.

Conclusion

TQM is closely linked to sustainability in all three companies analysed. Adopting TQM principles not only improves quality and operational efficiency but also contributes significantly to achieving sustainability goals. This study confirms the effectiveness of TQM as a tool for integrating sustainability into corporate strategies, offering valuable guidance for managers and a significant contribution to academic research.

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Track 6: Life Cycle Assessment

A preliminary LCA of rainbow trout farming: a Case Study on freshwater aquaculture in Italy

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Abstract

Marine and freshwater fish aquaculture plays a significant role globally in ensuring food security. In 2020, marine fish accounted for 39% of the total aquatic animal production, while freshwater fish constituted 33% of total aquatic animal production. This trend is particularly notable in Europe, where species like rainbow trout, seabass and seabream are extensively farmed. Among them, rainbow trout is one of Europe's top five farmed species in terms of production and in Italy it is the main breeding species. However, despite the sector's significance, there is a gap in the literature concerning the potential environmental impacts generated by farmed rainbow trout (e.g., nutrient discharge, use of non-renewable resources, overexploitation of fish stocks). To cover this gap, this study aims to assess the potential environmental impacts of the rainbow trout production process, accounting a cradle to gate approach: from egg to grown fishes, ready for market. These are assessed applying the Life Cycle Assessment (LCA) method, in order to identify the main hotspots of process. The case study is conducted on trout farming using primary data provided by an Italian company that encompasses the entire production process. The data are collected through questionnaires and site visits, focusing on feed consumption, natural resource utilization, and emissions generated. The main findings of this study allow to identify the key environmental hotspots along the different stages of trout production, providing a basis for informing decision-making on which processes could be optimize and improved to mitigate environmental impacts effectively.

Keywords: LCA, rainbow trout, freshwater aquaculture.

Introduction

In recent decades, global aquaculture has grown significantly to meet rising food demand. From 2000 to 2022, global production of farmed animals increased by 204 per cent to 87.9 million tonnes. Finfish, in particular freshwater species, dominate this sector, with their share increasing from 20 per cent in 1961 to 55 per cent in 2021 (FAO, 2024). European aquaculture growth by more than 70.7 per cent from 2001 to 2022, with freshwater finfish being the most farmed group.

Salmonids, especially trout, are among the most valuable traded aquatic species. In 2020, Europe produced 183 thousand tonnes of rainbow trout, with Italy being the third largest producer with 33.8 thousand tonnes (STEFC, 2023). However, the rapid growth of the aquaculture sector has raised a number of sustainability concerns. These include emissions leading to climate change, eutrophication, toxic and ecotoxic effects, use of antibiotics, land and water requirements for feed production, biodiversity loss, introduction of non-native species, spread of parasites and diseases, genetic pollution, reliance on capture fisheries and socio-economic issues (Kok *et al.*, 2020; Ghamkhar *et al.*, 2021). Sustainable strategies intensification is essential to address these issues. Among the different tools available to assess environmental impacts, there is a growing interest in the literature towards life cycle assessment (LCA) as a holistic method. LCA is one of the environmental accounting tools that can provide critical information needed to improve the sustainability of aquaculture systems (Philis *et al.*, 2019). Indeed, LCA has been used in previous studies on salmonid and trout farming (Boissy *et al.*, 2011), as it is a valuable assessment method, standardised by ISO principles in ISO 14040 and 14044 (2006 a, b), to identify and monitor potential hotspots in aquaculture (Aubin *et al.*, 2009; Jerbi *et al.*, 2012; Dekamin *et al.*, 2015). However, although rainbow trout is the main species produced in Italy (STEFC, 2023) and aquaculture generates various environmental impacts (Laso *et al.*, 2022), there is only one study in the literature that applies LCA for assessing Italian trout farm environmental impacts (Maiolo *et al.*, 2021), and only nine LCA studies at global level on trout, seven of which are included in Philis' review (Philis *et al.*, 2019), with two additional papers published after the cited review and up to the first half of 2024 (Sanchez-Matos *et al.*, 2023; Pouil *et al.*, 2024). In detail, these studies used the LCA method to assess the potential environmental impacts of the pre-fattening and growing phases of trout, often neglecting the sowing and weaning phases, or aggregating the growing phases and including post-harvest activities. They primarily focused on the impacts of raw materials, particularly feed, with quantities typically estimated based on feed conversion ratios (Philis *et al.*, 2019) rather than directly collected for each trout growing phase. Furthermore, they overlooked detailed electricity consumption for each growth phase (Sanchez-Matos *et al.*, 2023), the distinction between grid and sustainable energy sources, and the environmental impact of packaging. Various studies have compared the environmental impacts of trout farming in different systems, such as conventional versus land-based closed recirculating systems, focusing on differences in feed conversion rates (Aubin *et al.*, 2009) or oxygen consumption (D'Orbcastel, Blancheton and Aubin, 2009), with environmental flows often limited to nutrient balances (Henriksson *et al.*, 2012). Other LCA studies have compared production scenarios using conventional feeds with innovative feeds based on plant ingredients, recycled fish industry by-products or insecticides (Dekamin *et al.*, 2015).

Therefore, considering that to date, no LCA studies have comprehensively addressed all stages of rainbow trout production, from embryonic eggs to commercially sized fish (Philis *et al.*, 2019). Thus, by examining the potential impacts generated at each stage of the production process, this study provides a novel insight into the environmental impacts of rainbow trout (*Oncorhynchus mykiss*) farming, highlighting the different contributions of the same inputs at different stages of production. This aspect of carrying out a contribution analysis has been largely neglected in the literature. While Silvenius (2017) carried out a contribution analysis, it focused on the environmental impact contribution of clusters of national trout farms producing adult fish of different sizes, with impacts determined based on the weight of the final product at the farm gate. In contrast, this study captures, within a single production cycle, the specific impacts that contribute most to each of the three main impact categories presented, providing an innovative and comprehensive approach to understanding the environmental dynamics of rainbow trout (trout) farming.

Methods

This paper uses the LCA method to identify environmental hotspots in rainbow trout farming, providing insights into resource use and emissions. Following the ISO 14040-44 standards (ISO, 2006b, 2006a, 2020a, 2020b), this section includes four sub-sections to describe assumptions, approaches and choices made for goal and scope definition, including a brief description of case study (2.1), inventory analysis (2.2), impact assessment (2.3) and results and discussion (3) phases. This study provides a contribution analysis of how factors from the three different growth phases of the fish impact on the environment.

Goal and scope definition

The aim of this study is to assess the potential environmental impacts of trout production in a freshwater flow-through system (FWFT) fed by natural karst spring water in Italy. A contribution analysis allows for identifying potential environmental hotspots. To achieve this, a trout farm in the Triveneto region of Italy is selected as a case study (CS) and the potential environmental impacts throughout the entire growth cycle of the trout are assessed. Indeed, the farm manages the entire life cycle of trout, from embryonated eggs to market size fish. The farming process is investigated according to three main phases: i) hatchery, where eggs are incubated and fry are reared for approximately two months; ii) pre-fattening, where fish grow to 220-250 grams over eleven months; and iii) on-growing, where adult fish reach a final size of around 1,000 grams in approximately seven months. Strict protocols for feeding, cleaning and water management are followed to ensure fish health and growth. Data collection occurred in the first quarter of 2024, covering the period 2022-2023, as the trout life cycle is about 20 months. This preliminary assessment of the environmental performance of the system suggests potential improvements to help farmers reduce the environmental impact of aquaculture processes. The functional unit (FU) selected for the study is 1 tonnes of live weight (LW) rainbow trout, as it is the most commonly used in literature (Dekamin *et al.*, 2015; Philis *et al.*, 2019; Maiolo *et al.*, 2021; Sanchez-Matos *et* *al.*, 2023; Pouil *et al.*, 2024). The system boundaries, shown schematically in Figure 1, follow a cradle-to-gate approach, encompassing three main growth phases of trout reared in freshwater under continuous flow conditions.

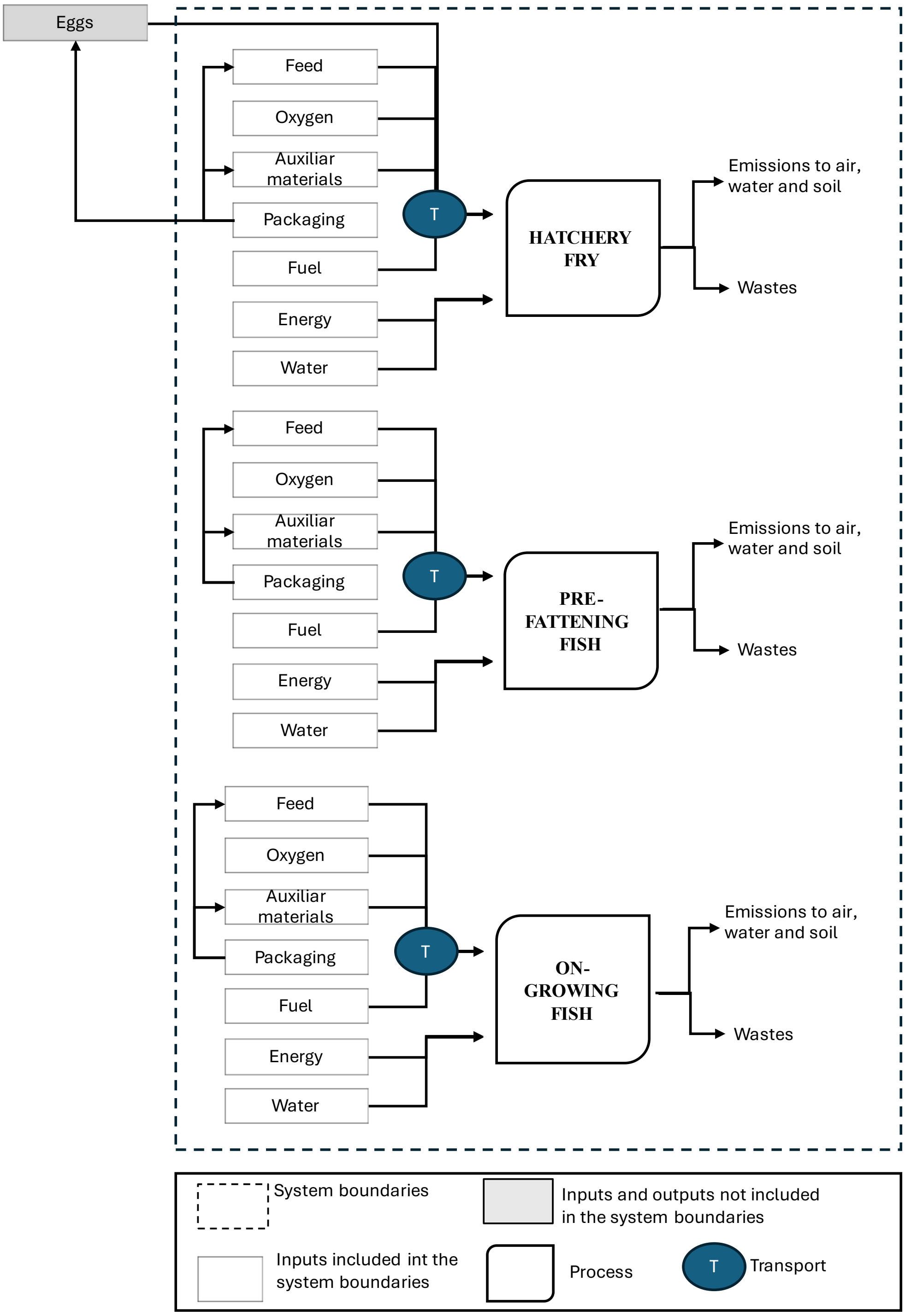

Figure 1*: System boundaries of the case study on rainbow trout production*

As highlighted in Figure 1, the study includes all the impacts linked to resource production, energy consumptions and water use, as well as all the contributes of internal transportation from one phase to another.

Instead, the production of embryonated eggs is excluded from the system due to missing data, but their transport from suppliers is included. Additionally, some other processes are excluded: a) the transport of market-ready fish to customers, b) the disposal of dead fish by an authorised company that uses them for processing into animal feed, c) the sludge produced by the farm that is generally used for agricultural purposes and whose contribution is excluded from the analysis based on previous studies (Besson *et al.*, 2016), and d) infrastructure, due to the significant time required to calculate their total input relative to their minimal impact (Ayer and Tyedmers, 2009, 2010). However, the energy and the fuel consumed at each stage are included. Both primary and secondary data are used. Primary data are collected through interviews with key managers. The farm provided data managed through its internal management system, which tracks the quantities of raw materials, energy and fuel consumed through supplier invoices. The farm provides data on the production batch because it has an in-house traceability system that keeps a daily log of all information relating to the farmed fish in each tank. Thus, all data are collected for the two calendar years covered and related to the production batch covered by this CS.

Secondary data are used when some data is missing, e.g., the amounts of direct emissions to water generated by feed. In this case, technical sheets of feeds are used. Other secondary data are related to the estimation of the background processes, obtained from the Ecoinvent 3.8 database (Moreno Ruiz *et al.*, 2021). The LCA study is performed using the SimaPro v. 9 software.

Inventory analysis

The inventory analysis involved the collection of data to quantify the inputs and outputs associated with the production of one tonne of LW rainbow trout (FU). As mentioned above, both primary and secondary data are used for the study. The first are collected through questionnaires, site visits and interviews with the production manager, owner and veterinarian of the organisation. The inventory includes information about feed, energy, water, oxygen and other resources used from the production from fingerling to adult fish and the release of farm emissions to the environment. Table 1 shows the input and output data included in the analysis in relation to each stage of growth to produce 1 tonne of LW trout.

Inputs were specific to the batch analysed, corresponding to the actual duration of each growing phase. The use of water from river was calculated from tank volumes and cross-checked with the farm's annual water flow analyses. The water entering the farm had an average flow rate of 0.4 m^3/s. The water from river is equal to the water back to river, as the farm uses a continuous water flow system, as commonly assumed in the literature (Maiolo *et al.*, 2021). Therefore, in the case of trout, water drawn from the river to supply the raceways for trout production was not taken into account because this water was returned to the river and thus reusable (Boissy *et al.*, 2011).

The feed data are based on the actual amounts used throughout the rearing period. The feed production process is modelled using Ecoinvent datasets (Moreno Ruiz et al., 2021). Unlike typical LCA studies of rainbow trout and salmonids, which often rely on estimates using feed conversion ratio (FCR), this study provides accurate feed data. The accuracy of the reported quantities was verified by estimating the FCR (FCR = kg of feed distributed / kg of live weight fish produced) for each stage of production. Feeding rates were monitored from hatching to pre-fattening, with later phases estimated from the farm's recorded FCR and compared with supplier rates and literature values (Philis *et al*., 2019).

Table 2*: Life Cycle Inventory: Input and output data for each phase is scaled to 1 tonne of live weight rainbow trout.*

		Phase		
Category	**Unit**	**Hatchery Fry**	**Pre-Fatty Fish**	**On-Growing Fish**
INPUT				
Feed	kg	7,56E-01	5,50E+02	5,18E+02
Disinfectant	l	2,98E-02	1,31E-01	1,31E-01
Diesel	MJ	3,45E+00	2,73E+01	5,14E+01
Electricity	kWh	3,00E+01	9,88E+00	2,43E+01
Electricity (pv)	kWh		5,37E+01	1,79E+01
Water (from river)	m^3	7,29E+02	2,37E+04	5,50E+04
Mixed petrol	kg	8,87E-03	1,95E-01	1,31E+00
Oxygen	kg	8,40E-03	1,47E+00	5,51E-01
Packaging (hdpe)	kg	9,95E-04	1,19E-02	1,19E-02
Packaging (ldpe)	kg	1,51E-02	6,45E+00	6,06E+00
Packaging (ps)	kg	3,98E-03		
Transport	kgkm	2,76E+04	7,79E+05	8,22E+05
OUTPUT				
1° phase hatchery	kg	2,87E+01		
2° phase pre-fattening	kg		4,24E+02	
3° phase on-growing	kg			1,00E+03
Water (back to river)	m^3	7,29E+02	2,37E+04	5,50E+04
Emissions to water (N)	kg	5,11E-01	1,51E+01	4,23E+01
Emissions to water (P)	kg	1,75E-02	2,23E+00	3,57E+00
Waste incineration (organic waste, PE, PS, PP, PB)	kg	4,37E-01	3,04E+01	2,89E+00
Waste recycling (PE)	kg	1,51E-02	6,45E+00	6,06E+00

Also the production of liquid oxygen from the cryogenic air separation process was considered, following the methodology used in other LCA studies on rainbow trout (Pouil *et al.*, 2024). Oxygen consumption was provided by the farm based on the quantities purchased for the batch. The quantity for each phase was allocated according to the fish movements, as oxygen is used in all phases for transport and in the hatchery and pre-fattening phases to enrich the water input.

Auxiliary materials use, such as disinfectants, was calculated according to the farm's internal hygiene and safety procedures. Packaging data refers to consumables and raw materials purchased by the company, as farmed fish arrive and leave the farm unpacked.

Fuel and energy consumption has been calculated based on the hours of use and power ratings of machinery and equipment, validated by electricity bills and fuel purchase records.

Transport was calculated based on the number of kilometers travelled annually by the farm's own truck, considering the real number of trips made exclusively for the batch analysed. Transport of raw materials has been calculated using supplier invoices for 2022-2023, estimating the kilometers attributable to the batch by knowing the distances between the suppliers and farm sites and the number of trips made.

Outputs included resource use within the system. Dead fish waste was calculated based on mortality rates provided by the farm and cross-checked with records from the authorised fish waste disposal company. Packaging waste from feed sacks, medicated feed, disinfectants and egg transport frames was weighed and calculated for each farming phase, categorised for accurate disposal tracking (recycling or incineration) and validated against company waste management records. Transport also includes the kilometers travelled to approve the fuel used in vehicles and equipment. In this case, the farm reported the number of approvals, assuming that the average distance to the supplier was always around 5 km. Emissions were calculated from feed technical sheets and compared with the farm's bi-annual chemical-physical analyses to ensure data accuracy for this analysis, using secondary Ecoinvent data.

Impact assessment.

For the impact assessment phase, the CML-IA baseline method (Guinée *et al.*, 2002) is selected according to the findings of Philis et al. (2019), which indicate this method as the most employed in salmonid LCA studies. For this preliminary study, only three key impact categories are selected, in line with the evidence presented in the existing literature (Grönroos *et al.*, 2006; Philis *et al.*, 2019), namely: climate change (GWP) (Aubin *et al.*, 2009; D'Orbcastel, Blancheton and Aubin, 2009), acidification (AP) (Avadí and Fréon, 2013; Chen X. *et al.*, 2015), and eutrophication (EP) (Ayer and Tyedmers, 2009). These impact categories were chosen due to their scientifically established characterisation factors, which have been thoroughly validated and widely discussed in LCA studies on trout production (Philis *et al.*, 2019).

Results and Discussion

Table 2 reports the characterization results of analysis, showing the potential environmental impacts for the FU selected.

Table 3: *Potential environmental impacts of the three rainbow trout farming stages* for FU (characterization results)

Impact category	Unit	Hatchery fry	Pre-fattening fish	On-growing fish	TOTAL
GWP	kg CO_2 eq	2.67E+01	1.15E+03	1.14E+03	2.32E+03
AP	kg SO_2 eq	8.77E-02	3.98E+00	3.90E+00	7.97E+00
EP	kg PO_4^{3-}eq	2.93E-01	1.61E+01	3.14E+01	4.78E+01

The table clearly shows that the greatest impacts in all categories are generated by the second and third phases. In particular, each phase contributes to each impact category as follows:

- hatchery fry phase contributes minimally to GWP (1.2%), AP (1.1%), and EP (0.6%);
- pre-fattening fish phase contributes significantly to GWP (49.6%), AP (49.9%), and EP (33.7%);
- on-growing fish phase contributes significantly to GWP (49.1%), AP (48.9%), and EP (65.7%).

In order to observe which is the main hotspot that affect each phase of growing of trout, a contribution analysis is conducted reporting the results in Figure 2. This detailed breakdown highlights the environmental inputs and outputs at each stage and provides insight into the main factors influencing the overall environmental footprint of the production system.

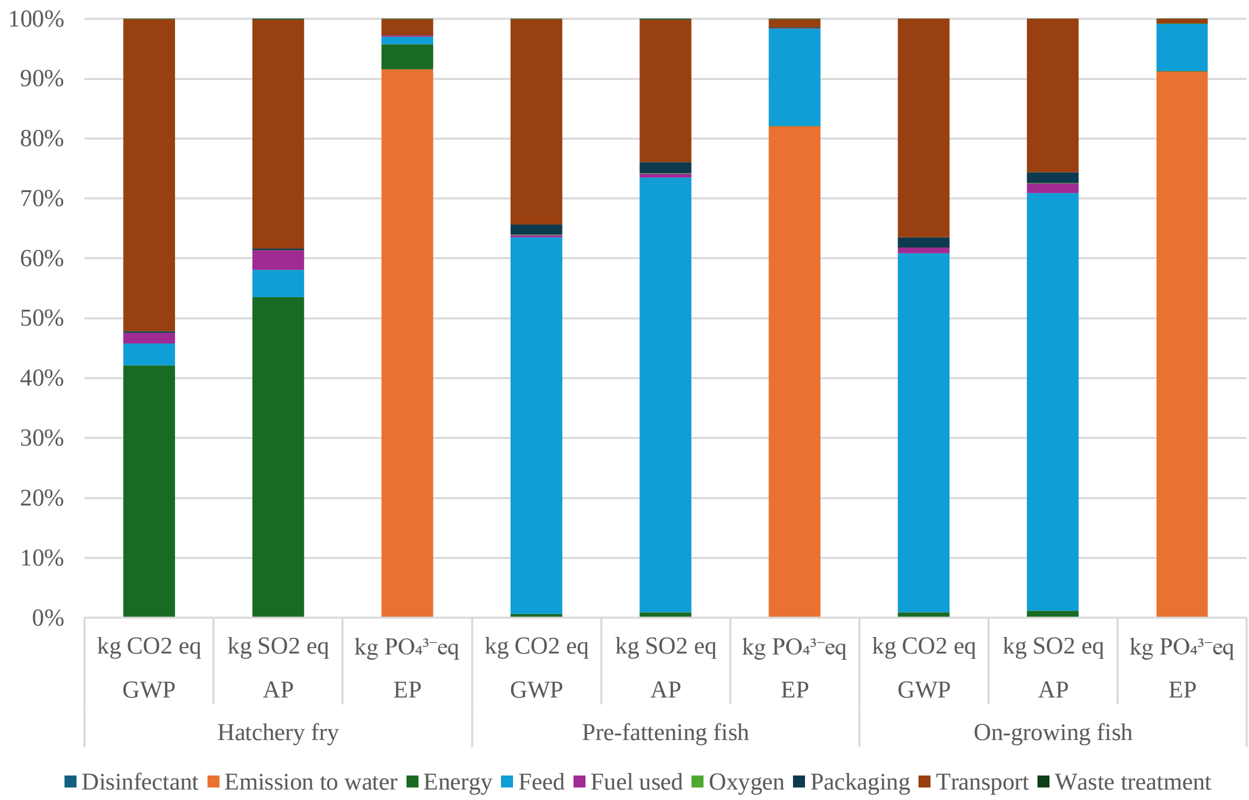

***Figure 2**: Contribution analysis for the three phases of the trout production system (characterization results).*

According to the graph of figure 1, it could be noticed that some major differences between the hotspots in the hatchery fry phase compared to the subsequent phases of pre-fattening and on-growing to adult fish exist.

In the hatchery phase, the main contributors to the GWP are energy (around 42%) and transport (52.2%). For the AP, the main contributors are also the energy (53.4%) and transport (38%). For EP, emissions to water dominate (91.5%).

In the pre-fattening phase, feed is the main contributor to GWP (63%), followed by transport (34.2%). For AP, feed contributes 72.5% and transport 23.8%. For EP, emissions to water (82%) and feed (16.2%) are the main contributors, with transport having a minor impact (1.4%).

In the on-growing phase, feed is the dominant factor for GWP (60%) followed by transport (36.5%). For AP, feed (70%) and transport (25.6%) are significant, while packaging is minor hotspot (less of 2%). For EP, emissions to water are the main contributor (91.2%), with feed contributing around 8%, while the transport contributes with less than 0.7%.

Additionally, in order to analyse if the results obtained in this CS are accurate, each impact category for each phase is compared with the literature results and discussed more in-depth in the following paragraph. In particular, the GWP for 1 tonnes of trout in this CS appears significantly better than that reported in the literature. Specifically, the GWP impact for trout is 21% lower than the literature reference value of 2,613 kg

CO_2 equivalent for inland water trout farming systems with continuous flow rivers (Philis *et al.*, 2019). This improvement is attributed to innovations in feed, with the commercial feeds used by the company being less impactful and more efficient in terms of both fish growth and environmental emissions (Chen X. *et al.*, 2015). The feed represents the main hotspot in this preliminary assessment, especially in pre-fattening and on-growing phases. It affects all categories significantly. For GWP, it contributes 59.9% (on-growing) to 62.9% (pre-fattening). Therefore, the preliminary results confirm that the feed is the largest contributor to these impacts (Aubin *et al.*, 2019), and it is consistent with the literature where feed production in land-based flow-through systems accounts for 48% to 88% of the impact categories considered (Ayer and Tyedmers, 2009). In this CS, feed contributes to 61% of total GWP related to life cycle of trout production. This result could be attributed to two factors that characterise the feeding process: feed is distributed only when the feed operators visually detect that the rearing fish are hungry, combined with a gradual transition to feeds containing higher percentages of plant-based ingredients and recycled by-product animal feed.

In order to fully understand the contribution of each trout growth phase to the impact categories, the distribution of different contributes to GWP is analyzed. The GWP is almost equally distributed between the pre-growing phase (49.2%) and the growing phase (49.6%), with the weaning and hatchery phases having a negligible impact (1.2%). In this CS, the most significant contributors to GWP are the transport of embryonated eggs and the use of grid electricity, accounting for 52% and 42% of the impact respectively. In particular as a hotspot, the transport results significant in hatchery and pre-fattening p; in particular for GWP (34.2% in pre-fattening to 52.2% in hatchery) and AP (23.8% in pre-fattening to 38% in hatchery).

EP impact is notable in the pre-fattening phase (23.8%). The impact on freshwater ecosystems is primarily influenced by the use of grid electricity, which accounts for about 70% of the impact, while egg transport contributes about 25%. This distribution is likely to reflect the initial rearing phase, which in this CS lasts about 2 months to produce juveniles averaging 10-15 grams. In contrast, other studies indicate a longer larval period to produce juveniles of approximately 70 grams. The farm's decision to limit the use of feed in the rearing phase only when fish are visibly hungry has probably resulted in a low overall impact on acidification (AP) and eutrophication (EP), contributing less than 1.1% and 0.6% respectively to the total AP and EP for the entire rearing cycle. Both the pre-fattening phase and the growing phase of adult fish have a similar impact on AP (around 49%). However, there is a significant difference in the impact on EP between these phases. The growing phase accounts for approximately 66% of the total EP impact for the entire rearing cycle. Specifically, the final growing phase of adult fish contributes more than 90% of the EP due to emissions released to the freshwater environment when process water is returned to the river. In addition, 8% of the EP is attributed to the use of high protein feed during this phase, resulting in a feed conversion ratio (FCR) of 0.9%. In the present trout LCA, the AP impact was found to be 7.97 kg SO_2 eq per tonne of LW trout. This is significantly lower than reported in other studies. For example, Grönroos (Grönroos *et al.*, 2006) reported 8.8 kg SO_2 eq per tonne LW trout, while Ayer and Tyedmers (Ayer and Tyedmers, 2010) calculated up to 63.4 kg SO_2 eq for similar outputs. For freshwater trout land-based systems in tanks, the average AP is about 16.3 kg SO_2 eq. Although the literature discusses whether there may be a correlation between AP and the FCR of the feeds used (Philis *et al.*, 2019), the AP in the present LCA is significantly lower than in previous studies. This could be due to an average FCR of 0.9-1, combined with the low average biomass density of less than 15 kg/m³ in the continuous flow water system that supports the entire aquaculture facility. Nevertheless, feed formulations can have a significant impact on AP values. In the present LCA, feed contributes to AP in the pre-growing phase (73%), followed by transport (24%). In the on-growing phase, AP is attributed to feed input (70%) and transport (26%). Acidification is strongly linked to fuel combustion and fuel consumption per kg of fish produced and can vary greatly depending on the region and fish species (Tyedmers, 2004; Pelletier *et al.*, 2007; Parker, 2012). In this LCA study, the EP is 47.5 kg PO_4^{3-}eq. The preliminary results of this study align with Boissy's findings on innovative feeds (Boissy *et al.*, 2011). EP seems to correlate with feed ingredient formulation and supports the view that feed is a major contributor to the environmental impact of fish farming (Boissy et al., 2011). EP values range from 42.2 kg PO_4^{3-}eq with standard feed to 47.9 kg PO_4^{3-}eq with new formulations based on soy and other vegetable ingredients. This supports the transition to innovative feeds used on the farm and confirms that EP is strongly related to the feed formulation and the feeding protocols used on the farm. Specifically, in this CS, the 43% of EP is attributed to phosphorus (P) emissions, 40% to nitrogen (N) emissions and 16% to the type of feed used. The production phases that contribute most to the total EP value are the growing phase of the adult trout, which accounts for 51% of the emissions leading to EP, and the pre-fattening phase, which contributes 16%. In detail, EP in the growing phase was mainly related to emissions (P and N), accounting for about 91% of total EP, and less than 8% to feed. The preliminary results of this study confirm the diversity found in the literature on this topic. Indeed, the average EP for trout in LCAs was around 50.7 kg PO_4^{3-}eq (Philis *et al.*, 2019) . Some researchers have investigated the replacement of fishmeal and fish oil with vegetable ingredients and found that the environmental impact of trout diets vary with the geographical origin of the fishmeal and fish oil (e.g. Peru or Norway) and the type of plant used (e.g. rapeseed or palm oil). In this study, the findings regarding EP highlight the heterogeneity of results reported in previous studies for this impact category. Thus, according to the preliminary results of this study, the EP seems to correlate with feed ingredient formulation and supports the view that feed is a major contributor to the environmental impact of fish farming (Boissy et al., 2011). The preliminary results related to emissions that impact EP must be subjected to further analysis in future studies. It should be noted that the EP method is currently unable to assess other potential releases, such as dead fish, faeces production, and feed loss during distribution, as it only evaluates the feed. In a final assessment of these impacts, individual pollutant emissions of various elements not considered in this preliminary analysis could be calculated, as they might demonstrate different impacts on EP. This approach has been previously utilised in a study which employed mass-balance methods (Besson *et al.*, 2016).

Conclusions

In conclusion, this LCA study of 1 tonne of LW trout farmed in northern FWFT Italy provides preliminary results on the impact categories of GWP, AP and EP, which are of significant interest to researchers. The study identifies hotspots contributing to these impact categories, with the highest impacts associated with phases of pre-fattening and on-growing fish, particularly due to feed use. This study represents the first attempt to model an LCA analysis of Italian trout aquaculture using water from natural springs with a constant temperature of 13°C throughout the year. The results show that the AP is significantly lower than reported in the literature, reflecting the responsible and sustainable practices adopted by the farm. By controlling the average biomass density in the trout pond, which never exceeds 15 kg/m³, the company ensures the dilution of biomass production emissions in water volumes that also guarantee oxygenation rates above vital minimums. This practice maintains the well-being of the fish, as evidenced by the fact that medicated feed was only used for a few days during the weaning and pre-fattening phases (when the fish had an average weight of 15 grams). The environmental sustainability of farm is also linked to the feeding protocol, which includes commercial feeds based on both fish and vegetable meal. Semi-automated feeding is always supported by a feeding operator who adjusts the amount and timing of feeding based on constant observation of fish movements. This approach reduces uneaten and lost feed in the water leaving the farm. The pre-growing phase has a slightly higher impact across all three categories, except for EP, which is more significantly influenced by the on-growing phase of adult trout. This may be due to the higher energy ingredients used in the feed formulation during the later stages of the on-growing phase. In both the pre-fattening and the on-growing phases, feed is the main source of environmental impacts, followed by transport and the use of electricity from the national grid. The main hotspots generating environmental impacts in the continuous flow production cycle of trout at the Triveneto company are a) feed, the main source of environmental impacts in both the pre-fattening and fattening phases. b) transport, the second largest contributor to AP and GWP impacts. c) electricity use, a significant contributor in hatchery to all three impact categories, particularly due to the reliance on electricity from the national grid. As the sector is energy intensive, a comprehensive LCA should include the calculations of energy indicators to provide a more complete understanding with trout farming. Indeed, future research should focus more on the energy aspects of trout aquaculture, in particular exploring the potential impact of using solar energy during all three phases of the rearing cycle, rather than only during the pre-fattening and growing phases, as is currently the case. To evaluate these contributions, a solution could be including the calculation of Cumulative Energy Demand (CED), which quantifies the total energy required throughout the production, use and disposal of a product or service. Moreover, a limitation of the present study is the need for a more in-depth evaluation of feeds, especially medicated feeds. This limitation is due to the lack of datasets that better represent the different types of feed, especially medicated feed. To address this, future research should focus on developing comprehensive datasets that accurately reflect the environmental impacts of different types of feed used in aquaculture. Furthermore, the preliminary results related to emissions must be subjected to further analysis in future studies. It must be acknowledged that the EP impact category is currently unable to assess other potential releases, such as dead fish, faeces production and feed loss during distribution, as it only evaluates the feed. In the light of the preliminary results reported, among the solutions proposed for future investigation, it is suggested that the effects of producing more sustainable feeds, such as those based on algae, should be evaluated in more detail and that it should be understood if there are benefits to be gained from the use of algae-based feeds. Similarly, the organic waste produced in aquaculture could be considered for its value in other sectors such as agriculture as bio-fertiliser, in the chemical and pharmaceutical industries for the extraction of valuable compounds. Finally, assessing the environmental impact of aquaculture infrastructure is crucial, especially in disadvantaged mountainous areas. Properly managed aquaculture can contribute to environmental conservation measure, helping to maintain the ecological state of the neighbouring area.

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Design and development of a life cycle model for the production of denim in small and medium enterprises

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Abstract

Life Cycle Inventory is the second phase of Life Cycle Assessment in which data on inputs and outputs of each unit process are collected. Such phase is crucial to guarantee good quality of the results. However, most of the time such studies rely on secondary data taken from datasets or tertiary data based on assumptions. This is particularly truth when small medium enterprises are involved in the supply chain. The main reason is that secondary data, such as those from Ecoinvent, are market average. Therefore, results could be significantly affected by uncertainty. The objective of this study was to conduct a Life Cycle Assessment of a product in which the supply chain is mainly composed of small companies. The case took into consideration the production of denim for the high fashion industry in Fashion Artlocated in Veneto, northeast of Italy. This choice is supported by the characteristics of the supply chain and the limited availability of datasets in Ecoinvent. The inventory phase was performed by collecting primary data through direct data collection in 118 companies among the processes that were outsourced to small enterprises (for sewing, washing, cutting and welding operations). Focusing on climate change, results showed that on average the 30% of the impacts are related to such processes. Results were confronted with Ecoinvent standard dataset showing that results would have been significantly underestimated by using secondary data. When small and medium enterprises are concerned the collection of primary data is confirmed to be crucial.

Keywords: Life Cycle Assessment, Data Quality, Fashion Industry, Small and Medium Enterprises

Relevant Topic: Sustainable Supply Chain Management, green supply chain and quality

Introduction

Significant water use, effects of chemicals used for dyeing processes, and the production and disposal of large quantities of unsold stock through incineration or landfill, along with limited end of life management practices, makes the fashion sector one of those with the highest impact on the planet (Pal, Gander 2018, Quantis, 2018). Increased consumer awareness and new regulations on climate change, as well as the recent EU regulation on the product digital passport (European parliament. Legardeur, Ospital, 2024) have accelerated the need for solid, consistent and transparent actions leading to results that support fashion brands' sustainability claims and initiatives. In this context a need for tools capable of measuring, reporting and giving guidance on where to intervene to reduce such impacts has emerged (Quantis, 2018). Among the different tools available, Life Cycle Assessment (LCA) has been extensively adopted and recognized to be a powerful tool to support companies in their transition towards more sustainable production systems (ISO, 2006). LCA is a standardized methodology that allows the analysis of a product, process or activity along all the stages of its life cycle aimed at determining its potential impacts on the environment. LCA is a comprehensive assessment that takes a product life cycle prospective and covers a comprehensive range of environmental impacts. These unique features of LCA facilitate avoiding problem shifting from one life cycle stage to another stage, or from one environmental impact to another (Finnveden & Potting, 2014). According to ISO 14040 (ISO, 2006) LCA is structured into 4 phases namely (i) defining the study's goal and scope, (ii) conducting the inventory analysis, (iii) calculating and assessing environmental impacts, and (iv) interpreting the results. LCA, despite its strengths, present several limitations that range from the subjectivity of value choices that need to be taken to the availability of data (Filleti et al., 2014). This latter emerged one of the main issues in the fashion industry (Uncu Aki et al., 2023). The main reason is that the sector is characterized by a significant amount of small medium enterprises (SMEs) that have limited knowledge and resource to monitor and collect environmental that are necessary to obtain solid LCA results (Daddi et al. 2015). The result is that the quality of data from SMEs are limited and sometimes even no datasets are available in literature **(**Daddi et al., 2015). Consequently, the results can be significantly uncertain. The aim of this work is to investigate potential solutions to improve the quality of data from SMEs when conducting LCA for fashion products. The research was carried out between 2023 and 2024 and refers to the production of high-end fashion denim from Fashion Art, a company located in the north-east of Italy. This choice was made because of the characteristic of the production processes characterized by small medium enterprises located in the same region.

Methods

The method used to carry out the research is LCA according to ISO 14040 and ISO 14044 (ISO, 2006a; 2006b). For the Inventory analysis part, a statistical champion of representative SMEs was determined. To verify the deviation of results from common LCA datasets used in the study a sensitivity analysis will be performed by substituting primary data with available datasets representing market average production processes. Hereafter the detail of the LCA study is presented.

Goal and scope definition

The goal of the study is to quantify the potential environmental impacts of a high-end fashion denim conducted by collecting primary data from SMEs enterprises and verify potential deviation of environmental impact assessment category results with those obtained by using commonly adopted dataset. Therefore, the functional unit of the system is defined as the production of one pair of jeans, the results will be reported per item considering an average sized and weight of a standard model of denim produced by Fashion Art. This size is representative of the market of the company. The weight is an average of the different denim fabrics implemented in the production. System boundaries (see fig.1) where defined adopting a cradle to gate approach and includes the following main operations most of which are outsourced to other SMEs:

- Cutting: the denim is cut into its shape. Processing is carried out using automated machinery programmed from time to time depending on the measurements of the starting denim and the size of the final garment to maximize the efficiency of cutting.

- Assembly and sewing: during the sewing and assembly stage another very important raw material is involved: thread. This can have different compositions depending on the specific stitching that will be done. The operation is manual and involves the use of sewing machines.

- Washing: all the washing stages during production are carried out in large industrial washing machines involving the use of specific chemicals depending on the type of fabric.

- Drying: this phase, like the previous one, is carried out in large industrial dryers. During this phase, the percentage of fabric shrinkage is also considered. Generally, the washing and drying phases are consequential and are carried out in the same factory.

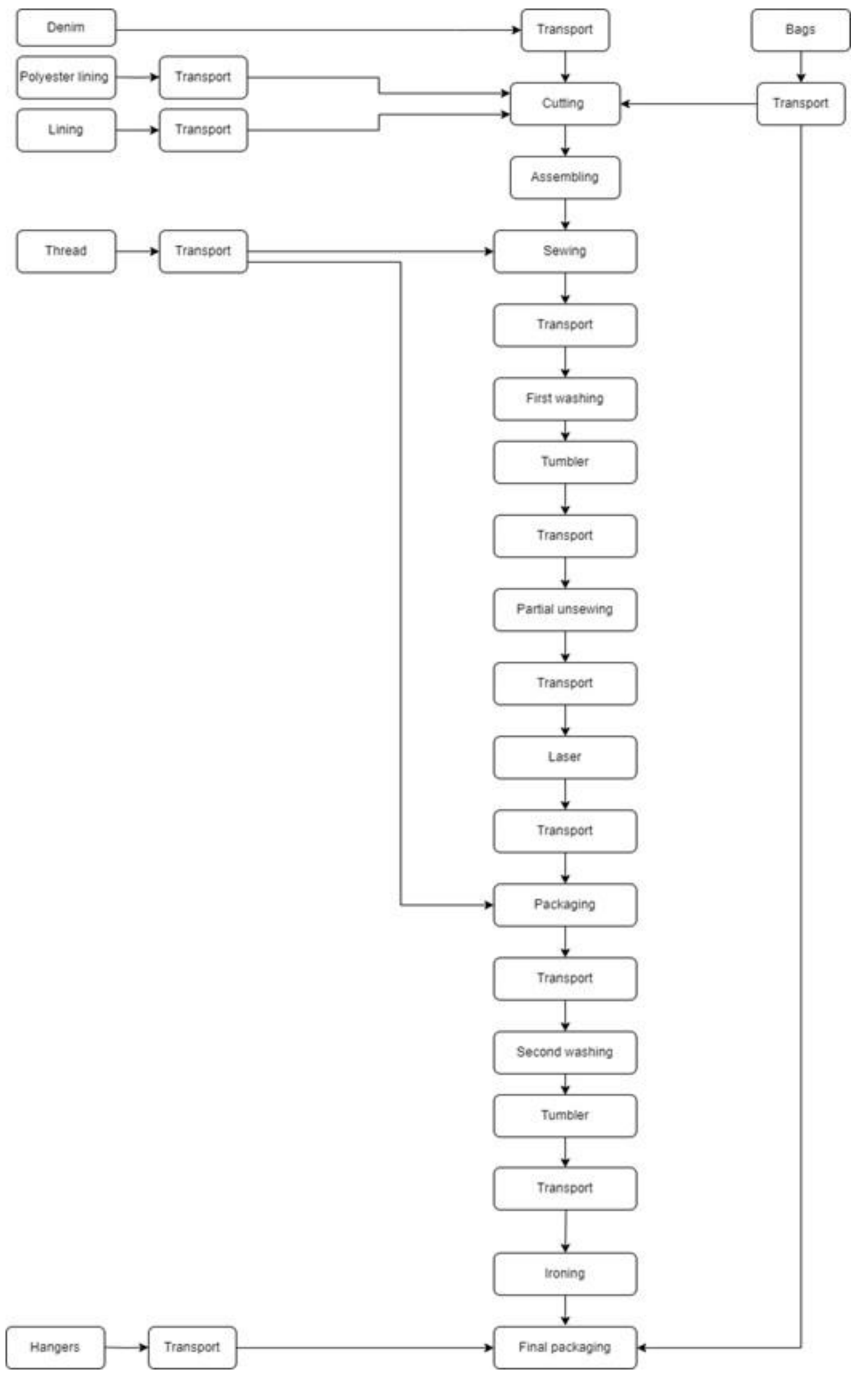

Figure 1. *System Boundaries.*

- Partial unsewing, this phase is not always carried out but depends on the trouser model being considered. It is generally carried out when there is a need to create a pattern in the trousers which must be uniform throughout the fabric.

- Laser: it is a processing step that allows a permanent pattern to be created in the fabric. Chlorine-based chemicals are often used to carry out this processing, alternatively ozone can be used.

- Sewing and packaging: these are those phases in which the product takes the form of finished product

- Second washing: is a simple final washing step that prepares the garment for final dispatch
- Ironing
- Final packaging: this is a delicate phase that can involve different types of packaging depending on the end customer for whom the product is produced.

Where needed, allocation was performed on a mass basis in all cases where data availability allowed, alternatively on an economic basis. The impact categories considered in this study are as follows: acidification potential, eutrophication potential, global warming potential, photochemical oxidant creation potential, abiotic depletion potential - elements, abiotic depletion potential - fossil fuels, water scarcity footprint (WSF). Most impact categories are taken directly from the CML-IA baseline method (eutrophication, global warming, ozone depletion and abiotic resource depletion) and CML-IA non baseline method (acidification). Water scarcity category is based on AWARE method and photochemical oxidation is based on ReCiPe 2008 (SimaPro database manual, methods library, 2020).

Life Cycle inventory model

The Life Cycle Inventory started with mapping and sampling all of the suppliers' services, workmanship and materials for the denim produce and classifying them according to turnover and type of workmanship. Doing so 118 companies were identified.

Table 1. *Supplier per process and products.*

Type of service/product	Number of suppliers
Accessories	2
Adhesive	2
Buttons	11
Sewing	15
Lining	5
Labelling	11
Laser	1
Washing	12
Ribbons	4
Leather	1
Embroidery	5
Epaulettes	1
Logistics	1
Ironing	4
Cutting	5
Fabrics	39
Zip	3

Two approaches were adopted to determine the dimension of the final sample to be investigated: cut off and sampling. The cut off is a methodology very often used in LCA analysis which allows for the exclusion of certain input and output flows from the analysis sample. The rules for carrying out the cut off may vary, but in general all flows which contribute less than 5% (or even 1%) are excluded from the analysis (ISO, 2006). In this study the cut-off rules selected was based on the total turnover of each supplier. Based on this value obtained, all companies whose turnover, when added sequentially, led to the threshold value being reached were excluded from the analysis. This methodology resulted in a representative sample of 38 companies; the sample respect the condition that at least one company per type of processing must be included in the final sample. After cut-off a sampling approach was adopted. This process represents the procedure by which, from a set of units called a population, a finite number of cases called a sample is extracted which is representative of the entire population. In this study, since the composition of the starting population was available, a non-probabilistic sampling was adopted and in detailed a quota sampling-type (Clarification of Ministerial Decree No. 56 of 21 March 2018). In this study the population was divided into a set of homogeneous strata within them according to the production type. The final sample consisted of 12 SMEs. The actual data collection phase was carried out by submitting a specially structured data collection form to each of the companies making up the representative sample.

Model for the discussion of results

Two approaches were applied for the discussion of the LCA results with reference to the research objectives. The first one entailed the application of sensitivity analysis with literature review impact assessment results. For this purpose, considering that a limited number of LCA study on denim are available, the study published by Levi Strauss on their 501 model (Levi Strauss & co. 2015) and the one from Nudie jeans (Åslund Hedman Emma. 2018) were selected. Comparison will be performed with reference to those impact categories that were consistently investigated in the three studies: Global warming (GWP100a), Eutrophication and Acidification.

The second one entailed the substitution of primary data with secondary data obtained from Ecoinvent (Ecoinvent, 2023) and Higgs datasets (Higg index learning center, 2024) for the processes that resulted to have the biggest contribution to the overall impacts.

Results and Discussion

Table 2 reports on the impact assessment category results expressed per functional unit.

Table 2. *Impact assessment results.*

Impact category	Units	Total
Acidification	kg SO2 eq	1,73E-01
Eutrophication	kg PO4 --- eq	2,11E-01
Global warming (GWP100a)	kg CO2 eq	2,88E+01
Photochemical oxidation	kg NMVOC	9,75E-02
Abiotic depletion, elements	kg Sb eq	1,26E-04
Abiotic depletion, fossil fuels	MJ	3,47E+02
Water scarcity	m3 eq	2,79E+02
Ozone layer depletion (ODP) (optional)	kg CFC - 11 eq	4,29E-06

Figure 2 reports on the contribution analysis expressed at life cycle stage level. For each impact category analysed, the highest results are obtained from raw materials, which means that the production of the raw materials fabric, adhesive, lining, zip and button has the highest impact in environmental terms. The second category that has a great impact on the production process is the manufacturing category which includes all the processes performed on the reference garment.

Regarding transport and packaging, their impact is only a few percentage points of the total. This means that their impact contribution to the total is almost negligible, and this gives a clear indication of where it is best to act first to reduce the impacts of the whole process.

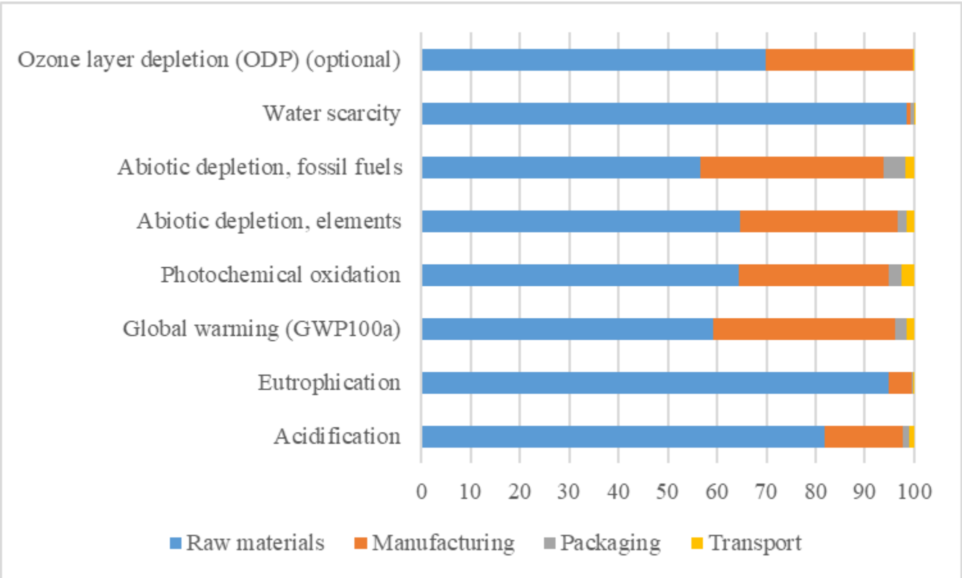

Figure 2*. Contribution analysis.*

Digging into the Raw Materials and Manufacturing phases more detailed contribution can be investigated. From this analysis, within the raw material category, the main impact is due to the fabric and lining. The reasons for this are probably related to the quantity, as of all the materials used, these two are undoubtedly present in the greatest quantity, and to the production process itself. For both in fact start with the cultivation of cotton, which must be transported and undergo a lot of processing that also involves the use of a variety of chemicals that therefore cause consequences for the environment. Among the manufacturing processes, sewing is the most impactful, certainly because it is carried out three times during the entire production process and involves a greater use of raw materials than the other processes. The second most impactful process is washing, again a plausible result as it involves the use of a significant amount of water and chemicals per garment.

Table 3 reports the results of the comparison of results with literature.

Table 3. *Comparison with literature review results.*

Impact category	Measurement unit	Case Study	Nudie jeans	Levi’s
Global warming (GWP100a)	kg CO2 eq	28,8	33,4	16,65
Eutrophication	kg PO4 --- eq	0,211	0,007	0,489
Acidification	kg SO2 eq	0,173	0,081	-

It can be derived that there is a significant variability in results when compared to literature. This could be partially justified if considering the origin of raw materials of the products investigated: both of the case study and Nudie jeans are based on organic cotton production vs Levi’s which is a traditional production.

Table 4 reports on the comparison of results when primary data or secondary data are concerned.

Table 4. *Comparison with secondary data results*

		Washing		Cutting and sewing		Denim	
Impact Category	Unità	Literature *	Primary data	Literature **	Primary data	Literature ***	Primary data
Acidification (fate not incl.)	kg SO2 eq	9,55E-04	4,80E-03	-	7,27E-03	1,40E-02	1,44E-01
Eutrophication	kg PO4--- eq	6,49E-04	1,31E-03	-	2,85E-03	9,00E-03	2,07E-01
Global warming (GWP100a)	kg CO2 eq	3,39E-01	3,48E+00	6,95E-01	1,97E+00	3,08E+00	1,60E+01
Photochemical oxidation	kg NMVOC	9,99E-04	6,94E-03	-	7,30E-03	9,00E-03	5,93E-02
Abiotic depletion, elements	kg Sb eq	1,25E-06	5,42E-06	-	1,07E-05	3,42E-05	7,70E-05
Abiotic depletion, fossil fuels	MJ	4,43E+00	4,28E+01	-	2,46E+01	3,81E+01	1,76E+02
Water scarcity	m3 eq	-3,70E-01	6,43E-01	-	4,57E-01	8,35E+00	2,86E+02
Ozone layer depletion (ODP) (optional)	kg CFC-11 eq	6,73E-09	9,88E-08	-	3,55E-07	1,91E-07	9,40E-07

Results of this sensitivity prove that there is significant variability between primary data and datasets that are usually designed for big enterprises supply chain. The results would have been most of the time significantly underestimated in most of the impact assessment categories.

Conclusions

This study has investigated the effects of data choices among primary and secondary data (dataset) is concerned when SMEs constitute a significant part of a supply chain of Fashion Art. The study refers in detail to the fashion industry that is characterized by such a condition. Results has proved that the use of dataset can significantly underestimate the final product's impacts. This could be a problem when LCA is used for decision making by driving Fashion Art to address wrong hot-spot and communicate results with a significant level of uncertainty. It must be considered that primary data collection always requires economic and other resource use that, depending on the nature of the company, could not be sustained by the commissioner itself. To solve such issue the study how the adoption of a cut-off and sampling rules could help to reduce such load (in the case study from 118 to 12 companies).

Further research and investigations are needed to consolidate and generalize the results of this work. It has to be noted that the development of market datasets divided per market characteristics could be a potential way to be investigated in solving such issue.

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The role of uncertainty in representative Italian LCA database: the case of olive datasets

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Abstract

Data uncertainty plays a crucial role in influencing the quality of results obtained from a Life Cycle Assessment (LCA) study. Alongside, the use of representative data for the agrifood sector is fundamental, on the one hand, to account for the various technological, biological, and environmental factors affecting its related productions and, on the other, to reduce their related uncertainty. In this regard, as part of a research project (PRIN 2017, ID code 2017EC9WF2) funded by the Ministry of University and Research (MUR), the Italian Life Cycle Inventory Database of Agrifoods (ILCIDAF) database has been developed in order to provide LCA practitioners with regionalised data for four mains Italian agrifood products, i.e., olive oil, wine, citrus and bread/pasta. This paper aims to analyse two different approaches to calculate the uncertainty related to the regionalised data for Italian olive production included in the ILCIDAF database. In addition, these two approaches are compared in order to understand how these data and their related uncertainty may affect the final results. In the ILCIDAF database, the datasets for olive production have been developed by normalising the input and output to the olive yield of 19 Italian regions and considering its temporal variation between 2015 and 2020. In this context, the first approach consists of calculating the uncertainty connected to the temporal fluctuation of each region, assuming that the uncertainty is related to the annual variation of olive yield among regions. Instead, the second approach involves the use of the basic uncertainty reported in Ecoinvent for some categories of products and emissions. Results underscore that the uncertainty calculated according to the annual olive yield fluctuation is overestimated for the input and underestimated for the direct emissions when compared to the one based on Ecoinvent. Consequently, this contributes to differences in the uncertainty of the LCA outcomes, highlighting that the use of inappropriate uncertainty values may significantly affect the results.

Keywords: Life Cycle Assessment, ILCIDAF database, Olive, Regionalised data, Uncertainty

Relevant Topic: Fostering sustainable transition

Introduction

The agri-food sector plays a fundamental role in the achievement of sustainable development and the related Sustainable Development Goals (SDGs). According to OECD/FAO (2024), the World population is expected to grow by 700 million people by 2033, resulting in an increasing demand for agri-food products and consequently causing environmental, economic and social issues. For example, focusing on global greenhouse gas emissions (GHGs), the growing food consumption may contribute to about 288 million tonnes of carbon dioxide equivalent (CO_2eq) per year by 2100 (Yin et al., 2024). In this regard, among scholars, institutions and businesses there is common consensus on the need to identify and assess sustainable strategies for reducing environmental charges related to agri-food systems. Among the various methods available for assessing the environmental performance of agri-food systems, the Life Cycle Assessment (LCA) is considered one of the most suitable and adopted due to its specific focus on a life cycle perspective (Notarnicola et al., 2017). Indeed, LCA is a standardised method which allows the assessment of the potential environmental impacts of a product, process or service throughout its entire life cycle, thus including raw material extraction, transformation and manufacturing, distribution, use and end-of-life (Guinée, 2002). Among the four phases characterising the LCA framework (ISO, 2006a; ISO, 2006b), the inventory analysis includes the collection and quantification of the inputs and outputs needed to carry out the LCA study. With specific regard to agri-food products, the inventory should be built using, as much as possible, representative and regionalised data (Notarnicola et al., 2022). This is particularly important to improve data quality and reduce the uncertainty of the LCA results. Indeed, agricultural practices implemented in the agri-food sector depend on biological, technological and environmental factors which may strongly vary among countries and regions and their related geographical characteristics (Liliane and Charles, 2020). In this context, the national research project PRIN 2017 (ID code 2017EC9WF2) funded by the Italian Ministry of University and Research (MUR), aimed at developing the Italian Life Cycle Inventory Database of Agrifoods (ILCIDAF), with the scope to provide regionalised data to be used in LCA studies, for four main Italian agri-food products, i.e., olive oil, wine, citrus and bread/pasta. Starting from the datasets provided by the ILCIDAF database, this study aims to analyse and compare two different approaches to calculate the uncertainty related to the regionalised inputs and outputs for olive production in 19 Italian regions. In particular, the first approach consists in calculating the uncertainty of data considering the annual variation of olive yields among regions, in the period 2015-2020, which represents the timeframe selected for developing the ILCIDAF database (ILCIDAF, 2024). While the second approach is based on using the basic uncertainty related to some categories of products and emissions and reported in the Ecoinvent database (Ecoinvent, 2024). The latter represents the most common method adopted to calculate uncertainty in commercial databases.

After this introduction, the paper is structured as follows:

- Methods section, in which a description of the ILCIDAF database is reported as well as the two approaches used to calculate the uncertainty are described;
- Results and discussion section, in which the results related to the uncertainty analysis calculated using the two approaches are compared and discussed;
- Conclusions section, in which the main remarks of the study are reported.

Methods

The ILCIDAF database consists of 924 datasets, among which 384 are related to the agricultural phase for olive production (ILCIDAF, 2024). The datasets are related to 19 of 20 Italian regions (excluding Valle D'Aosta for which data were not available) and are built using both literature and statistical sources (secondary data), and data obtained through direct interviews and questionnaires (primary data). To pursue the aim of this study, the uncertainty is calculated for 19 datasets based on secondary data and related to the average olive production in 19 Italian regions, thus including all the processes involved in the agricultural phase (e.g., fertilisers and pesticide use, irrigation, transport, etc.). The functional unit selected per each of the datasets is represented by 1 kg of harvested olives, while system boundaries follow a cradle-to-distribution approach. It is important to highlight that the datasets are developed starting from the yield of harvested olives per each region. In this regard, to address the annual variation in olive production, a six-year period is considered focusing on the timeframe from 2015 to 2020. Then, the average production per each region is calculated as the mass (expressed in kg) of harvested olives per year, by the olive tree cultivated area (expressed in ha) per year. A detailed description of the technical and scientific profile as well as of the procedures applied for developing the datasets for olive production in the ILCIDAF database are reported in Saija et al. (2024).

According to ISO (2006a; 2006b), uncertainty analysis is a sensitivity check to be performed at the level of Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA) phases in an LCA study. Regarding the LCI phase, the uncertainty of inputs and outputs shall be evaluated in order to understand how data variability may affect the outcomes of the LCIA. Thus, uncertainty is strongly related to the quality of the data used to carry out the LCA study as well as to their spatial and temporal variation (ISO, 2006b). Different methods are available in the literature to measure uncertainty. Among these, the most commonly adopted is the one based on the use of the so-called pedigree matrix (Weidema and Wesnæs, 1996) and on the calculation of a geometric standard deviation (GSD) (Ciroth et al., 2012). The pedigree matrix allows the assignment of quality levels, based on expert judgment, through data quality indicators (DQIs), which consist of five quality scores to be referred to specific quality parameters, i.e., reliability, completeness, temporal correlation, geographical correlation, and further technological correlation. Then, each quality score is associated with an additional uncertainty as reported by Ciroth et al. (2012). Thus, the overall uncertainty (U_c) of the inventory data is represented by the GSD of a basic uncertainty (U_b) to which various additional uncertainty factors related to the five quality parameters (U_1, U_2, U_3, U_4, U_5) are added (Ciroth et al., 2012). The resulting value is dimensionless and can be equal to 1, representing a low uncertainty, or higher than 1 (the higher the value the higher the uncertainty).

Focusing on the aim of the study, two different approaches are adopted to calculate the uncertainty related to the investigated ILCIDAF datasets (figure 1). In particular, the first approach (Approach 1) adopted for measuring the uncertainty is based on the use of the GSD of elementary flows (e.g., fertilisers, pesticides, water, electricity, etc.) as the basic uncertainty calculated focusing on the temporal variation of olive yield (throughout the timeframe 2015-2020) in each region. Thus, it is assumed that the uncertainty may be related to the annual fluctuation of olive yields among the 19 Italian regions. On the other hand, the second approach (Approach 2) involves the use of the basic uncertainty reported in Ecoinvent and related to some categories of products and emissions according to Ciroth et al. (2012). For both approaches, the quality levels according to the DQIs approach are also assigned to include additional uncertainty. In this regard, considering that the 19 datasets evaluated in this study are developed using secondary sources, various data present the same quality scores. Overall, the 19 ILCIDAF datasets taken into consideration have an average DQI equal to 2.05, resulting in a good level of data quality.

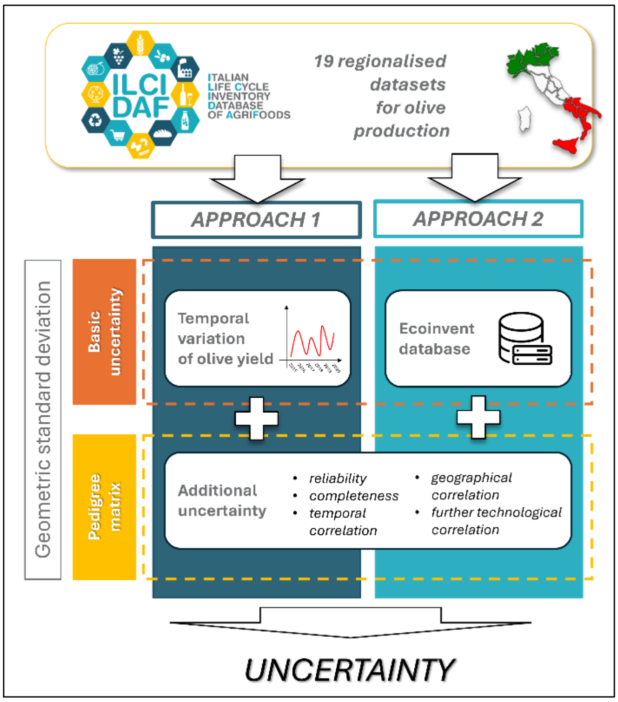

Figure 1. *Graphical representation of the two approaches applied to calculate the uncertainty of the ILCIDAF datasets.*

Results and Discussion

Figure 2 reports the results related to the comparison of the two approaches applied for calculating the uncertainty. Overall, the main findings show that, when Approach 1 is applied considering the annual variation in olive yields among the Italian regions, the uncertainty compared to the Approach 2 is overestimated for most of the inputs and underestimated for the outputs, with specific regard to the air, water and soil emissions. The uncertainty calculated using the Approach 1 shows differences among the elementary flows accounted for the regionalised datasets but remains within acceptable values for most of them. For example, focusing on Molise, the uncertainty ranges from 1.08 for water and soil emissions to 1.64 for packaging materials. This low uncertainty is mainly due to the lower annual variation of olive yield while maintaining a high olive harvesting over the years (about 2,000 kg/ha). Despite this, remarkable differences and higher uncertainty values emerge for the ILCIDAF datasets related to Lombardy, Veneto and Campania. Indeed, these regions are characterised by a significant variability in annual olive yield within the timeframe of six years considered for the Approach 1. Focusing on Lombardy, which has the highest values among the 19 Italian regions, the uncertainty shows a percentage variation ranging from 98% for the emissions to water and soil to 51% for the packaging materials, when compared to Molise region. An in-depth analysis of the elementary flows underscores that all the inputs and outputs show uncertainty values lower than 1.5 in 16 of the 19 ILCIDAF datasets, except for the data related to transport activities and packaging materials.

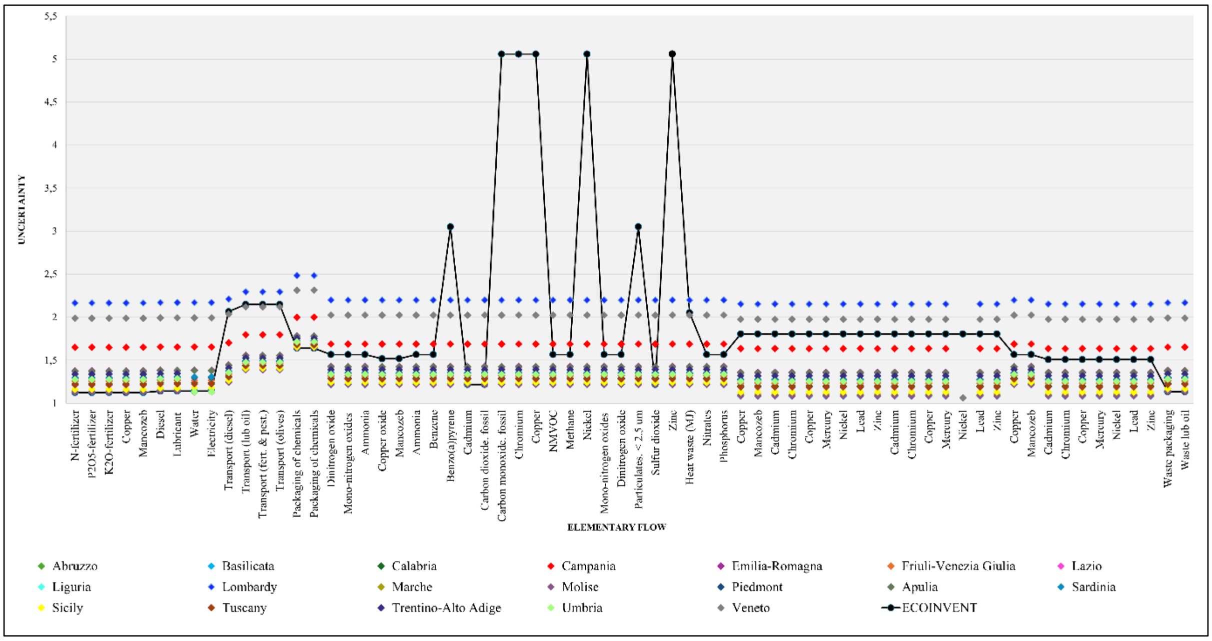

Figure 2. *Comparison between the uncertainty of ILCIDAF datasets calculated considering the annual olive yield variation for the 19 Italian regions and the basic uncertainty reported in Ecoinvent.*

It is important to highlight that a significant overestimation of uncertainty values for air emissions may occur when the basic uncertainty reported in Ecoinvent (Approach 2) is applied. This is because in the Ecoinvent database a high uncertainty and, consequently, low data quality is reported for air emissions, specifically for those related to heavy metals, such as Chromium, Copper and Zinc. In this context, the investigated ILCIDAF datasets are characterised by a lower uncertainty related to heavy metals. This is mainly due to the good quality scores allocated to heavy metals estimation in the datasets, for which regional and crop-specific data are adopted according to Notarnicola et al. (2023).

The results here reported permit to highlight the importance of adopting the most suitable method for calculating data uncertainty in LCA study, specifically when regionalised data are used to assess agri-food systems. In this regard, the use of GSM values based on temporal variability of olive yields may strongly affect the uncertainty of representative inventory data and consequently of the LCIA outcomes.

Conclusions

The aim of this study was to analyse and compare two different approaches to calculate the uncertainty related to the regionalised datasets included in the ILCIDAF database, reporting data related to the production of olives in 19 Italian regions. In particular, the Approach 1 involved the calculation of uncertainty considering the olive yield variability, among each region, in the period from 2015 to 2020. On the contrary, the Approach 2 was based on using the basic uncertainty values report in Ecoinvent for some products and emissions. The main findings pointed out that using Approach 1 instead of Approach 2 resulted in an underestimation of the uncertainty for most of the inputs as well as an overestimation of the outputs, with specific regard to the direct emissions to air water and soil. The results from this analysis are in line with the outcomes from previous studies available in the literature (e.g., Yang et al. 2018), confirming that geographical variability plays a fundamental in agri-food systems. In addition, this study highlighted the need to calculate data quality and uncertainty using sector-specific GSD values in LCI datasets, associated with DQIs, also including temporal variability in yields, when agri-food products are investigated.

Acknowledgment

This article is part of the results of the research project "Promoting Agri-Food Sustainability: Development of an Italian LCI Database of Agri-Food Products (ILCIDAF)" (PRIN – Progetti di Ricerca di Interesse Nazionale 2017- Prot. 2017EC9WF2, settore ERC SH2, Linea C – funded by the Ministry of University and Research).

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Life Cycle Assessment in the cosmetic sector: critical issues related to life cycle inventory data availability

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Abstract

Life Cycle Assessment (LCA) is increasingly employed for assessing the potential environmental impact of cosmetic products. However, findings of a preliminary literature review on LCAs in the cosmetic sector showed that there are critical issues related to the availability of life cycle inventory data for many cosmetic ingredients. Missing data is a key challenge facing LCA studies, indeed the scarcity of complete and reliable inventory data may limit the effectiveness of the analysis. In this context, this study intends to further investigate the results emerging from the literature analysis and verify the availability of life cycle inventory data for cosmetic ingredients in some of the most known and used commercial databases, namely Ecoinvent, Agri-footprint, European Life Cycle Database (ELCD), World Food LCA Database (WFLDB), and United States Life Cycle Inventory (USLCI). Following this aim a case-study on a cosmetic product has been performed. Primary data of a cosmetic solar cream were collected, and a list of 18 ingredients (each composed by one or more substances) was identified. Secondary data on the resulting 28 substances contained in the ingredients were then searched in the databases. Preliminary results confirm that inventory data for almost all the substances are missing in the considered databases. In details, the few inventory data available concerns a total of 5 substances (4 in Ecoinvent and 1 in Agri-footprint), allowing to obtain secondary data for only 6 of the 18 identified ingredients. Substances similar to those for which the lack of inventory data occurs are identified, as already proposed by other scholars when performing LCAs with missing data.

Keywords: Life cycle assessment, cosmetic product, life cycle inventory, secondary data

Relevant Topic: Circular economy and sustainability

Introduction

The cosmetic industry is one important and fast-growing sector in the global economy (Statista, 2022). The sector is expected to continuously grow with an Average Growth Rate (CAGR) of 2.6% at European level, from 2022 to 2027 (Mordor Intelligence, 2021), and of 5.5% at global level, from 2021 to 2028 (Zion Market Research, 2021). However, as the sector grows, the environmental pressure related to the entire life cycle of cosmetic products increases as well (Cosmetics Europe, 2019).

In this context, a previous literature review carried out by the authors of this paper pointed out an increasing interest in sustainability and circular economy (CE) concepts of both companies and scientific community (Mondello et al., 2024). Particularly, the attention of companies regards solutions for mitigating the environmental impacts of all the phases of a cosmetic product's life cycle, i.e. sourcing, manufacturing, packaging, distribution, consumer use and post-consumer use, and disposal (Bom et al., 2019). Consequently, cosmetic companies started to use a Life Cycle Thinking (LCT) approach, and specifically the Life Cycle Assessment (LCA) method, to identify practices and strategies with a reduced environmental footprint along the whole life cycle of cosmetic products (Cosmetics Europe, 2019).

The LCA is a standardized method which allows to assess the environmental impacts of a product, a service or a process, along the entire life cycle (ISO, 2006a; ISO, 2006b). According to the International Organization for Standardization (ISO), the application of the LCA method includes four phases as follows: i) goal and scope definition, ii) life cycle inventory analysis, iii) life cycle impact assessment, iv) interpretation (ISO, 2006a). Each of these phases implies important methodological choices, for example the definition of a functional unit (FU) and system boundaries (SBs) for the goal and scope definition phase, or of the typology of data and related databases (DBs) for their collection for the life cycle inventory (LCI) phase.

However, methodological choices for carrying out LCA studies in the cosmetic industry are influenced by the complexity of the sector. For example, many issues arise regarding the availability of LCI data on cosmetic products' ingredients (e.g. Secchi et al., 2016). Indeed, cosmetic products are mainly composed by chemical substances, which could contribute to nearly all the life cycle impact assessment (LCIA) impact categories considered in a LCA case-study (Hauschild et al., 2013). However, many issues arise within the collection of chemical-related data due to the complexity of their synthesis and production processes (Fantke and Ernstoff, 2018). In addition, when performing an LCA of cosmetic products, many data on chemical substances may not be available to the manufacturer, thus sourcing data from suppliers may cause additional difficulties (Bjørn et al., 2018).

To the best of authors' knowledge, there is a lack of review studies which focus on the methodological choices for performing LCA case-studies of cosmetic products. In addition, studies which explicitly take into consideration the availability of inventory data for cosmetic products' ingredients are still missing.

Therefore, this study has two main aims: i) identify the main methodological aspects regarding LCA of cosmetic products, ii) verify the availability of LCI data for a cosmetic product.

Methods

Firstly, a scoping review (Arksey and O'Malley, 2005; Peters et al., 2015) is carried out for analysing the methodological aspects, emerging from the scientific literature, of applying LCA in the cosmetic industry. The aim is to identify the main characteristics and complexities that should be considered when modelling an LCA study of a cosmetic product.

The literature review is carried out according to the Preferred Reporting Items for Systematic Review and Meta-Analyses guidelines (PRIMA) (Moher et al., 2009). For the identification of the sample, a search query is defined for collecting all the studies which report LCA implementation in the cosmetic industry, as follows: "Life Cycle Assessment" OR "LCA" AND "cosmetic*". The query is employed on Scopus and Web of Science databases, using the search fields limited to title, abstract, and keywords. A time frame is not defined, but the search is updated on March 15, 2024.

The search strategy is summarized in Figure 1. A total of 222 studies are collected, of which 120 from Scopus and 102 from Web of Science. The sample is restricted to only articles and reviews published in English (n=191), then also duplicates (n=64) and full-text non available (n=8) are excluded. The abstract and full-text screening is performed, allowing to exclude further 89 studies according to specific exclusion criteria, i.e. i) LCA is not referred to Life Cycle Assessment; ii) a LCA case-study is performed, but not related to the cosmetic industry. Finally, other 24 studies are excluded due the object of the LCA case-study reported is not a cosmetic product, allowing to obtain a final sample of 7 studies, of which 6 articles and 1 review.

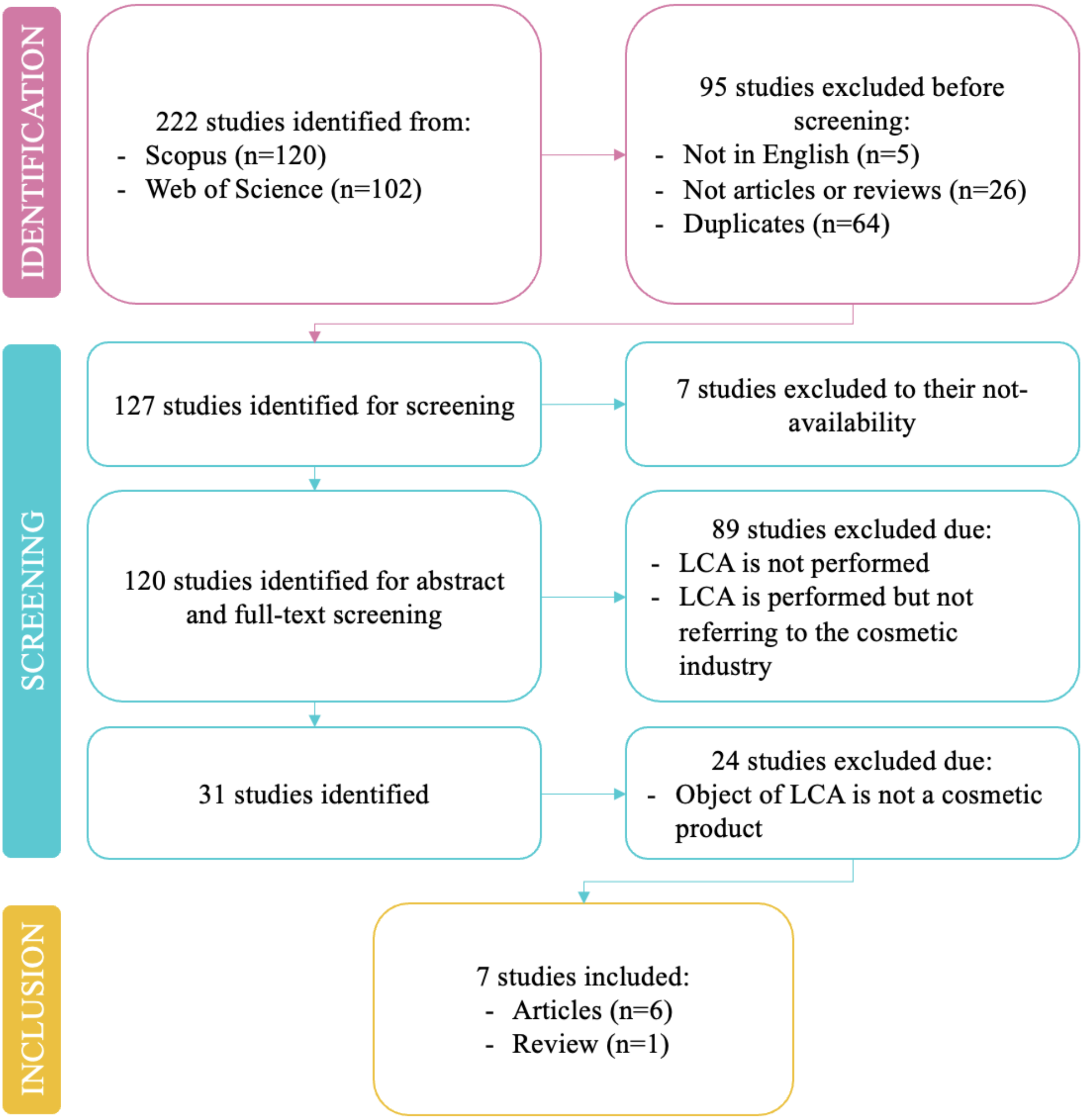

Figure 1. *Search strategy of the scoping review (based on PRISMA).*

Then, a LCA case-study (ISO, 2006a; ISO, 2006b; ISO, 2020a; ISO, 2020b) of a cosmetic product is performed according to the findings of the scoping review. Particularly, a focus on LCI phase is made due to the related critical issues found in literature.

The LCI of a cosmetic product, which is a solar cream, is carried out. All the input materials collected into the LCI are referred to 1 product, consisting of a 198 g bottle containing 200 ml of cream, which represents the functional unit. A cradle-to-gate approach is considered for defining the system boundaries, which include raw materials sourcing and manufacturing of the cream. The packaging process is excluded from this study due to the aim of verifying the availability of LCI data of cosmetic ingredients. The system boundaries are represented in Figure 2, in which all the life cycle phases of a cosmetic product are represented according to the classification of Bom et al. (2019).

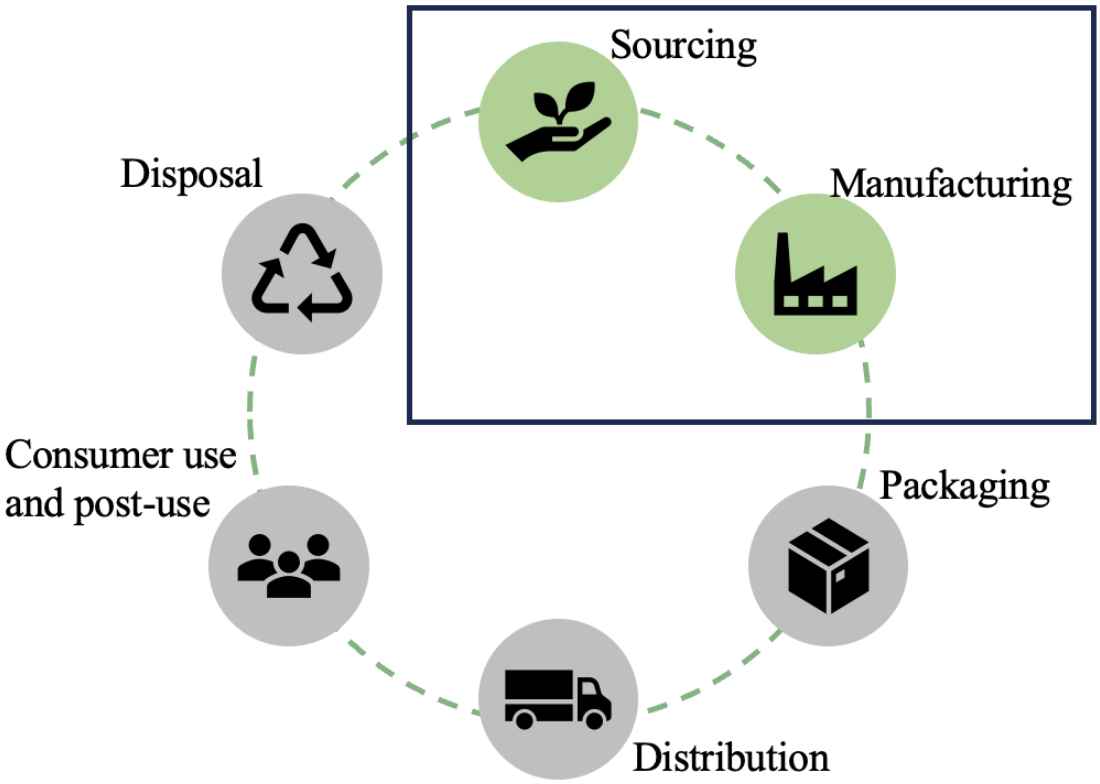

Figure 2. *System boundaries of the LCA case-study of a cosmetic solar cream.*

The LCI phase includes the collection of primary data and the search of secondary data. Primary data are collected from the productive plant of the cosmetic product, which is located in Central Italy. Secondary data are searched in some of the most known and used commercial databases, i.e. Ecoinvent, Agri-footprint, European Life Cycle Database (ELCD), World Food LCA Database (WFLDB), and United States Life Cycle Inventory (USLCI). The search is carried out using the SimaPro software (PRé Sustainability, 2024).

Results and Discussion

In this section, the results of the preliminary scoping review and of the LCI of the cosmetic solar cream are presented and discussed.

Regarding the scoping review, the analysis is carried out on the final sample of 7 studies reporting LCA case-studies of cosmetic products. Despite the small number of case studies available in the literature, in this paper the sample is used to extract first useful considerations for modelling the solar cream case study.

Considering the goal of these LCA case-studies, the aim is to assess the environmental hotspots (e.g. Rocca et al., 2023) or to compare the environmental profile of products considering different formulations (e.g. Secchi et al., 2016). Regarding the chosen functional unit (FU), they are mainly unit-related (n=3) - which are expressed in terms of number of units (e.g. number of cosmetic products) - and mass-related (n=3) ones - which are expressed in terms of kilograms or similar (e.g. 1 kg of product) - while only one study (L'Haridon et al., 2023) uses multiple FUs. However, two of the three mass-related FUs are defined as the quantity of one unit of product. Thus, the unit-related FUs emerge as the most suitable one to use for performing an LCA case-study of cosmetic products.

Regarding the system boundaries (SBs), most of the studies use the cradle-to-grave approach (n=5), considering the entire life cycle of cosmetic products, while others (n=2) use the cradle-to-gate one, considering only the phases included within the company gates and excluding distribution and subsequent phases. Results highlight that using a cradle-to-grave approach could provide more consistent results of environmental impact related to the products, due to the contribution which could derive from the phases of distribution, use, and end-of-life of cosmetic products. For example, the study of Kröhnert and Stucki (2021) reports that the use phase of a shampoo is the life cycle phase that contributes the most to many impact categories. On the contrary, Tamburic et al. (2023) point out that the manufacturing phase of emulsions is the most contributing in terms of environmental impacts. Another example is the study of Rocca et al. (2023), which exhibits that for a mascara the main critical processes are the raw materials and primary packaging ones. Thus, many differences occur for different cosmetic products' categories. Therefore, despite a cradle-to-grave approach is the most recurring in the sample of this scoping review, the SBs of the LCA must be modelled according to the goal of the study and to the specific product which represents the object of the study.

Specifically considering the LCI phase, the type of data employed for performing the studies and the related databases are considered. Most of the studies employ only secondary data (n=5), while the remaining ones employ both primary and secondary data (n=2). The search of secondary data is performed using the Ecoinvent database, solely (n=5) or in combination with other databases (n=2). In detail, L'Haridon et al. (2023) employ also the Agribalyse and the WFLDB, while Rocca et al. (2023) employ also the Agri-footprint and the ELCD. Overall, a predominant use of secondary data from the Ecoinvent database emerges. However, complete and reliable inventory data on many cosmetic ingredients, that are chemical substances, are missing (e.g. Secchi et al., 2026). Thus, potential solutions are considered to avoid this lack. For example, Secchi et al. (2016) propose to use inventory data on similar substances in terms of molecular structure, synthesis, manufacturing, or refining processes. The construction of proxy inventory is presented also in other studies (e.g. Krohnert and Stucki, 2021; Tamburic et al., 2023).

Regarding the LCIA phase, SimaPro is the most employed software (n=5). All the studies take into consideration midpoint impact assessment methods. Many impact categories are considered in almost all the studies, regardless of the employed impact assessment methods. Those which receive much attention are climate change, freshwater ecotoxicity, and freshwater eutrophication.

Finally, regarding the interpretation phase, is analysed whether sensitivity analyses are performed in the studies, also considering the reported sensitive parameters. It is interesting to note that 4 out of the 7 studies report a sensitivity analysis, but none of these take raw material production into consideration as a sensitive parameter despite the recurring critical issue reported on the lack of inventory data for the production of many substances used in the formulation of cosmetic products. For example, the study of Secchi et al. (2016), which proposes the use of proxy inventory data, then performs two sensitivity analysis but only considering the assumptions on transport and irrigation of olive trees (from which a bio-based ingredient is obtained for the day face cream object of the study), and the application of different LCIA methods as sensitive parameters. Another example is the study of Tamburic et al. (2023), which propose the use of inventory data on substances similar to ones used in the formulation of the analysed cosmetic product (due to the lack of inventory data for the production of these used substances), but then do not perform any sensitivity analysis investigating further about these substitutions.

This scoping review allows the identification of the main characteristics and criticalities of methodological aspects of LCA case-studies of cosmetic products. Thus, the LCA case-study performed in this study is carried out considering the results obtained from the scoping review. In particular, the main methodological choices deriving from the scoping review results and the proposed solutions are summarized in Figure 3.

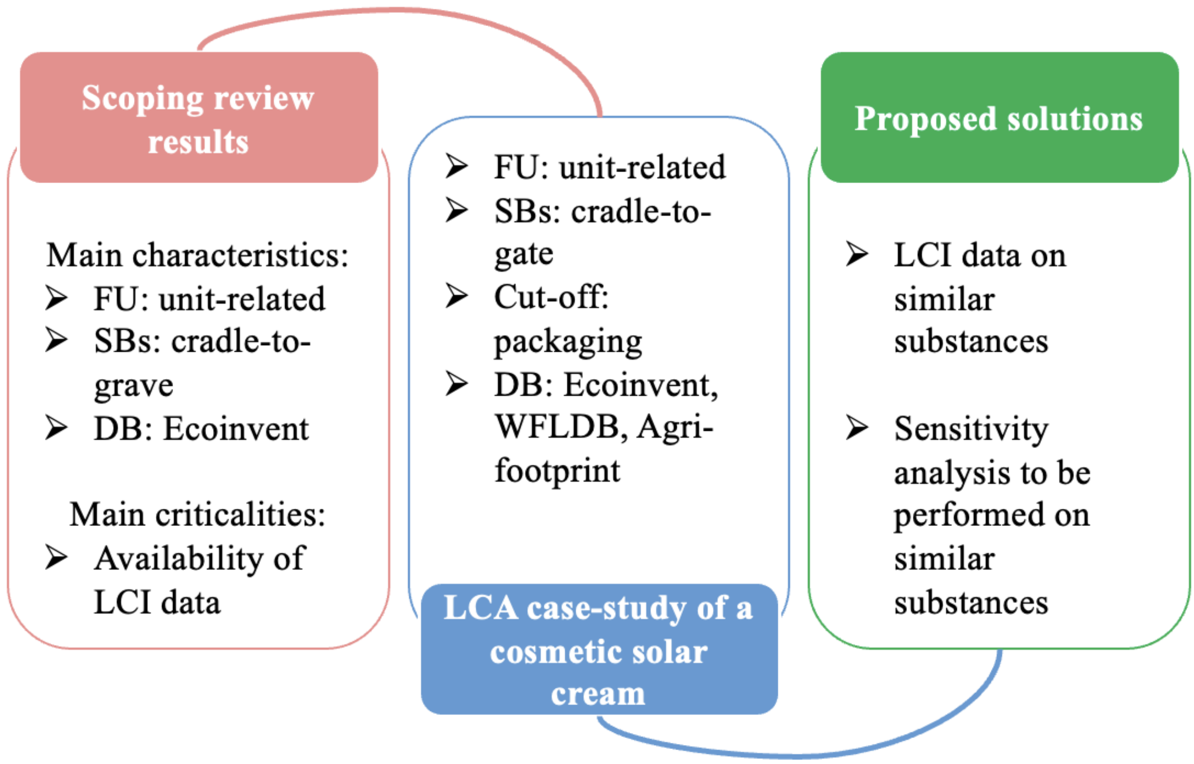

Figure 3. *Overview of scoping review results, methodological choices of LCA case-study, and proposed solutions.*

The LCA case-study performed in this study has a cosmetic solar cream as object of the analysis. In details, a unit-related FU is defined as "1 cosmetic solar cream", with reference flow of "1 bottle of 198 g containing 200 ml of solar cream", which expresses the quantity of product necessary to satisfy the function of the product system. This choice is due to the fact that the unit-related FUs emerge as the most suitable for conducting LCA case-studies of cosmetic products (e.g. Rocca et al., 2023; Kröhnert and Stucki, 2021). Then, despite the cradle-to-grave SBs approach emerges as the most used for LCA case-studies of cosmetic products, in this study a cradle-to-gate approach is employed. Indeed, due to the aim of this study, which is of verifying the availability of inventory data concerning the cosmetic ingredients, only the phases of sourcing of raw materials and manufacturing of the product are considered, while the packaging phase is excluded (see Methodology paragraph and Figure 2).

The LCI phase is performed starting from primary data collection. A total of 18 ingredients are identified, which are composed by one or more substances. The included substances are a total of 28, for all of which secondary data are searched in the above cited databases. Table 1 reports how the LCI of this case-study is constructed, showing databases from which inventory data are collected. In addition, the level of match between International Nomenclature Cosmetic Ingredients (INCI) name of substances and the related processes found in databases is reported according to the following classification: level 1, green colour, when inventory data for a substance are available in the databases; level 2, orange colour, when inventory data on similar substances are employed; level 3, red colour, when no data on the substance or similar ones are found either, thus data on generic organic or inorganic chemical production processes are used. For the similar substances, choices are based on similarity of chemical structure or manufacturing processes. When the choice is made according to findings of other studies, the reference is reported in Table 1. When the related processes of substances are found in the database, the reference is not reported due it is the database itself. Finally, when a similar process is chosen by the authors of this study, no other references are reported.

Table 1. *Life Cycle Inventory data for cosmetic solar cream*

INCI name	Process name	Level of match	Databases	Choice also made in (Reference)
Amber extract	Chemical, organic, GLO, chemical production, organic, cut-off, U	3	Ecoinvent	
Ascorbyl palmitate	Ascorbic acid, RER, ascorbic acid production, cut-off, U	2	Ecoinvent	
Benzyl Alcohol	Benzyl alcohol, RER, benzyl alcohol production, cut-off, U	1	Ecoinvent	
Butyl methoxydibenzoylmethane	Chemical, organic, GLO, chemical production, organic, cut-off, U	3	Ecoinvent	
C12-C15 Alkyl benzoate	Chemical, organic, GLO, chemical	3	Ecoinvent	

	production, organic, cut-off, U			
Caprylic/capric triglyceride	Caprylic-capric acid (C8-C10) from coconut oil fractionation, at plant (WFLDB)/GLO U	2	WFLDB	
Caprylyl/capryl glucoside	Chemical, organic, GLO, chemical production, organic, cut-off, U	3	Ecoinvent	
Cetearyl isononanoate	Fatty alcohol production from coconut oil, ref	2	Ecoinvent	Tamburic et al. (2023)
Citric acid	Citric acid, RER, production, cut-off, U	1	Ecoinvent	
Deionised water	Water, deionised, Europe without Switerzerland, water production, deionised, cut-off, U	1	Ecoinvent	
Disodium EDTA	EDTA, ethylenediaminetetraacetic acid, RER, EDTA production, cut-off, U	2	Ecoinvent	
Ethylhexyl triazone	Chemical, organic, GLO, chemical production, organic, cut-off, U	3	Ecoinvent	
Ethylhexylglycerin	Glycerine, RER, production, from epichlorohydrin, cut-off, U	2	Ecoinvent	
Glycerin	Glycerine, RER, production, from epichlorohydrin, cut-off, U	1	Ecoinvent	
Helianthus annuus seed oil	Crude sunflower oil, from crushing (solvent), at plant, IT mass	2	Agri-footprint	
Lauryl glucoside	Glycerine, GLO, stearic acid production, cut-off, U	2	Ecoinvent	
Lecithin	Soybean lecithin, from crushing (solvent), at plant, IT mass	1	Agri-footprint	
Leuconostoc/radish root ferment filtrate	Chemical, organic, GLO, chemical production, organic, cut-off, U	3	Ecoinvent	
Magnesium aluminium silicate	Sodium silicate, without water, in 37% solution state, RER, sodium silicate production, furnace liquor, product in 37% solution state, cut-off, U	2	Ecoinvent	
Octocrylene	Benzyl chloride, RER, benzyl chloride production, cut-off, U	2	Ecoinvent	Secchi et al. (2016)
Phenoxyethanol	Esterification of soybean oil, RoW, glycerine	2	Ecoinvent	Tamburic et al. (2023)

Polyglyceryl-2 dipolyhydroxystearate	Chemical, organic, GLO, chemical production, organic, cut-off, U	3	Ecoinvent	
Raphanus sativus seed extract	Chemical, organic, GLO, chemical production, organic, cut-off, U	3	Ecoinvent	
Rosmarinus officinalis leaf extract	Chemical, organic, GLO, chemical production, organic, cut-off, U	3	Ecoinvent	
Sodium lauryl glucose carboxylate	Polycarboxylates, 40% active substance, RER, production, cut-off, U	2	Ecoinvent	
Tocopherol	Cottonseed oil, refined, RoW, cottonseed oil refinery operation, cut-off, U	2	Ecoinvent	Tamburic et al. (2023)
Tocopherol acetate	Cottonseed oil, refined, RoW, cottonseed oil refinery operation, cut-off, U	2	Ecoinvent	
Xanthan gum	Guar gum at plant (WFLDB)/IN U	2	WFLDB	

It has to be noted that inventory data of only 5 out of the 28 substances are found, of which 4 are provided from Ecoinvent and 1 from Agri-footprint database. Inventory data for other 14 substances are found using similar ones, which are provided from the Ecoinvent database, except 2 from WFLDB and 1 from Agri-footprint. For the remaining 9 substances, inventory data regarding the productive process of organic chemical substances are selected from Ecoinvent. As already highlighted in the results of the scoping review, Ecoinvent emerges as the most complete database of data for cosmetic products also in the case study. Indeed, inventory data of a total of 25 out of the 28 substances of the cosmetic solar cream are collected from Ecoinvent.

Overall, the problem of missing data for cosmetic ingredients emerges from both the scoping review and the case-study of the cosmetic solar cream. However, the implications which arise from this issue are not well discussed in the sample of the scoping review. Few studies only report that the missing of data on raw materials is a limitation of the LCA study (Tamburic et al., 2023) and that the use of proxy processes could influence the robustness of LCA results obtaining underestimate impacts (Secchi et al., 2016).

This issue is also reported in the Product Category Rules (PCR) of cosmetics (soap, perfume and toilet preparations) (PCR, 2024). The PCR state that specific data should be preferred, but the use of proxy data is permitted when specific ones are not available for the background processes. In addition, specifically referring to chemicals, the PCR suggests the use of stoichiometry for the modelling of chemical processes (PCR, 2024). However, this option could further complicate the LCA study making it even more time and resource spending, considering that the use of stoichiometry for the modelling of chemical processes requires the involvement of chemistry experts.

Indeed, the missing of specific data represents an important issue for which solutions must be found, especially if concerning the core process of a system, which in the case-study presented in this study is represented by the manufacturing process. Another potential solution to avoid the use of proxy data is implicitly proposed by the four Environmental Product Declaration (EPD) which are available for some cosmetic products (EDP, 2024a; EPD, 2024b; EPD, 2024c; EPD, 2024d). In these declarations, the LCI of the products is based on generic substances selected by their function (e.g. emollients, antioxidants, etc.). However, also this potential solution may decrease the reliability of studies in the sector, due to the poor specificity of the data.

Despite that, the use of proxy inventory data is the most used solution for performing a LCA case-study of cosmetic products avoiding the lack of specific data for many cosmetic ingredients (Tamburic et al., 2023; Secchi et al., 2016). Thus, the modelling of the case-study here presented is based on the findings of the scoping review and proxy data are used. Further research is needed to verify the reliability of results. For example, a sensitivity analysis should be performed considering the inventory data.

Conclusions

This study firstly aims to identify the methodological choices of LCA case-studies of cosmetic products by performing a scoping review. Secondly, a LCA case-study of a cosmetic solar cream is performed with the aim of verifying the availability of LCI data due to related criticalities that emerged in literature.

The scoping review is carried out on a sample of 7 studies, which have different cosmetic products as object of analysis. Unit- or mass-related FUs are mostly employed in the studies, which mainly adopt a cradle-to-grave approach for defining the system boundaries of the study. Primary data and secondary data are employed for the construction of LCI in almost all the studies (n=5), while the remaining ones employ only secondary data. However, a lack of complete and reliable inventory data on cosmetic ingredients is highlighted. Most of the studies report the use of the SimaPro software and all of them take into consideration midpoint impact assessment methods. Finally, just over half of the sample reports sensitivity analyses aimed to test the robustness of results. However, no study has performed sensitivity analyses considering inventory data as a sensitive parameter.

According to the results of the scoping review, the case-study of a cosmetic solar cream is carried out. A unit-related FU is defined as 1 cosmetic solar cream. A cradle-to-gate approach is employed due to the aim of the study of verifying the availability of inventory data for cosmetic ingredients. Thus, the analysis focuses on the sourcing and manufacturing life cycle phases of the product.

Primary data are collected from the productive plant of the cream, which is located in Central Italy. This step allows the identification of 18 ingredients, which are composed by a total of 28 substances. Inventory data are searched for each of the substance in some of the most known and used databases, i.e. Ecoinvent, Agri-footprint, WFLDB, ELCD, and USLCI, using the SimaPro software.

Inventory data are found for only 5 substances, of which 4 from Ecoinvent and 1 from Agrifootprint database. For the remaining substances, inventory data on similar ones (n=14) or on the generic process of organic chemicals production (n=9) are employed mainly from the Ecoinvent database.

Overall, the critical issues related to the availability of inventory data for cosmetic ingredients are confirmed by the results of this case-study. In addition, the Ecoinvent database emerges as the most suitable for conducting the LCI phase of LCA studies of cosmetic products, as already reported in literature. In fact, although the data for most of the substances of the product that is the object of this analysis are not available, Ecoinvent is the most used database to find data for alternative but similar substances.

However, the LCI obtained in this analysis implies some limitations. The use of inventory data on similar substances or on generic processes could influence the impact assessment results. Consequently, sensitivity analysis should be carried out for verifying the potential change in results that derives from the use of inventory data of one substance rather than another. Thus, further research will be oriented to perform a sensitivity analysis on inventory data with the aim of checking the robustness of results based on LCI data on similar substances.

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Life cycle perspective in the textile supply chain: Analysis of Improvement PracticesAnalysis of Improvement Practices

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Abstract

Textile manufacturing is characterized by consumption models based on low-cost fast fashion, rather than on a durable good idea. For this reason, it has become one of the sectors with the highest environmental impacts. The aim of this study is to reveal environmental impacts along the textile supply chain, based on a life cycle perspective to improve resources and waste management.

This study presents a systematic literature review, performed through ISI Web of Knowledge database, with the keywords: ("supply chain" OR "supply chains") AND (lca OR "life cycle assessment" OR "carbon footprint" OR "life cycle") AND (circular* OR clos* OR loop* OR recycle* OR recover*) AND (textile* OR apparel OR cloth* OR garment OR fashion) and leading to 57 articles. The articles were selected to include only those with a circular supply chain vision. At the end of this step, 30 articles were obtained, which were further analyzed.

The research focused on the identification of the phases with a more impact, between production, distribution, use and end of life, and on possible reduction solutions in terms of circularity.

From the results, the diversity and complexities of the entire system emerge and most of the impacts are relative to production and raw materials, followed by transport and final disposal.

Further studies are necessary to improve data collection along the supply chains in order to apply strategies aimed at reducing environmental impacts. Furthermore, a change is necessary, both in consumption habits and in a complete vision of the practices along the supply chain.

Keywords: textile, supply chain, life cycle perspective, circular

Relevant Topic: **“**Sustainable Supply Chain Management, green supply chain and quality”

Introduction

In recent decades, the textile industry has undergone a rapid transformation, particularly in the apparel sector, from quality production that lasts over time, towards large-scale collections, produced with high frequency. This new trend has developed due to the increase in supply and to the diversification of global distribution chains and online sales markets. Nowadays, besides the luxury sector, which is aimed at a specific customer and characterised by the use of sustainable materials and practises, a new approach has arisen based on the rapid turnover of garments and textiles, known as "fast fashion" (Leal Filho et al., 2024). This term includes clothing, footwear and household textiles, and is characterised by a highly industrialised model of mass production and consumption. These items are often imported and made from cheap low-cost fabrics and labour coming from poorly regulated countries (Brydges, 2021).

The textile industry has expanded globally, in search of cheap resources and market opportunities, especially off-shore in the Far East. China, India, and the USA are significant players, China being the largest producer of textile products, and accounting for 36.3% of global textile and apparel exports (Zhang et al., 2022; Sarokin and Bocken, 2024). The growing demand and new applications in clothing have led to a substantial increase in the annual global textile fibre production. Every year the textile industry supplies more than 100 million tons of products to the market and is projected to reach 146 million tons (17.1 kg) per capita by 2030 (Jail et al., 2023; Leal Filho et al., 2024). Projections indicate that by 2030, the global textile market will be worth an estimated 3 trillion US dollars in retail sales, with an expected annual growth rate of 5.8% (Leal Filho et al., 2024).

The fashion industry is emerging as one of the most criticised industries, raising the environmental burden, and the question regarding the longevity of an item of clothing generates one of the major concerns related to sustainability (de Albuquerque Landi et al., 2023). The production chain, in fact, follows a linear model made up of three main operations, namely the collection of raw materials, the production process, and waste management, which, if compared to other supply chains, is still linked to a low circularity. Consequently, this approach causes important impacts related to the excessive production and disposal of tons of textile wastes, which are difficult to recycle due to their composition and the manufacturing process applied during production. For example, a polyester cotton textile product, made with bio-based cotton and fossil fuel-based PET plastic material, due to ill-fated design, results in the creation of a mixed product which cannot be easily recycled (Islam, et al., 2022).

The fibres can be natural, from plant- or animal-based origin, or synthetic. Plant-based natural fibres are generally extracted after a retting or decortication process in order to remove undesired cell components (Li et al., 2021). Cotton represents the most consumed natural fibre in the textile and clothing industry. Regarding animal-based natural fibres, the most popular worldwide are silk and wool. In the field of manmade fibres, it is possible to distinguish between organic and inorganic ones. Organic fabrics are made from natural materials (e.g. wood, regenerated fibres), whereas inorganic ones are made from synthetic polymers (Amicarelli et al., 2022). Each type is responsible for specific environmental impacts, in terms of energy and water consumption, as well as chemicals used during manufacturing, especially during the dyeing process (Ding et al., 2019; Zhang

et al., 2022). On one hand, the plant-based fibres consume natural resources during growth, harvesting and processing of the plant, while on the other, synthetic fibres are a source of concern due to health risks from chemical use, petroleum consumption and waste management (Zhao et al., 2021; Amicarelli et al., 2022).
To counteract these aspects, product and process innovations have emerged to develop more sustainable manufacturing practices, such as eco-design innovation, circularity, cradle-to-cradle design, closed-loop fashion, through regenerative and shared approaches (Islam, et al., 2022).
Implementation of sustainable practices is a means of strategic advantage to gain competitive benefits and address resource scarcity, consequently supporting the sustainable development of the clothing industry. Due to the fact that consumers are highly influenced by new fashion trends, the clothing industry should place a central focus on consumer perception (Islam, et al., 2021).
The purpose of the present research is to investigate the environmental concerns associated with the textile supply chain with a life cycle perspective, revealing the improvement practices over textile products life cycle.

Methods

The intent of this research was to give an answer to the following research questions (RQ):

RQ1: How is the life cycle perspective incorporated in the textile supply chain in case of circular loops?

RQ2: What are the improvement practices associated with the textile supply chain arising from a life cycle perspective from a circularity perspective?

To give an answer to these questions, a systematic literature review was conducted according to Snyder (2019). This research was developed according to the steps proposed by Durach et al. (2017), identifying the required features of primary studies, the baseline sample, the synthesis sample and finally performing the literature synthesis.

Required features of primary studies

This literature review started by analyzing studies where the main life cycle methodologies were applied or discussed, namely the Life Cycle Assessment (LCA) and the Carbon footprint (CF) methodologies (Hellweg and Milà i Canals, 2014; Notarnicola et al., 2012). Thus, in line with our RQs, only studies related to LCA or CF application or discussion for textile products in case of circular loops were included in this research, considering only articles published in journals, written in English and obtained through the selected keywords.

Baseline sample

A research by keywords was performed in ISI Web of Knowledge database in April 2024. The keywords were selected and combined to collect articles dealing with the focus of this study. The final combination of keywords was ("supply chain" OR "supply chains") AND (lca OR "life cycle assessment" OR "carbon footprint" OR “life cycle”) AND (circular* OR clos* OR loop* OR recycle* OR recover*) AND (textile* OR apparel OR cloth* OR garment OR fashion). At the end of this step, 57 articles were obtained.

Synthesis sample

The articles obtained from the previous step were further selected, focusing on those dealing with textiles and textile products and with a life cycle perspective application or discussion with reference to possible circular loops. At the end of this step, 31 articles were obtained. Then, based on a relevance analysis, 30 articles were finally selected to proceed with the next step.

Literature synthesis

A descriptive analysis of the articles included in the synthesis sample was performed, to underline the main features, such as year of publication, journal, and life cycle perspective applied or discussed. To perform a content analysis, the selected articles were analyzed separately to identify the circular practices associated with the textile supply chain arising from a life cycle perspective and thus giving an answer to RQ1. Successively, they were crossed to identify how the life cycle perspective is applied or discussed in case of circular loops along the supply chain of textiles and textile products, addressing RQ2.

Results and Discussion

In this section, the descriptive analysis of the articles included in this research and the results obtained through the content analysis are presented.

Descriptive analysis

Among the 30 articles included in this research, it was obtained that the first one was published in 2012 and most articles were published more recently, especially from 2020 (Figure 1).

The Journal of Cleaner Production is the journal presenting the greater number of articles, namely 9 out of 30, followed by Sustainable Production and Consumption with 4 articles, and by Environment, Development and Sustainability with 2 articles. Overall, the articles selected are published in 18 different journals, ranging from journals focusing on recycling and waste management to journals specific for the textile sector, as can be seen in Table 1.

Figure 1. *Year of publication of the articles included in this research*

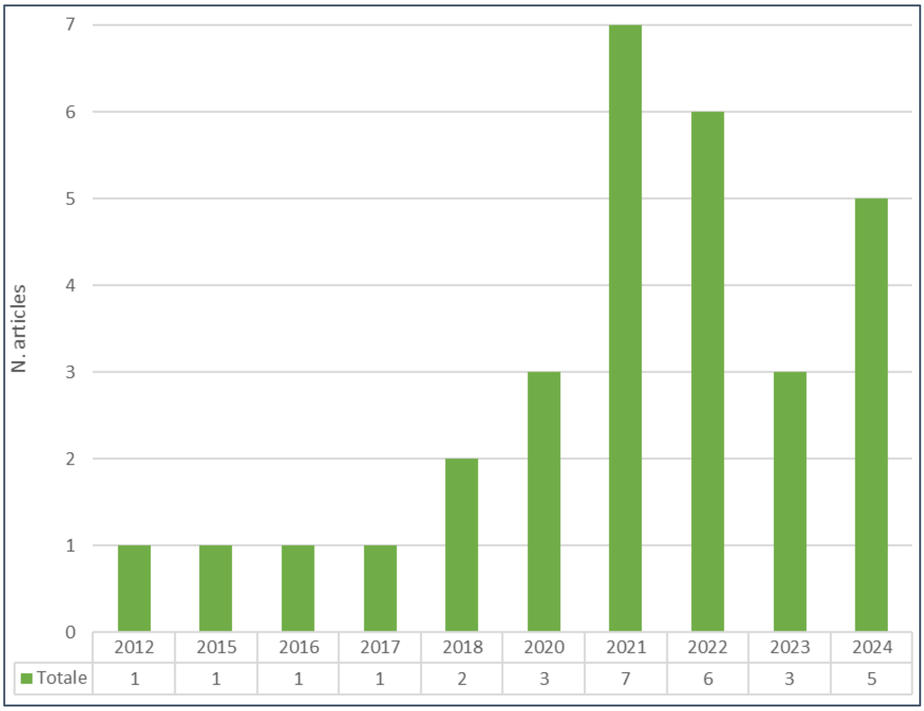


Table 1. *Articles included in this research*

Authors	Year	Journal
Amicarelli et al.	2022	Waste Management
Avadi et al.	2020	Int J Life Cycle Assess
Bonilla et al.	2015	Supply Chain Management: An International Journal
Brydges	2021	Journal of Cleaner Production
Chen et al.	2024	Journal of Cleaner Production
Frota de Albuquerque Land et al.	2023	The International Journal of Life Cycle Assessment
Fung et al.	2020	Production Planning & Control
Giungato et al.	2024	British Food Journal
Glew et al.	2012	Journal of Cleaner Production
Hossain et al.	2024	Environment, Development and Sustainability
Howard et al.	2022	Resources, Conservation & Recycling
Islam et al.	2021	Journal of Fashion Marketing and Management: An International Journal
Islam et al.	2022	Recycling
Jain et al.	2023	Management of Environmental Quality: An International Journal
Jia et al.	2020	Journal of Cleaner Production
Leal Filho et al.	2024	Textile Research Journal
Li and Ma	2018	Sustainable Production and Consumption

Martin and Herlaar	2021	Sustainable Production and Consumption
Moazzem et al.	2021	Sustainable Production and Consumption
Moazzem et al.	2022	Environment, Development and Sustainability
Munasinghe et al.,	2016	Sustainable Production and Consumption
Paras and Pal	2018	Int J Adv Manuf Technol
Patwary et al.	2023	Sustainability
Rehman et al.	2024	Journal of Cleaner Production
Rossi et al.	2021	International Journal of Sustainable Engineering
Sarokin and Bocken	2021	Journal of Cleaner Production
Testa et al.	2017	Journal of Cleaner Production
Vanacker et al.	2022	Journal of Cleaner Production
Zhang et al.	2022	Water Research
Zhao et al.	2021	Journal of Cleaner Production

Content analysis

The content analysis is performed to highlight how the life cycle perspective is incorporated in the textile supply chain in case of circular loops, thus giving an answer to RQ1 (section 3.2.1) and the improvement practices associated with the textile supply chain arising from a life cycle perspective from a circularity perspective, thus giving an answer to RQ2 (section 3.2.2).

The life cycle perspective in the textile supply chain

The life cycle perspective is applied in the textile supply chain in different ways, ranging from the application of LCA methodology to the employment of life cycle thinking as a base to develop qualitative and quantitative analyses (Table 2).

Overall, LCA and CF are the main methodologies applied, in some cases employed in combination with other methodologies, such as energy footprint, water footprint, social life cycle assessment, value mapping and waste flow mapping. Avadì et al. (2020) performed an LCA of organic and conventional cotton products from Mali including the processing of seed cotton in ginning plants to produce cotton fibre bales (cradle to processing plant gate), revealing that the impact is due to the industrial inputs in the agricultural phase. Based on a single score contribution analysis, they obtained that for conventional cotton, pesticide applications are the main cause of impact, followed by mineral fertilisers. For organic cotton, they obtained that the main contributor are pesticides due to the organophosphorus compounds, and organic fertilisation. Moreover, the ginning phase represent less than 3% of the total impacts. In their study, They obtained that considering hectars of cultivation conventional cotton is more impacting that organic cotton, but opposite results are obtained per ton of seed cotton due to the yield. Glew et al. (2012) which estimated the influence of the end of life scenarios on the environmental impact of product supply chains comparing biomaterial and petrochemical products. They obtained that biomaterial products emit marginally less greenhouse gasses (GHG) than petrochemical products (from cradle to gate). However, when the end of life is included in the estimations, biomaterial products present lower impact that the petrochemical ones, demonstrating that refurbishing, reusing of some components and waste recycling can reduce carbon emissions, compared to landfill disposal. Jain et al. (2023) quantified the impacts of textile and yard industry on the supply chain showing that raw cotton and electricity consumption are two main contributors to the environmental impact. LCA was also applied to calculate the impact of t-shirts and polyester jackets highlighting that for the t-shirts the great contribution is due to consumer usage, mainly due to energy consumption during apparel care, whereas for polyester jackets the greater contributor is the production and revealing the recycled polyester, recycled cotton and organic cotton can reduce the impact of all categories (Moazzem et al., 2021). The life cycle perspective is incorporated applying the LCA methodology also by other scholars, e.g. for leather shoe supply chain showing that the main contributors are the slaughtering and tanning processes (Rossi et al., 2021) and for improving recycled wool through an action research (Testa et al., 2017). Zhang et al. (2022) used LCA to quantify the impacts of nonaqueous solvent dyeing, which helps reducing the water consumption but could affect the water quality due to organic solvents losses.

Multi-methodological approaches, combining LCA with other tools, were used e.g. to explore the adoption of circularity along the supply chain through value mapping and highlighting the importance of the design phase and on the selection of the suppliers (Howard et al., 2022) or to map the waste streams based on life cycle management, showing that the environmental impacts across product life cycles can be reduced if there are improvement in resource efficiency, an increase in product's life extensions, and of materials which can be originated from recycled sources (Rehman et al., 2024). Beyond these, Martin and Herlaar (2021) evaluated the environmental and the social impacts associated with waste wool for sweater production, showing that the largest contributions are due to energy consumption during processing. Zhao et al. (2021) applied LCA and Water Footprint to analyse a denim product, showing that the denim fabric production and cotton fibre production respectively generate significant carbon emissions and water consumption.

An application of the life cycle perspective is also performed through the application of the CF methodology, which was used to estimate the emissions at sectorial level associated with offshoring, showing that the reduction of the emissions is a combination of different factors associated with production processes and transportation (Bonilla et al., 2015); at organizational level for a slow fashion brand showing that the main emissions are due to indirect activities related to raw products and materials, transportation and use phase (Frota de Albuquerque Land et al., 2023). At sectorial level, CF was also employed to give an overview of the impacts and solutions, underlining the complexities related to raw materials, production techniques, and product life cycles and that cultivation, processing, and transportation of the materials generate significant emissions (Leal Filho et al., 2024). Giungato et al. (2024) calculated the CF of protective facial masks against

SARS-CoV-2 used in the food sector, investigating the effect of materials and dry sanitisation. The authors showed that the production of textiles in PP, and their disposal were the main contributor to CF. The CF methodology was also used in combination with the energy footprint calculations to analyse the supply chain of some garments, showing that the highest impact is due to raw materials production, highlighting the importance of procurement policies (Munasinghe et al., 2016).

Beyond these methodologies, qualitative and quantitative research approaches were also applied, along with an article focusing on a descriptive analysis. Fung et al (2020) developed a case study for sustainable planning strategies in supply chain systems and Brydges (2021) based on interviews with the founders, CEOs, and/or brand sustainability managers of 19 Swedish fashion brands, mapped circular economy strategies. The authors proposed examples of circular practices including new design strategies (such as seasonless collections) and the increase of life span. A prospective study from a life cycle thinking point of view was developed by Patawary et al. (2023). Sarokin and Bocken (2021) explored pursuing profitability in slow fashion, highlighting a misapplication of circularity to circularity to drive sales growth and highlighting the need of prioritizing the reduction of consumption and production. Li and Ma (2018) used a descriptive analysis to study the certification standards related to recycled materials involving textiles based on life cycle thinking. Hossain et al. (2024) performed a quantitative analysis through questionnaires to assess the influence of employees' green behaviour and organisational green culture on environmental sustainability practices among textile small and medium enterprises, showing that cultivating green behaviour among employees within an organisation is critical. Paras and Pal (2018) studied the clothes 'reuse' in Nordic countries using the Markov chain for LCA and to develop a model to count the number of cycles or trips that a clothing product could make in a reuse-based closed loop cycle.

Several studies (7 out of 30) present a literature analysis, focusing on different topics or perspectives but revealing insights for our research. Amicarelli et al. (2022) performed a literature review to tackle the take-make-waste approach in the textile production industry through life cycle perspective, revealing that the production and use phases are the main contributors, whereas the end-of-life generally has a minor impact. They showed that distribution and consumption phases are less investigated, and pointed out that new consumption patterns, such as sharing and renting platforms, are less investigated and data are needed. Chen et al. (2024) focussed on the decarbonization practices in the textile supply chain. The life cycle perspective was employed to assign the decarbonization practices to the different stages of the textile supply chain, namely production, distribution, use, and disposal/recycling. With reference to production, the authors revealed product eco-design, supplier selection criteria, clean technology adoption, and waste management strategies; with reference to distribution, they highlighted green logistics implementation and supplier localization initiatives; for the use phase, they identified monitoring and reporting carbon emissions as well as promoting sustainable consumption initiatives. With reference to disposal, they took into account product life extension measures and reverse supply chain processes. Islam et al. (2021) mapped the practices in textiles, apparel and fashion industries considering the life cycle perspective and highlighting that individual functions are more focussed, whereas green process and technologies development with stakeholders, collaborative energy consumption and resource optimisation, harvesting and reuse of water, bio-diversity, sustainable washing and dyeing techniques, waste reduction in packaging and embroidery are less investigated. Islam et al. (2022) revealed the recycling perspectives of circular business models highlighting the importance of efficient municipal solid waste management, the establishment of a plastic hubs, implementation of extended producer responsibility, strategic partnership, incentives, and product design. Jia et al. (2020) analyzed the circular economy applications in the textile and apparel industry throughout the product life cycle, observing the complexity of basic materials and constituents, product function and aesthetics, which combined together limits the but also determines the extent to which goods could be recycled after use. They showed that design plays a key role in allowing efficient closed loop supply chain practices, e.g., recycling. Other authors highlighted the importance of product durability considering the life cycle perspective in combination to eco-design (Vanacker et al., 2022) and confirming the importance of the production stage and use stage along the supply chain of apparels and textile products (Moazzem et al., 2022)

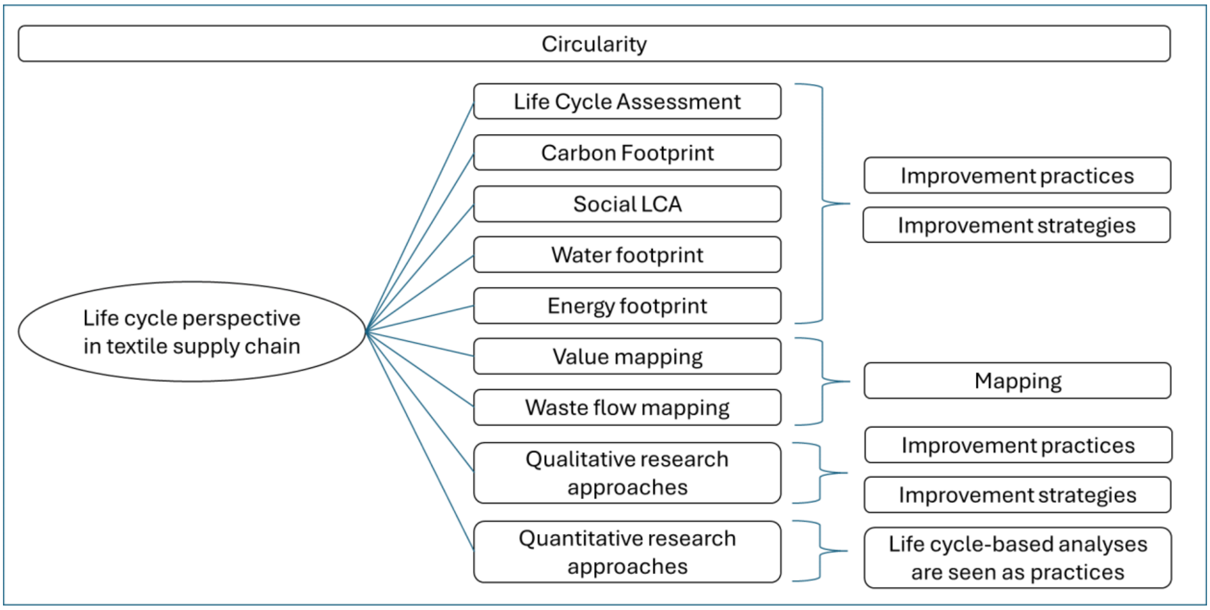
It emerged that in case of circularity loops, the life cycle perspective is incorporated in the textile supply chain through i) the main life cycle-based methodologies to reveal improvement practices and strategies, ii) through mapping approaches to map the supply chain or the waste flows; iii) qualitative research approaches based on life cycle thinking to reveal improvement practices and strategies; iv) quantitative research approaches considering life cycle analyses as an environmental practice.

An overview of how the life cycle perspective is incorporated in the textile supply chain in case of circular loops is reported in Figure 2.

Table 2. *Methodologies applied in the selected articles*

Methodology applied	N. of papers
Case study	4
CF	4
CF and energy footprint	1
Descriptive analysis	1
LCA	7
LCA and SLCA	1
LCA and WF	1
Quantitative study	2
Literature Review	7
Value mapping, LCA	1
Waste Flow Mapping (WFM) assessment and LCA	1

***Figure 2**. Overview of how the life cycle perspective is incorporated in the textile supply chain in case of circular loops*



3.2.2 Improvement practices

The improvement practices suggested in the analyzed articles and associated with the textile supply chain arising from a life cycle perspective from a circularity perspective are reported in Table 3. It emerges that the improvements are incorporated already in the design phase, including criteria regarding the recycled contents of the materials used, the recyclability of the products after use and the reuse (e.g. Sarokin and Bocken, 2021). With reference to the raw materials, it is revealed that the main improvement practices regard the cotton cultivation and in particular the reduction in the use of pesticides and water (e.g. Avadi et al., 2020). Specific changes in the manufacturing process are also proposed, regarding the yarn spinning phase and the deying systems (e.g. Moazzem et al., 2021 and Zhang et al., 2022), along with the improvement of inventory management and the waste flow mapping (Rehman et al., 2024) and waste valorization (e.g. Martin and Herlaar, 2021). Auding and monitoring of suppliers practices are also highlighted (e.g. Islam et al., 2021). With regard to distribution, improvement practices include intermodal transport and packaging improvements (e.g. Bonilla et al., 2015). Product services employment, along with cooperation among different actors along the supply chain are also revealed as improvement practices (e.g. Sarokin and Bocken, 2021).

***Table 3.** Improvement practices along the textile supply chain from a life cycle perspective in case of circularity*

Reference	Improvement practices
Avadi et al. (2020)	Focus future studies on the impacts of pesticides and of the substances end up in the soil with a more detailed modelling and the consumption of rain water
Glew et al. (2012)	Designing for reuse and recycling should be prioritised along with favouring

	biomaterials over petrochemicals
Moazzem et al. (2021)	Reducing resources used in cotton cultivation using use of organic cotton or recycled cotton fiber. Change of fibers Change of yarn spinning systems Increase of apparel lifetime, use of energy-efficient washing machine, use of front-loading washing machines, and avoiding dryer use and reducing consumer washing frequency.
Rossi et al. (2021)	Replacement of lorries by train or ship Substitution of cotton with jute Different procurement mix of leather from suppliers
Testa et al. (2017)	Collaboration among many local actors
Zhang et al. (2022)	Take into consideration nonaqueous dyeing systems but also the related loss of solvents
Rehman et al. (2024)	Improving inventory management Mapping of waste flow
Howard et al. (2022)	Using of recycled materials Aftercare repair service Long-term relationships and auditing with suppliers Behaviour change and knowledge sharing
Martin and Herlaar (2021)	Valorising waste wool Selecting electricity mix for processing and manufacturing
Zhao et al. (2021)	Change the traditional irrigation regime in cotton production Increasing water productivity Sharing successful experiences Change of consumption patterns
Bonilla et al. (2015)	Intermodal transport, transport consolidation and recycling
Frota de Albuquerque Land et al. (2023)	Use of recycled wool Reduction of washing frequency Change of packaging materials
Giungato et al. (2024)	Improve sanitary sterility of the reused products
Leal Filho et al. (2024)	Extending the life cycle of textiles through reuse, recycling Eco-design
Munasinghe et al. (2016)	Consider washing behaviour; types of raw material; recyclability; durability and biodegradability of raw material at the design phase Collaboration and knowledge sharing with raw material suppliers (increasing solar energy supply, optimizing lighting and cooling system during production
Amicarelli et al. (2022)	Improve data collection related to sharing and renting platforms

Islam et al. (2021)	Collaborative approaches Eco-design Auditing and monitoring suppliers
Islam et al. (2022)	Apply technological innovation (e.g. Three-dimensional printing, sensor-based RFID tags, digital twins, additive manufacturing, Industry 4.0, and the Internet of Things)
Jia et al. (2020)	Design for recycling biodegradable clothing Tools for textile traceability
Brydges (2021)	Eco-design (seasonless collections; quality driven) Developing in-house clothing rental, resale programs, Partnerships with second-hand businesses Encouraging consumers to take better care of their clothes (mending, washing) Extending garments life (upcycling)
Sarokin and Bocken (2021)	Collections can be constructed to be operationally slow Product services employment
Lin and Ma (2023)	Propose approaches of future green certifications, strengthen the criteria requirements of the delivery stage and use stage, increasing transportation considerations in the delivery stage, and increase usage scenario consideration in the use stage Reduce packaging materials
Hossain et al. (2014)	Developing environmental conservation policies and processes Enabling workers to develop autonomous motivational states Organising training and seminars

Conclusions

The textile sector represents one of the pillars of the global economy, offering job opportunities and significantly contributing to the economic growth of many countries. It is a rapidly expanding market, thanks to mass consumption models and diversification of sales channels. On the other hand, this sector generates great concerns linked to low circularity, the consumption of natural resources, and waste management.

Through this study it emerges that the production and manufacturing phase of a fabric, such as an item of clothing, can have a greater impact on the environment. Furthermore, composite materials are difficult to manage at the end of their life. It is therefore necessary to adopt a series of measures that allow this supply chain to implement circular economy practices to mitigate these impacts. Furthermore, more detailed studies are needed to implement new processing technologies and diversify the use of raw materials. Finally, from this analysis, it emerges that to achieve sustainability objectives, investments and economic efforts on behalf of companies are necessary. Therefore, only with cooperation between multiple enterprises, it will be possible to address these challenges and at the same time ensure profitability for this industry given its global value, volume and importance.

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Track 7: Quality Innovation in Food Sector

The impact of Lean Manufacturing on the operational performance of Greek food companies.

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Abstract

The purpose of the present study is to determine the impact of Lean Manufacturing (LM) on the operational performance (OP) of food manufacturing companies. Based on a structured questionnaire, a survey was carried out. A sample of Greek food manufacturing companies was randomly selected and 122 of them responded and completed the questionnaire. The impact of LM on OP was determined through the Linear Regression Analysis. The findings support a significant and positive impact of LM on the food company operational performance. The small size of the sample of the responding Greek food manufacturing companies and the subjective character of the data collected, constitute the main limitations of the present study. Based on these limitations, future studies can be conducted. The present study findings can guide the managers of food manufacturing companies to improve their OP through implementing LM practices. This is the first study that focuses on the impact of LM on the operational performance of food manufacturing companies operating in the Greek business environment.

Keywords: Lean Manufacturing, operational performance, food companies, Greece.

Introduction

Lean Manufacturing (LM) has emerged as a crucial approach for enhancing operational performance by emphasizing waste reduction and value creation. Originating from the Toyota Production System, LM principles focus on continuous improvement, efficiency, and the elimination of activities that do not add value (Womack & Jones, 2003). The implementation of LM practices has been extensively documented across various industries, including automotive, aerospace, and more recently, the food manufacturing sector. This sector faces unique challenges, such as product perishability and stringent quality standards (Dora et al., 2016; Vlachos, 2015).

In Greece, the food manufacturing industry, largely made up of small and medium-sized enterprises (SMEs), plays a crucial role in the national economy. Despite its importance, there is a scarcity of empirical research examining the effects of lean manufacturing (LM) practices on the operational performance of food companies. The comprehensive impact of lean production practices, which include both 'social' and 'technical' factors, on the operational performance of manufacturing companies in general, remains somewhat ambiguous (Sahoo, 2019). Moreover, there is limited literature addressing the influence of LM practices on both operational performance (OP) and business performance (BP) in SMEs, with only a handful of studies demonstrating significant benefits (Susanty et al., 2021). This study aims to address this gap by exploring the relationship between LM and OP in this sector.

Literature Review

Lean Manufacturing

Lean Manufacturing (LM) practices incorporate a variety of methodologies aimed at improving operational efficiency. Total Productive Maintenance (TPM) optimizes the effectiveness of manufacturing equipment through proactive and preventative maintenance, ensuring machines are always ready and minimizing downtime (Boyle & Scherrer-Rathje, 2009; Dora et al., 2016). Just-in-Time (JIT) production and delivery focus on reducing inventory and enhancing production efficiency by producing only what is needed, when it is needed, thereby reducing waste and improving flow (Ahmed et al., 2021) . Continuous Improvement, or Kaizen, promotes incremental improvements in all aspects of manufacturing processes, fostering a culture of ongoing enhancements (Malmbrandt & Åhlström, 2013). Quality tools and techniques help maintain organized workspaces and reduce variability in processes, leading to higher consistency and fewer defects (Putri & Dona, 2019). Supplier partnership and involvement are essential for developing collaborative relationships with suppliers, ensuring timely delivery, and maintaining high-quality standards (Cox et al., 2007). Furthermore, employee involvement and training are crucial as they engage employees in problem-solving and continuous improvement activities, enhancing their skills and fostering a sense of ownership and commitment (Zokaei & Simons, 2006).

Operational Performance (OP)

Operational performance (OP) is measured using various metrics that indicate the efficiency and effectiveness of manufacturing processes. Delivery reliability indicates the ability to deliver products on time and in full, ensuring customer satisfaction and reliability (Nawanir et al., 2013). Quality measures the conformance of products to specifications and the reduction of defects, which are critical for maintaining high standards and reducing rework (Boyle & Scherrer-Rathje, 2009). Flexibility represents the ability to adapt to changes in demand and production requirements, essential for responsiveness in a dynamic market (Malmbrandt & Åhlström, 2013). Speed and productivity measure how quickly and efficiently products are produced, indicating the overall efficiency of the production process (Dora et al., 2016). Employee morale indicates the level of employee satisfaction and engagement, significantly impacting productivity and turnover rates (Nawanir et al., 2013). The cost of quality (CoQ) includes all costs associated with ensuring and maintaining product quality, from prevention and appraisal to internal and external failures (Boyle & Scherrer-Rathje, 2009). Health issues within the workforce, which affect productivity and can lead to increased absenteeism and turnover, are also important metrics (Nawanir et al., 2016). Lastly, inventory reduction measures the efficiency in managing and reducing inventory levels, crucial for reducing holding costs and improving cash flow (Boyle & Scherrer-Rathje, 2009).

The Impact of LM on Food Company Operational Performance

The influence of LM practices on OP is significant in various manufacturing sectors, including food companies. Lean production methods enable companies to manage resources effectively, design better operational strategies, and reduce waste (Shah & Naghi Ganji, 2017). Lean practices help organizations address economic challenges, improve quality, and stay competitive by meeting customer expectations and planning processes accordingly (Shah & Naghi Ganji, 2017). Implementing lean tools in the food industry can lead to substantial cost savings and increased value by eliminating waste and improving customer value (Vlachos, 2015) . Studies have shown that lean practices enhance operational efficiency, productivity, and product quality in food processing sectors (Dora et al., 2016; Putri & Dona, 2019). The adoption of lean practices can also facilitate sustainable competitive advantages by reducing costs and improving market responsiveness (Psomas & Deliou, 2023).

Moreover, LM practices can help food companies identify and eliminate various types of waste, thus making process improvements (Kiran et al., 2023) .The lean concept is widely implemented to reduce the occurrence of defective products and waste that do not provide added value (Putri & Dona, 2019). The adoption of a lean production system acts as an improvement mechanism for organizational performance (Satolo et al., 2017). Lean tools and practices can significantly improve production efficiency and product quality in the food processing sector (Ahmed et al., 2021). However, commercial returns from participation in LM may not be acceptable for many actors in the food supply chain in the long-term (Cox et al., 2007).

Integrating LM with Industry 4.0 technologies can further improve quality, eliminate waste, and enhance competitiveness in the food business environment (Psomas & Deliou, 2023). The overall impact of lean production on organizational performance is evident through the reduction of waste, improved quality, and increased efficiency (Shah & Ganji, 2017).

Research Question (RQ): What is the impact of LM on the operational performance of food manufacturing companies?

Methodology

Questionnaire development

A survey was conducted to address the research questions. A structured questionnaire was employed as the data collection method, as it is the preferred approach in survey research studies on Lean Manufacturing (LM) (Jasti & Kodali, 2014). The first part of the questionnaire included questions regarding the profiles of the respondents and their companies. The second part focused on LM practices, while the final section addressed OP metrics.

The questionnaire instrument was evaluated through face-to-face interviews with professionals and academics. Additionally, it was pilot tested with 10 companies in Greece to ensure clarity of wording and appropriateness. Since the questionnaire was developed based on a comprehensive literature review, evaluated by experts in the field, and pilot tested, it possesses sufficient content validity, meaning that all aspects of these topics are represented by their associated questionnaire items (Keramida et al., 2023; Psomas et al., 2018).

Respondents were asked to indicate the degree of implementation of LM practices and OP in their companies using a seven-point Likert scale, where 1 represented zero degree of implementation, 2 very low degree, 3 low degree, 4 medium degree, 5 high degree, 6 very high degree, and 7 an extremely high degree of implementation.

Data Analysis

To assess the impact of LM on OP, Linear Regression Analysis was conducted, with the composite measure of LM serving as the independent variable and OP as the dependent variable. The assumptions for linearity, homoscedasticity, independence, and normality were tested and satisfied. Data processing was carried out using SPSS version 20. This methodology aims to assess the effect of LM practices on OP and ensure the reliability and validity of the regression results, ultimately aiding in the understanding of the benefits and impacts of integrating LM practices into traditional manufacturing processes.

Results

The analysis of the survey conducted on 122 food companies provides insightful data regarding the participants' educational backgrounds, industry experience, and company sizes. The majority of participants hold university degrees (49.2%), with a significant portion (38.5%) possessing postgraduate or PhD qualifications, indicating a highly educated sample. In terms of industry experience, 39.3% of the participants have 6-15 years of experience, while 23.8% have less than 5 years, reflecting a diverse range of professional expertise. The company size distribution reveals that most companies are small to medium-sized enterprises (SMEs), with 59.0% having fewer than 50 employees.

The survey offers valuable insights into their certification statuses and export activities. According to the results, approximately half of the companies (49.2%) have obtained ISO 9001:2015 certification, which establishes criteria for quality management systems. Furthermore, the data shows that a significant majority (78.7%) of the companies export their products, indicating a robust international market presence.

The regression analysis between Lean Practices (LP) as the independent variable and OP as the dependent variable demonstrates a significant positive correlation (Pearson Correlation: 0.493, $p < 0.001$) (Table.1), with LP explaining 24.3% of the variance in LO ($R^2 = 0.243$). The ANOVA results (Table.2) ($F_{1,120} = 38.575$, $p < 0.001$) further confirm the significance of this relationship. The regression coefficient ($\beta = 0.332$, $p < 0.001$) indicates that improvements in Lean Practices are associated with better OP.

Table 1. *Model Summary.*[b]

Model I	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	0.493[a]	0.243	0.237	0.55372	1.931

a. Predictors: (Constant), Lean b. Dependent Variable: OP

Table 2. ANOVA[a]

Model	Squares	df	Mean Square	F	Sig.
Regression	11.827	1	11.827	38.575	0.000[b]

Table 3. Coefficients [a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std.Error	Beta			Tolerance	VIF
Constant	2.923	0.267		10.947	0.000		
Lean practices	0.332	0.053	0.493	6.211	0.000	1.000	1.000
a. Dependent Variable: OP							

Discussion

This research offers a thorough examination of the effects of Lean Manufacturing (LM) practices on the operational performance (OP) of food manufacturing companies in Greece. Lean Manufacturing, which focuses on minimizing waste and enhancing value, has been extensively studied in various industries. However, this study addresses a significant gap by concentrating on the food manufacturing sector, which presents unique challenges such as the perishability of products and stringent quality requirements. The study's results demonstrate a significant positive correlation between the implementation of LM practices and operational performance, suggesting substantial benefits for food manufacturing companies, particularly small and medium-sized enterprises (SMEs).

The data reveals that a large portion of the surveyed companies are staffed by highly educated individuals, with many holding university degrees or higher qualifications. This level of education likely aids in the comprehension and execution of LM practices. The experience levels among participants, ranging from seasoned professionals to newer entrants, provide a diverse array of perspectives. The prevalence of SMEs in the sample highlights the importance of the study's conclusions for this vital segment of the Greek economy.

The survey results regarding certification and export activities reflect the sector's dedication to quality and international market presence. Nearly half of the companies have achieved ISO 9001:2015 certification, showing their commitment to stringent quality management systems. Furthermore, the fact that a significant majority are involved in exporting indicates their ability to compete in global markets and underscores the necessity for efficient operational practices.

The regression analysis uncovers a strong positive link between LM practices and operational performance. With a Pearson correlation coefficient of 0.493 and a regression coefficient of 0.332, both statistically significant, the data suggests that enhancements in LM practices are closely tied to improved operational outcomes. The ANOVA results bolster the statistical significance of this model, and an R^2 value of 0.243 indicates that nearly a quarter of the variance in operational performance is attributable to LM practices. This underscores the practical importance of implementing LM methodologies.

These results are consistent with findings from other manufacturing sectors, where LM practices are known to boost efficiency, cut waste, and improve quality. For the food manufacturing industry, these benefits can lead to better management of perishable products, compliance with strict quality standards, and greater market responsiveness. By embracing LM practices, food manufacturing companies can realize significant cost savings, enhance customer satisfaction, and secure a competitive advantage.

Future research should extend these findings by examining the long-term impacts of LM practices on both operational and business performance metrics. Moreover, integrating LM with Industry 4.0 technologies, such as the Internet of Things (IoT) and data analytics, could further optimize these practices. It would also be beneficial to investigate the obstacles SMEs face in adopting LM practices and to develop strategies to overcome these challenges. Comparative studies with other countries or regions could provide broader insights into the global application of LM practices in the food manufacturing sector. Finally, qualitative research through case studies or interviews could offer deeper understanding of how LM practices improve operational performance and identify best practices for their successful implementation.

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Exploring Consumer Attitudes Towards Novel Foods: A Study on Edible Insects Consumption Among University Students in Italy and Poland

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Abstract

Novel foods are foods or food ingredients that are not yet consumed on a wide basis by any population or by a proposed target population. 'Novel Food' can be newly developed, innovative food, food produced using new technologies and production processes, as well as food which is or has been traditionally eaten outside of the EU. Edible insects represent a globally recognized emerging food resource, with more than 2,100 species routinely consumed in about 130 countries, according to data from the Food and Agriculture Organization of the United Nations (FAO). However, consumers play a key role in determining the success of new food technologies in the marketplace. Their consumption can contribute significantly to global food security. After a short narrative review, based on how heuristics and individual differences among consumers influence the acceptance of agri-food technologies, this paper presents the preliminary results of an anonymous survey aimed at assessing attitudes and intentions to consume and acquire new, innovative foods containing edible insects (fresh, frozen, dried, powdered) by university students in Catania (Italy) and Lesser Poland Voivodship (Poland). Food neophobia, disgust sensitivity and cultural values are crucial personality factors for explaining individual differences and preference to accept these disruptive food technologies.

Keywords: Novel foods, survey, edible insects, new technologies, sustainability

Relevant Topic: Sustainable consumption and consumer

Introduction

Technologies used in the food supply chain have improved the safety, nutritional value and sustainability of food (Salomone et al., 2012; Cancemi et al, 2020; Spadaro et al. 2020). However, consumers often do not perceive these technologies positively. When faced with innovative technologies that could transform food systems, crucial questions emerge: why do consumers reject technologies considered safe by experts? What factors influence their perception and acceptance?

Consumers play a crucial role in determining the success of new food technologies in the marketplace. Many see the use of food technologies as being at odds with healthy and tasty food, presenting a challenge to the food industry. It is therefore appropriate to take consumer opinion into account at an early stage of product development.

The article examines consumer perceptions about new new raw material in food production such as edible insects EI. Families of insects such as Coleoptera (cockroaches and beetles), Orthoptera (locusts, crickets, grasshoppers), Arachnids (spiders and scorpions), and Homoptera (cicadas), have, for some time, been an integral part of the diet in many developing countries. For example, in China, the consumption of silkworms, cicadas, and crickets is a common practice, while in Thailand, fried, boiled, or grilled insects are common. In Africa, lepidopteran larva is one of the most widely consumed insects, available in various forms such as fresh, dried, pickled, or stewed with tomato sauce. These technologies, although not necessarily new in their invention, are considered so because of their recent introduction to the market in several countries.

Factors influencing consumer attitudes and acceptance of technologies are analyzed. Often, consumers rely on simple clues or heuristics, such as perceived naturalness or a sense of distaste for the unfamiliar, in addition to trust in the food industry. Individual differences, such as technological neophobia or sensitivity to food disgust, explain various attitudes toward these technologies.

Edible insects represent a globally recognized emerging food resource, with more than 2,100 species routinely consumed in about 130 countries, according to data from the Food and Agriculture Organization of the United Nations (FAO). Their consumption can contribute significantly to global food security. The nutritional composition of insects is highly variable and depends on their stage of development and growth substrate. Their protein content, makes them an equivalent or superior nutritional source to many traditional foods such as salmon, chicken, beef and pork.

In Italy, interest in entomophagy has increased significantly since 2015, during the Milan EXPO, which launched the slogan “Feeding the Planet, Energy for Life” promoting innovative ideas in food. Prior to the EXPO, the Food and Agriculture Organization (FAO) of the United Nations had already begun to encourage entomophagy as part of its Zero Hunger mission. The FAO believes that, with a steadily growing world population, insects can offer sustainable, high-protein and nutritious food solutions that can contribute, significantly, to food security and environmental protection.

In Europe, edible insects are regulated by Novel Food Regulation 2283/2015, which requires EFSA (European Food Safety Authority) approval for each species and derived product intended for human consumption .

As of today, April 2024, the following insect species are authorised for food use in Italy:

1. Tenebrio molitor (tenebrion larvae)

2. Locusta migratoria (grasshopper)

3. Acheta domesticus (house cricket)

4. Alphitobius diaperinus (chicken beetle).

However, it is important to note that no insect species or its derivative is currently approved for use in novel foods in Italy. Commercialization of insects as food will be allowed only when a specific authorization is issued at the European Union level pursuant to Regulation (EU) 2015/2283 on novel foods. Therefore, at the moment, it is necessary to wait for further regulatory developments for the use of insects as food in Italy. This is because the European Novel Food Regulation has included insects among novel foods, providing strict authorization procedures for their placing on the market.

In Italy, the Civil Code (article 2135). and subsequent regulations have expanded the definition of agricultural entrepreneur to include insect farming, recognizing their potential as both food and feed.

Indeed, insects represent a sustainable food option in terms of land and water use, although in the Western world they are not yet considered a customary dish. Interest in these foods in Europe and Italy has greatly increased even though questions have been raised regarding their regulation. In fact, food professionals are looking for new foods but ones that are environmentally friendly, nutritionally sound, and easily available. This interest must be accompanied by appropriate legislation to ensure food safety and the proper circulation of these novel foods in the marketplace.

Interest in edible insects is not limited to their nutritional value. They meet WHO (World Health Organization, 2020) requirements in terms of essential amino acid content and offer higher digestibility than plant proteins with a slight difference from animal proteins. Insect flours possess water and lipid retention capacities, emulsifying and foaming properties. They are proven health benefits due to their antioxidant, hyperglycemic and hyperlipidemic properties, which include inhibition of α-amylase activity, reduction of glucose diffusion and starch hydrolysis. They are also able to bind cholesterol and bile salts and inhibit lipase activity.

Insect-based food production offers several environmental benefits, including reduced greenhouse gas emissions, lower water use, and a better food conversion ratio. The negative environmental effects caused by agricultural production are a major concern (Bekuma et al., 2019; Uwizeye et al., 2020). Food production significantly accelerates GHG emissions, and the livestock supply chain in particular further contributes to global GHG and anthropogenic nitrogen emissions. In addition, in recent decades, there has been excessive use of fertilizers and pesticides that lead to multiple environmental problems, such as water pollution, soil acidification, nitrogen deposition, and greenhouse gas emissions.

Despite the benefits, the consumption of edible insects has critical issues related to food safety, allergenicity, and especially acceptance by Western consumers. Farmed insects, raised under controlled conditions, reduce the risk of microbial contamination, but processing must follow strict production standards . In addition, insects can cause allergic reactions similar to those caused by crustaceans, and specific treatments can reduce their allergenicity.

Food neophobia and disgust are the most significant barriers to the acceptance of insects as food, although studies have shown a greater susceptibility of Western consumers to complex products containing insect dust.

Food neophobia can be defined as consumers' reluctance to new, unfamiliar foods. It is a key scenario of the future trend toward insect consumption (Verbeke, 2015).

According to recent studies in the majority of consumers, insects arouse disgust and this bias allows only limited marketing (Arena et al., 2020; Caparros et al, 2016; Gmuer et al, 2016; Verbeke, 2015; Hartmann and Siegrist, 2017; Tan et al.,2015).

In Florença et al.'s (2022) study “The Motivations for Consumption of Edible Insects: A Systematic Review,” the literature highlights which drivers positively and negatively influence the consumption of edible insects.

Specifically, addressing the main determinants that negatively affect the consumption of EI, it was observed that they are related with some socio-demographic characteristics such as age, gender (females), living environment (rural areas) and occupation (students) as well as with sensory attributes such as appearance, odour, taste and presentation mode (whole insects). Some other factors that also negatively influence EI consumption are related to tradition/culture, social influence, country of origin, lack of familiar, past experience, religion, safety, risks, poor supply, seasonality, price, lack of knowledge. animal suffering, food neophobia, disgust, feeling of “dirty”, variety seeking tendency, food technology neophobia, intention to try and finally, uncertainty.

Concerning the drivers that positively correlate to the consumption of EI, these are related to age, gender (males), level of education (high), main occupation, level of income (high), level of knowledge, interest in entomophagy, children’s preferences, hidden in food, quality, price, convenience, ease of identification, taste, preparation method positive sensory expectations, positive attitudes to new food experiences, curiosity, social influence, intention to try. acceptance of sushi, eat in ethnic restaurants, familiarity/past experience, place of travel, nutritional value, sustainability, health benefits, perceived positive attributes and general benefits.

Methods

The research concerns a survey of attitudes towards new technologies and intentions to consume foods containing edible insects among students at selected universities and colleges. The research was conducted among university students from the University of Catania (Italy) and the University of Lesser Poland Voivodship (Poland) (Mikulec et al., 2024). The first research results were obtained from the University of Catania.

In this article we present the main results related to the opinions of the students of the University of Catania. The 49 students, to whom the questionnaire was submitted, are predominantly female (27) and are all residents of Catania. They are very young and have a median age of 20, with a slightly higher mean (21.78) and standard deviation of 5.59. Their field of study is divided between the medical area (35) and the economic and social area (14). Their financial position is predominantly good (at least good in 69,39%).

The data relating to the characteristics of Italian students are shown in Table 1.

Table 1. *Demographic and baseline characteristics*

Demographics		
Gender	n.	%
Male	22	44,90%
Female	27	55,10%
Study profile:	n.	%
medical and health sciences	35	71,43%
economics and management	13	26,53%
social sciences	1	2,04%
Age		
Media	21,78	
Median IQR	20,00	
SD	5,59	
Financial situation	n.	%
insufficient	2	4,08%
sufficient	13	26,53%
good	26	53,06%
very good	6	12,24%
high	2	4,08%

Results and Discussion

The statistical sample appears to be poorly engaged in professional work, has a high commitment to learning, has a strong focus on foods with high nutritional value and on the appreciation of the culinary traditions of the region of origin. The students demonstrate a high level of health consciousness and physical activity. They are not very able to evaluate the convenience and speed of food preparation. The overall results are shown in the graph below.

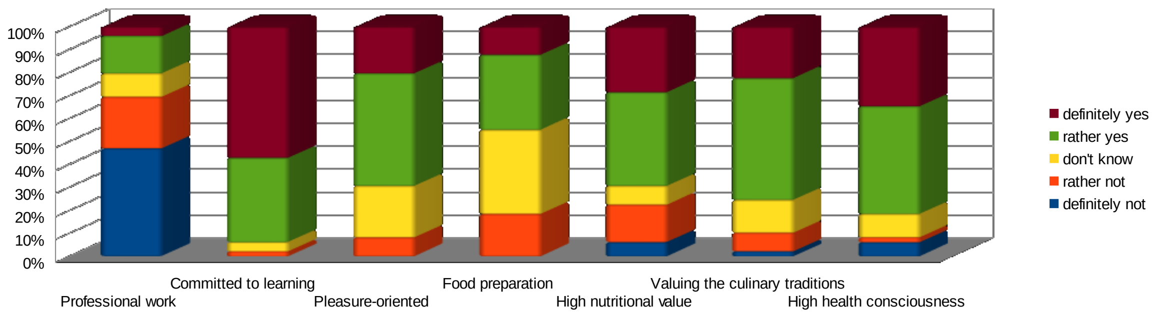

Figure 1. Lifestyle (Authors' elaboration)

The students indicated which protein sources currently dominate their diet. Examination of the data revealed chicken (91.84%) as the predominant source of protein, followed by fish (77.55%), eggs (73.47%), and beef (67.35%). The use of algae, soybeans and other plants (quinoa, amaranth) is very low.

The overall results are shown in the graph below.

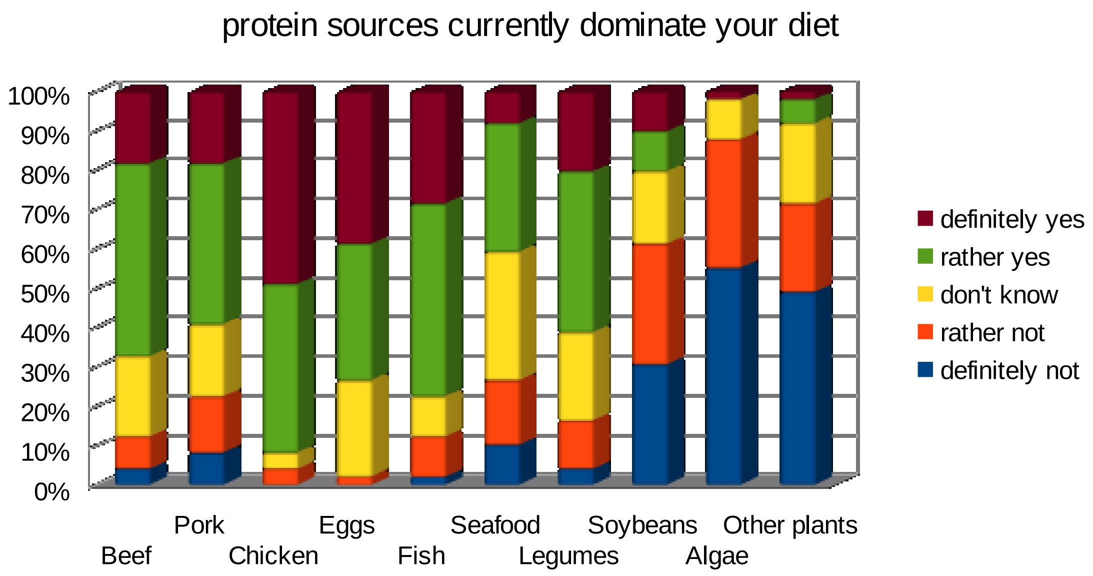

Figure 2. Protein graph (Authors' elaboration)

The students, who had generally never tried to prepare a dish with insects or insect-based ingredients and who had never eaten insects or foods containing them, were asked for further thoughts on the consumption of edible insects. Below are the considerations and in the following graph the results of the answers.

1) I think buying new food containing insects is a good idea.
2) I think buying new food containing insects is a wise choice.
3) I like the idea of buying new, innovative food containing insects.
4) Buying new innovative food containing insects would be pleasant.
5) I have not tried insects and foods containing insects and do not intend to try them.
6) I don't like edible insects and foods containing insects. It tastes terrible and I won't try it again.
7) I have never tried edible insects and foods containing insects, but I would try them if I had the chance.
8) I haven't tried insects and foods containing insects and don't intend to try them.
9) I really like edible insects and foods containing insects. I think it is tasty and I eat it.

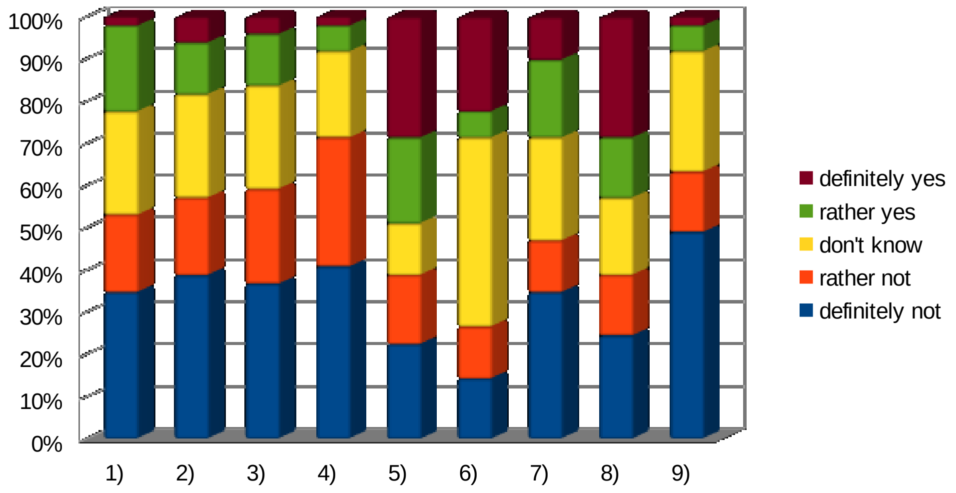

Figure 3. Opinion of Edible insects (Authors' elaboration)

The results show a clear neophobia and distaste for food from edible insects.

Considerations were also asked about the use of 'new foods' and environmental aspects. Below is a list of the sentences submitted for evaluation.

1) What would be your willingness to pay for "new foods" containing edible insects in their composition (fresh, frozen, dried, powdered, e.g., flour) that have attributes such as CO2 reduction, nutritional information, health information, attractive taste,
2) When I buy food, I try to pay attention to how its production affects the environment.
3) I try to avoid food products whose production is harmful to the environment.
4) I am interested in how food production affects the environment.
5) The naturalness of production methods is important to me.
6) I try to buy organic products.
7) I try to avoid products with food additives.

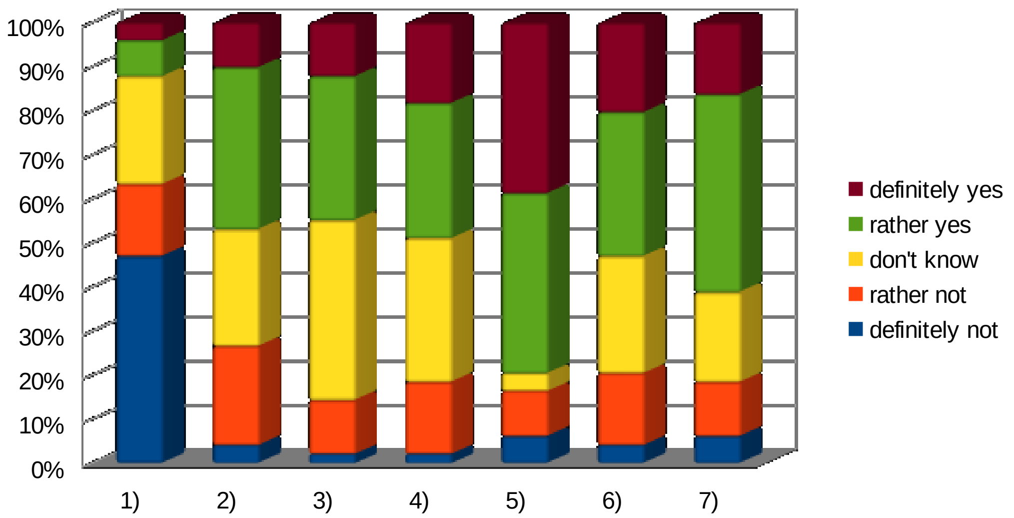

Figure 4. Edible insects and environmental aspects (Authors' elaboration)

The sample of students shows good attention to the importance of environmentally friendly food.

In addition, considerations of quality and health benefits were asked. Below are the sentences under analysis.

1) The quality certificate of the food I buy is important to me.
2) The naturalness of production methods is important to me.
3) I care about healthy eating
4) I try to make my diet healthy and balanced
5) When shopping, I choose products that have labels indicating their health benefits.

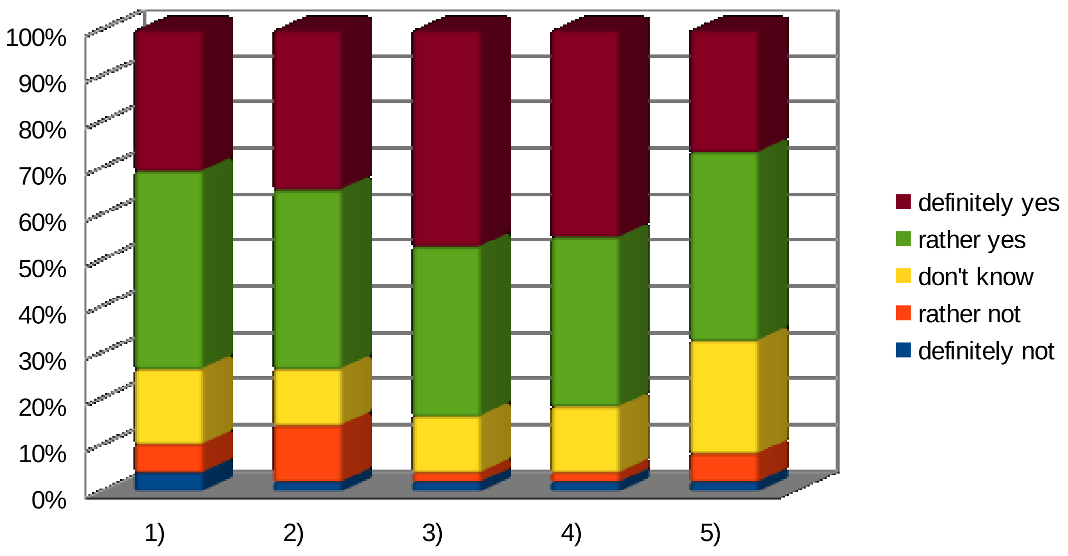

Figure 5. Quality certification and health benefits (Authors' elaboration)

The results show a particular focus by students on certification, quality aspects and attention to health benefits.

The final considerations of the student sample focused on the consumption of edible insects as a source of protein, and their importance on environmental and health impact. The following are the sentences evaluated.

1) Edible insects as sources of protein have similar nutritional value to the meat
2) Edible insects as protein sources are an insufficiently researched product
3) Production of food containing proteins extracted from edible insects will not contribute to environmental protection
4) The production of edible insects has a less negative impact on the environment than the production of meat from slaughtered animals and poultry.
5) Consumption of edible insects as a source of protein can contribute to reducing CO2 emissions
6) Concerns that consuming edible insects as a source of protein may be hazardous to health
7) Food containing edible insects as a source of protein is unpalatable
8) Food containing edible insects as a source of protein has an attractive taste and smell
9) I do not trust foods containing edible insects as a source of protein (e.g. dried, insect meal, etc.).
10) I constantly try new foods containing edible insects in their composition.

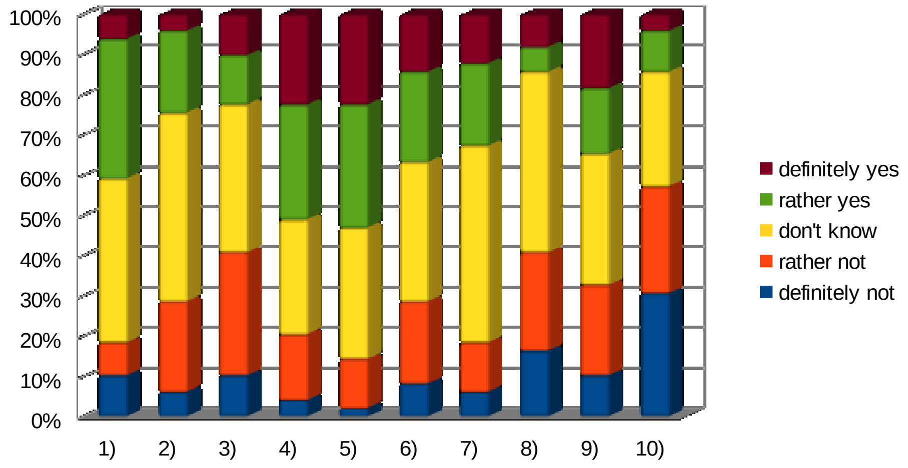

Figure 6. Importance on environmental and health impact (Authors' elaboration)

Examination of the latest responses shows that environmental and health aspects are very important.

Finally, an analysis of the data is presented, which takes into account the different gender focus and different study profile on insect consumption.

This analysis shows a better propensity of the male gender (31%) to consume edible insects, as shown by recent studies (Clarkson et al., 2018).

This analysis also shows a higher propensity of medical students (20%) to consume edible insects, as shown by recent studies (Szendrő et al., 2020).

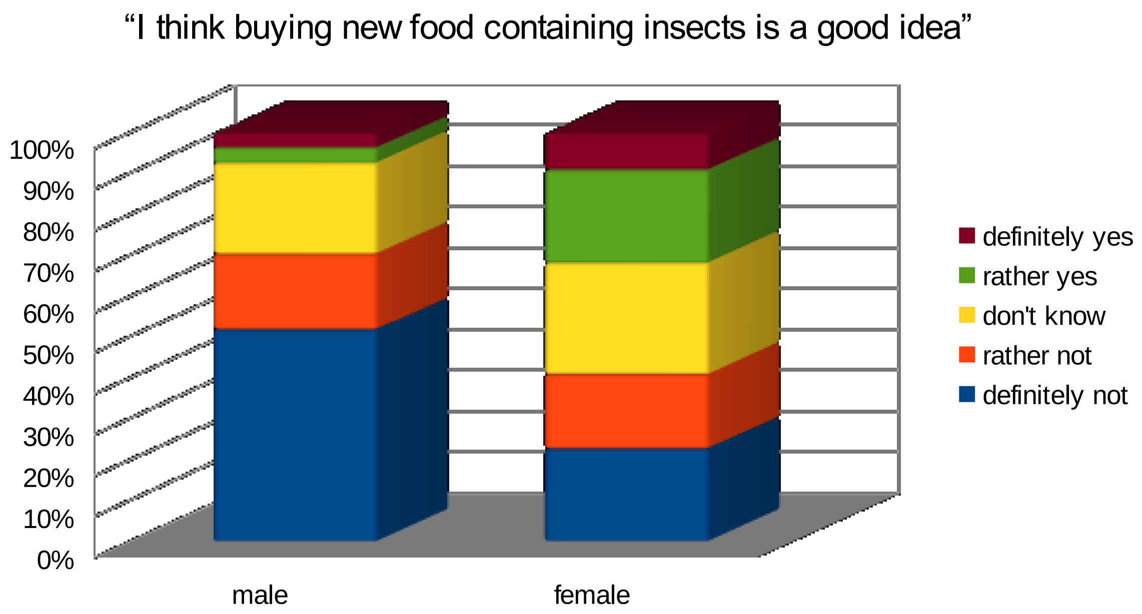

Figure 7. ***Gender analysis: “I think buying new food containing insects is a good idea” (Authors' elaboration)***

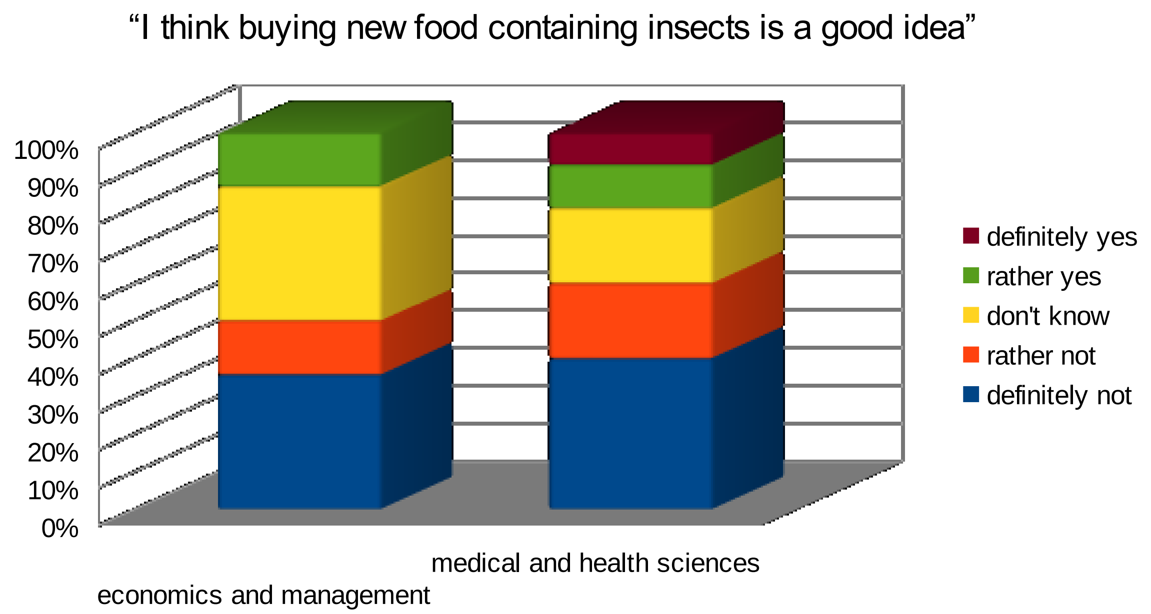

Figure 8. ***Study profile: “I think buying new food containing insects is a good idea” (Authors' elaboration)***

__Table 2.__ Chi square test

I think buying new food containing insects is a good idea.					
Gender	definitely not	rather not	don't know	rather yes	definitely yes
male	14	5	6	1	1
female	5	4	6	5	2
test chi square < 0,01					
Study profile					
economics and management	5	2	5	2	0
medical and health sciences	14	7	7	4	3
test chi square <0.01					

The goodness of the data is supported by the chi-square statistical test performed on the data.

Conclusions

The insect food and feed industry offer promising solutions to address the challenges of the global food system, i.e. population growth, limited natural resources and the reduction of food waste. This innovative and technological food industry sector is considered strategic by national and international authorities, in line with the Sustainable Development Goals (SDGs) and the reform of European policies aimed at more sustainable and circular food supply chains (e.g. Farm to Fork, F2F strategy).

The insect sector is still in its infancy with limited impact on consumption. However, the legislative framework on Novel Food and recent authorisations by the European Commission are helping to expand the market, facilitating access to these products and leading to increased consumption, especially through stealth entomophagy (products containing hidden insects).

Preliminary results on the sample of students at the University of Catania reveal an accentuated neophobia and distaste to the consumption of edible insects as food, despite their notable importance as a source of protein and their importance in terms of low environmental impact and relevance in terms of health. Contrary to the studies cited in the literature, students at the University of Catania have little inclination towards the consumption of edible insects. Once again, as confirmed by studies already conducted on the subject, men seem to be more willing to consume them.

Future research will analyse the data in comparison with the results of student responses from universities in the Lesser Poland Voivodship.

Acknowledgements

Project funded under the National Recovery and Resilience Plan (NRRP), Mission 4 Component 2 Investment 1.3 - Call for tender No. 341 of 15 March 2022 of Italian Ministry of University and Research funded by the European Union – NextGenerationEU; Project code PE00000003, Concession Decree No. 1550 of 11 October 2022 adopted by the Italian Ministry of University and Research, Project title "ON Foods - Research and innovation network on food and nutrition Sustainability, Safety and Security – Working ON Foods".4.

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Are we ready? Italian consumers' perceptions of cultured meat.

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Abstract

Cultured meat, produced in vitro through the cultivation of animal stem cells, is a radical innovation that is preparing to enter the market. Environmental impacts (especially CO2) for food could reduce the negative externalities of meat production and consumption and pave the way for a more sustainable food system. However, it is necessary to investigate consumers' propensity to accept it. The research explores consumer perceptions of cultured meat in Italy, where cultured meat production is banned. In detail, the authors analyze opportunities, challenges and implications related to the future diffusion of this novel food by connecting it to sustainability and quality issues. The study adopts an exploratory and inductive design approach, carried out through a qualitative approach based on in-depth interviews with Italian consumers. According to interviewees, cultured meat promotes sustainable development by protecting the environment, raw materials and human and animal habitats. However, more loyalty is needed regarding this novel food's quality, safety, and health effects. Findings highlight the fear of Italians regarding introducing this novel food as it can damage the actors involved in the agri-food supply chain. Most respondents believe that the manufacturing process is unreliable and that rigorous quality standards and controls must be performed to ensure the safety and reliability of the final product. The study describes consumers' opinions on the potential and doubts about consuming cultured meat and their perceptions on how sustainable, healthy and quality this novel food can be considered, providing suggestions for companies, policymakers and suggestions for future research.

Keywords: Cultured meat, Novel food, Consumers intention, Consumer perception, green technologies, sustainable quality

Introduction

The agri-food sector has come under increased scrutiny in recent years for its climate impacts, ethical impacts and human health consequences (Scollan et al., 2014; Stephens et al., 2018). These concerns and the growing demand for protein products have pushed workers and companies to produce more sustainable alternatives defined as novel food. European Commission defined 'Novel Food' as a "newly developed, innovative food, food produced using new technologies and production processes, as well as food which is or has been traditionally eaten outside of the EU" (European Commission, 2022). These novel foods are crucial for food security, safety and sustainability. One of the most significant technological advances in food production is the development of cultured meat (Seah et al., 2022; Treich, 2021).

This type of in vitro-produced meat has been gaining more and more popularity in recent years. This type of production helps reduce environmental problems associated with animal farming (Pakseresht, Kaliji and Canavari, 2022). According to the life cycle analysis (LCA), cultured meat would require less water (82-96% less), produce fewer greenhouse gases (78-96% less), use less energy (7-45%) and would involve less land use (less than 99%) compared to conventional meat production (Tuomisto, Ellis and Haastrup, 2015).

Consumers are informed about animal abuse and welfare issues and consider intensive farming and slaughter unethical. However, the literature highlights that consumers are unaware of environmental externalities (Siegrist and Hartmann, 2020). In any case, the main motivations that lead to changing food consumption with reduced meat consumption appear to be the desire to combat animal cruelty and environmental externalities (Onwezen et al., 2021).

Therefore, this new food reduces environmental problems, but manufacturing companies must use renewable energy resources to concretely and effectively pursue sustainable development (Lynch and Pierrehumbert, 2019). Cell culture technology requires efficiency of energy resources and water use (Moritz et al., 2015). Furthermore, further investments are needed to increase production and lower the price, especially compared to plant-based alternatives (Mattick and Allenby, 2012).

However, the literature highlights that consumer acceptance is the main obstacle in the diffusion and marketing of cultured meat (Hocquette, 2016). Empirical research on consumer behaviour towards cultured meat is scarce and based on limited literature (Bryant and Barnett, 2018; Onwezen, Bouwman, Reinders and Dagevos, 2021). Awareness and knowledge of the technology used in production influence consumer attitudes (Wu, 2010). Consumer scepticism towards new technologies in food production is often attributed to a lack of awareness of the technology and its benefits (Lusk, Roosen and Bieberstein, 2014). Previous studies have highlighted how the availability of information can influence the acceptance of these novel foods (Bekker, Fischer et al., 2017; Gasteratos and Sherman, 2018; Rolland, Markus and Post, 2020).

The literature review highlighted the need to understand the factors determining consumer acceptance of cultured meat (Harguess, Crespo and Hong, 2020; Onwezen, Bouwman, Reinders and Dagevos, 2021; Siegrist and Hartmann, 2020). In fact, it is crucial to delve into cultured meat's healthiness, safety, naturalness and sustainability characteristics (Siegrist et al., 2018). In light of this research gap, our study explores, through in-depth interviews, the perceptions of Italian consumers on the diffusion of this new food and investigates their point of view on quality, sustainability, ethics and socio-economic aspects connected to the production and marketing of cultured meat.

The results of our study provide suggestions for companies and policymakers on which aspects and factors to invest in addressing and communicating with consumers.

The paper is structured as follows. Section 2 presents the results of our empirical study. Section 3 presents the qualitative findings, and Section 4 discusses the findings. Finally, Section 5 provides conclusions, the study's limitations and future perspectives.

Method

The research adopts a qualitative investigation using in-depth interviews. The qualitative investigation aims to investigate the consumer perceptions of cultured meat in Italy, where cultured meat production is banned. The authors analyze opportunities, challenges and implications related to the future diffusion of this novel food by connecting it to sustainability and quality issues. A semi-structured interview outline with 22 questions was developed. The track is structured in this way: firstly, general questions were asked about the diffusion of these new foods of the future, followed by consumer perceptions on cultured meat, which were explored in detail by connecting it to the themes of quality, sustainability, ethics and socio-economic aspects. During May 2024, 34 in-depth face-to-face interviews were conducted to explore the cultured meat phenomenon by examining the perceptions and expectations of Italian consumers. Following data saturation principles for theory-based interview research (Francis et al., 2010), data collection continued for 34 interviews until data saturation was achieved. In line with this approach, the decision to collect more data is based on the non-emergence of new themes and on the researcher's perception of what he is hearing (Saunders et al., 2018). Participants were selected through a snowball approach (Guido, 1999; Guglielmetti Mugion et al., 2018; Pasca and Arcese, 2024). The interviews were recorded and transcribed; then, two researchers analysed and coded the text using the MAXQDA18 software to eliminate bias and subjective interpretations.

Results

Sample characteristics'

The sample comprises 34 interviewees: 20 males and 14 females. Most respondents belong to the 18-25 age group (17 respondents), followed by 11 consumers over 56. Among the respondents, 18 are students, and 9 are private sector employees. Furthermore, 15 respondents have a diploma, 11 have a master's degree, and seven have a bachelor's degree. Figure 1 shows that 28 interviewees follow the Mediterranean diet, three consumers follow a protein diet, one is vegetarian, and two are celiac. Figure 2 shows the following distribution of weekly meat consumption: 1 time (2), two times (1), 1-2 times (8), 2-3 times (11), >3 times (11) and never (1).

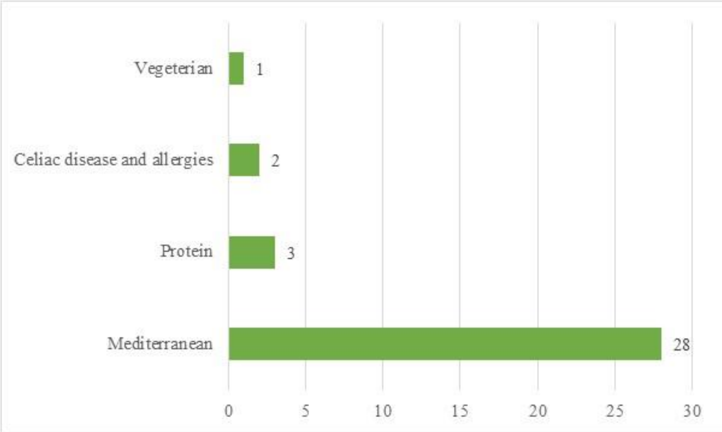

Figure 1. *Diet habit*

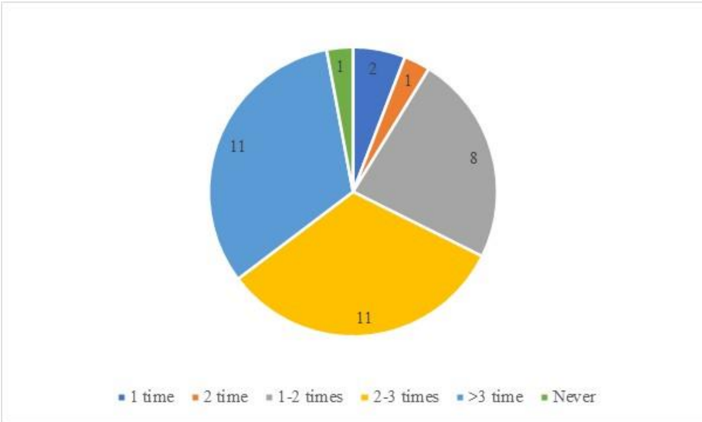

Figure 2. *Distribution of weekly meat consumption*

Qualitative results

The authors analyzed the results of the interviews through quotation and frequency tables on the key topics raised.

A significant number of the interviewees (28) demonstrated a commendable level of environmental and animal welfare consciousness. They acknowledged the potential adverse effects of conventional meat consumption on the environment and resources. Their concern extended to the need for community education on intensive farming and animal treatment. Interestingly, 30 interviewees advocated for a balanced approach to conventional meat consumption, emphasizing the importance of its origin and supporting sustainable and ethical farming.

Interviewees identified as novel foods: insects (18), cultured meat (12), cricket flour (10). Interviewees consider cultured meat a non-natural/artificial food that contributes (see Figure 3) to sustainability through reducing greenhouse gas emissions, more efficient use of natural resources, and promoting animal welfare through the reduction of intensive farming. Furthermore, these new foods would make it possible to satisfy the world population's needs, pursue Goals 1 and 2 of the 2030 Agenda, and save natural resources.

"Foods of the future can support sustainability by promoting animal welfare, reducing greenhouse gas emissions, using natural resources more effectively, and diversifying their energy sources to include more environmentally friendly options."

"These food can conserve resources thanks to these new foods. Additionally, they do not necessitate massive amounts of water or extensive soil exploitation."

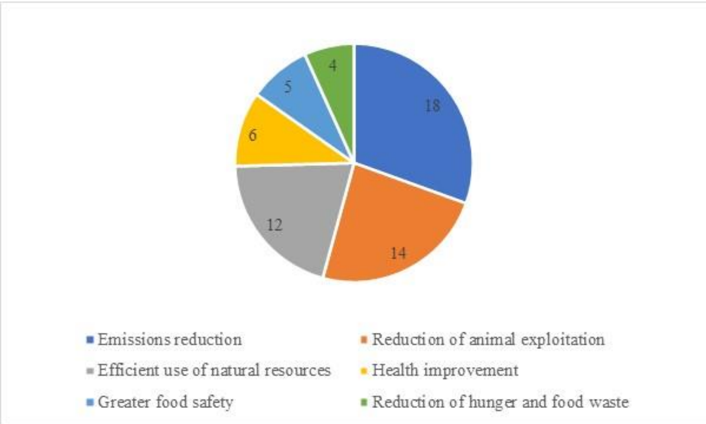

Figure 3. *Cultured meat benefits*

However, as shown in Table 1, some interviewees are opposed to introducing this new food due to the lack of information on its preparation and production and its actual safety. Furthermore, according to some interviewees, it jeopardizes the Italian agri-food economy, reducing the workforce in the sector.

"Introducing cultured meat puts small farmers at risk and negatively impacts the agricultural sector and the local economy."

"The introduction of cultured meat impacts the agriculture industry by creating new avenues for production research and development."

The introduction of this new food would distance Italians from culinary tradition.

Table 1. *Cultured meat risks*

Risks	**Frequency**
Health effects	17
Loss of culinary traditions	13
Economics consequences	8
Food safety	8

The majority of consumers (17) are not willing to consume cultured meat due to their lack of confidence in its health effects; the remaining interviewees, however, would try it out of curiosity (11*): "I would like to try it to test the taste and quality of the product*" and to preserve the animals and the environment (7).

Regarding the quality issue connected to cultured meat, the need has emerged for consumers to have more information on the production process, checking that it complies with nutritional quality standards. According to interviewees, the nutritional composition of cultured meat can be designed to be similar to that of traditional meat. Cultured meat could be a source of proteins and nutrients identical to conventional meat, as it is produced from animal stem cells (18). According to 16 interviewees, cultured meat does not have the same nutritional properties as traditional meat. According to eighteen responders, the flavour and texture of cultured meat are not comparable to those of cultured beef. However, 14 customers claim that cultured meat can have the same taste and texture as regular meat. Two respondents claim that while cultured meat can mimic the flavour of real flesh, it cannot replicate its texture.

Cultured meat is connected to issues of sustainability and ethics. In fact, *"cultured meat would solve the problems related to world hunger as it is a source of protein"*. There would be greater availability of meat. Others, however, claim that the new food's high production and sales costs would not help end world hunger (12). The remaining six interviewees view cultured meat as a tool that can supplement dietary protein, particularly in areas where food is scarce, rather than as a panacea for world poverty.

Consumers highlighted that cultured meat could have a lower environmental impact than traditional meat production, requiring less space, water and raw materials. However, it is also essential to consider other factors such as the energy needed for laboratory production and waste management.

Ten respondents said introducing this new food improves community well-being by lowering pollution, protecting the ecosystem, and increasing access to food.

"Cultured meat may provide a more sustainable and safe supply of protein, lowering the risk of illnesses associated with eating tainted meat. Furthermore, lowering dependency on intensive farming might contribute to better animal welfare".

According to 22 interviewees, cultured meat puts traditional culinary culture at risk. "*Standardized foods are not part of the Italian culinary tradition".* However, for other consumers, the innovation would not put traditional culinary culture at risk. Respondents were asked how much they would be willing to pay for this new food: 14 said they would pay much less than traditional meat; 9 consumers would be willing to pay more for the environmental benefits that would be obtained; 5 interviewees would pay the same price to buy conventional meat and instead, six interviewees would refuse to purchase cultured meat.

Italy is the first country in the world to have banned the production and marketing of cultured meat. Below is the opinion expressed by those interviewed:

Table 2. *Ban on the production and trade of cultured meat in Italy*

Quotations	**Frequency**
"Italy has adopted a cautious approach to cultured meat in light of the effects on conventional industries and food safety. The decision is meant to safeguard the nation's economy and the farmers and meat producers."	20
"The manufacture should be banned since insufficient knowledge and assurance exists. It can potentially destroy Italy's agricultural economy, and its long-term repercussions on consumers are unknown."	7
"To conduct additional research and testing before releasing this product onto the market, Italy has decided to prohibit its manufacture and marketing."	7

Discussions

Understanding and exploring consumer perceptions and expectations about cultured meat is crucial in order to accept this new food technology (Pakseresht, Kaliji and Canavari, 2022). The main reasons that would push consumers to accept this novel food are the environmental benefits (such as CO2 reduction and reduction in the use of raw materials) and the improvement of animal welfare. This new food is considered more sustainable than traditional meat. The analysis revealed the need to provide more information on the preparation and production phases of cultured meat and further research its effects on health and nutritional values (Rombach et al., 2022). Investing in food safety and transparency through investments in Research and Development is crucial to obtain more information on the effects of this novel food. Italy has banned the production and marketing of cultured meat. This ban exists due to the need to protect the national agri-food heritage, as well as the health of citizens. However, other countries are seeing strong growth in the cultured meat sector. This is mainly due to the production capacity of "conventional" meat, which will no longer be able to meet the growing demand linked to the increase in the world population and access to meat from developing economies.

Furthermore, compared to conventional meat production, cultured meat could reduce land use by up to 99%, water use by up to 96%, and greenhouse gas emissions from meat production by up to 96% (Mazac, Järviö and Tuomisto, 2023). Another reason is the decline in meat consumption among the non-vegetarian population. This is linked to the growing attention to animal welfare and leads producers to evaluate alternative production methods to remain in the market. Finally, cultivated meat would limit the pathologies associated with the consumption of red meat and the contamination of meat by pathogens, which are typically related to the intensity of livestock farming. This new food can contribute to sustainable development, particularly by increasing access to food (Verbeke et al., 2015). Cultured meat could challenge traditional Italian culinary culture; however, significant investments are needed to protect small and medium-sized businesses in the sector and farmers and constantly increase consumer awareness on these issues.

Conclusions

The following study explores consumer perceptions of cultured meat in Italy, where its production is banned. The authors analyze opportunities, challenges, and implications related to the future diffusion of this novel food by connecting it to sustainability and quality issues. The results highlighted how crucial it is for governments and companies in the sector to invest in raising awareness of the benefits of cultured meat for animal welfare and environmental sustainability. It is necessary to provide information on the reliability and safety of cultured meat production. Therefore, investing in developing safe and effective technologies, applying laws that guarantee the quality and safety of products and encouraging collaboration between the public and private sectors to promote the introduction of technology in the food sector and protect all stakeholders involved in the production chain. The present study has some limitations. The authors explored consumer perceptions of cultured meat despite its marketing ban in Italy. Future research could expand the sample size, replicate the study in other countries, and implement different methodologies.

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Promoting Agroecology and Innovative Approaches to Enhancing Food Security: A Case Study of Women's Cooperatives in Senegal

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Abstract

The Senegalese agri-food industry, while significant in Africa, exhibits a notable dual structure with a modern sector alongside numerous formal and informal food processing units. Small-scale women-led cooperatives, often operating with limited resources within local communities, naturally adopt practices that emphasize environmental stewardship and resilience. By promoting policies that incentivize sustainable farming methods, investing in training, and supporting community-led initiatives, it is possible to shift towards a more resilient and equitable food system. The paper focuses on enhancing the multifunctional activities of a women's cooperative in the Thiès region through an agroecological approach. Supported by the SB-AGROIN project, funded by the Italian cooperation agency, the cooperative has established a new processing unit in Keur Moussa. The project aligns with the principles of agroecology, emphasizing sustainable agricultural systems and social equity. It aims to strengthen the agrifood supply chain, enhancing food security and income for local female producers. The initiative involved the implementation, within the processing unit, of a quality and hygiene management systems to meet local standards, facilitating potential market expansion. The actual production includes jams, syrups, fruit juices. In addition, an enriched millet flour for infant nutrition has been added among the produced items. Thus, the flour was specifically compared for its antioxidant properties with a similar semi-industrial one, aiming to explore its potential positioning within the local market. The study finally contributes to understand challenges and opportunities for small-scale food processors in Senegal. It highlights the importance of agroecological principles in promoting sustainable food systems and equitable market.

Keywords: Agroecology, Food Security, Antioxidant properties, Quality Management System, Women-led-cooperative

Introduction

This study was conducted as part of the three-year project “Social business e sviluppo innovativo della filiera agro-industriale nella regione di Thiès (SB-AGROIN) - AID 011894,” implemented by ASeS Agricoltori Solidarietà e Sviluppo and funded by the Italian Agency for Development Cooperation. The project's goals included enhancing food security and increasing the income of small-scale farmers in the Thiès region, Senegal, by improving their production techniques and developing the agro-industrial supply chain. To achieve these aims, the project focused on establishing a fruit and vegetable supply chain to boost the quantity of processed agricultural products sold in the local Thiès market. This paper details the findings of an action-research project conducted by ARCO; a university action-research center established in 2008 at PIN S.c.r.l. (Polo Universitario “Città di Prato”) – University of Florence. Within the SB-AGROIN project's framework, the creation of social enterprises was promoted to facilitate the dissemination and use of innovative production methods to enhance agricultural output and contribute to the agro-industrial sector's growth in the Thiès Region. These social enterprises are funded through a revolving fund set up at a local microfinance institution. As a project partner, ARCO provided support to a social enterprise specializing in the processing of fruits, vegetables, and cereals, managed by the women’s social enterprise of Ker Moussa (RFPT), with its production center established by the project. ARCO assisted the RFPT network in drafting production guidelines to ensure that processed products adhere to hygienic and quality standards. The subsequent action-research aimed to align operations with hygiene standards and enhance quality procedures in compliance with local regulations and best practices, while also considering potential export opportunities. The Senegalese agri-food industry, ranking second in Africa after Ivory Coast, displays a notable duality between a modern, organized sector and numerous formal and informal food processing units. However, the quality of product transformation remains below standard, especially among small-scale fruit and vegetable processing enterprises, which face challenges in obtaining market information and developing effective commercial strategies. According to a market analysis conducted under the SB-AGROIN project, in 2019, 92% of households in the target area of the Thiès region consumed syrups and processed fruit juices. The market segments were characterized as follows: The hibiscus juice market was highly competitive, with about fifteen suppliers, where four, including the RFPT, were competing for the top spot. The baobab juice market was intensely contested, with four major suppliers evenly splitting the market share. The ginger juice market faced competition from around a dozen suppliers, with two leading suppliers capturing 20% and 13.32% of the market share, and the RFPT holding 6.66%. The ginger syrup market was dominated by the RFPT, holding 96% of the market share, while another network held 4%. Overall, competition was fierce in a region with many transformation enterprises. The power of suppliers, especially for raw materials, varied throughout the year due to seasonal fluctuations in certain products. Customer bargaining power was weak, with a significant threat from substitute products. The threat of new entrants into the agri-food sector remained high. Customers prioritized active ingredient content, hygiene and cleanliness, shelf life, and price when making purchasing decisions. The most requested products from the RFPT network of Keur Moussa were ginger, lemon, and hibiscus syrups, as well as ginger, hibiscus, and tamarind juices (SB-AGROIN, 2022). In Senegal, the consumption of infant flours is largely dominated by imported products. There is a diverse range of brands available, especially from countries such as Brazil, Morocco, and Spain. Notably, some of these imported flours are perceived as local by both distributors and the general population. In rural areas, the consumption of these flours is minimal and primarily limited to regions near production sites. The preference for imported products stems from the perceived higher quality and reliability associated with foreign brands. This perception poses a significant challenge for local producers, who struggle to compete not only in terms of quality but also in brand recognition and distribution networks (UNICEF, 2020). This paper also examines a local Senegalese infant flour preparation made by RFPT. This flour is a blend of various flours from cereals, legumes, and locally used medicinal plant species, including millet (*Panicum miliaceum* L.), maize (*Zea mays* L.), peanuts (*Arachis hypogaea*), cowpeas (*Vigna unguiculata* L.), moringa (*Moringa oleifera* L.), salt, and sugar. This traditional Senegalese flour preparation, known locally in Wolof as "*sunguf fernet*" is typically prepared by women in rural areas. It is a highly nutritious dish primarily intended for infants, but it is also suitable for the elderly, malnourished, or sick individuals.

Methods

The action-research described in this paper is based on activities carried out under a funded project. The first activity of the action-research was to assess the compliance with hygiene standards and regulation in the newly built processing unit of Ker Moussa. Preliminary analysis of the supply chains and sectors under study involved a territorial framework and the identification of relevant supply chains, primarily through desk-based analysis of available documents and publications. These included documents on ongoing projects, reports on previous activities, technical reports, national policy documents, and import/export data. This was followed by a needs analysis, usually conducted with key project stakeholders through semi-structured interviews and focus groups with project beneficiaries, local partners, potential beneficiaries. Based on the territorial context, challenges and weaknesses of producers and entrepreneurs are considered, including issues related to associations, business support services, and access to credit. Moreover, within a perspective of improvement of the production process, this paper describes the introduction of hygiene procedures and best practices in the processing unit. Information obtained during interviews, combined with structural and management elements gathered from field visits to production activities, provided an overview of the operational procedures in the visited enterprises. This helped to compare the existing operational and management model with standardized quality requirements adopted internationally and in potential sales markets. In order to achieve the above-mentioned objectives, this action-research study has adopted a methodology based on the active involvement of the project beneficiaries. In particular, the activities were carried out before and during a field mission: a) Desk-based analysis and existing regulation and standards; b) Meeting with the group of 12 women from the RFPT to discuss their progress, needs, and challenges encountered in their production activities and the establishment of the transformation center; c) Gathering information for the preparation of a hygiene and quality procedures manual for the Keur Moussa transformation unit. The site visit focused first on the audit of the newly constructed facility, which was in the initial stages of setup and furnishing, with operationalization scheduled shortly. The audit, carried out without the presence of the group of 12 women of RFPT, focused on a structural audit to assess compliance with hygiene and sanitation requirements. It also aimed to evaluate the premises, arrangement of materials and equipment, and overall conditions. Later, on site observation of the complete cycle of two of their characteristic productions (fruit juice production and jam production). Lastly, 2 training days on food hygiene and good practices. The training was tailored to existing procedures and conducted in the facility's areas for direct demonstrations. The global application of Hazard Analysis and Critical Control Points (HACCP) is crucial for reducing foodborne outbreaks and boosting consumer confidence in food products (Boutou, 2008). As global food trade grows, harmonizing HACCP regulations across borders is necessary to maintain consistent food safety standards worldwide. Implementing HACCP globally can protect public health, promote international trade, and enhance the overall integrity of the food industry. Standardized procedures and good manufacturing practices (GMP) support process efficiency, improving the quality and hygiene of production (Borsacchi et al., 2005). In Senegal, the mandatory application of hygiene and quality procedures should align with both national regulations and international standards and GMPs (Ndiaye, 2018). The action-research described in this paper took inspiration from ISO 22000:2005 for all prepared documents (e.g., check-lists, training material, and the Keur Moussa Transformation Unit Quality Manual). This international standard guide agro-food companies in implementing efficient food safety systems. ISO 22000 can be complemented by other recognized standards to enhance quality, hygiene, and product safety management systems. The standard recommends "operational prerequisite programs" (PRPs) to manage food safety risks within the work environment effectively. PRPs should consider potential hazards and the risk of cross-contamination involving biological, chemical, and physical risks. These programs should also address facility and machinery design and construction to minimize risks. Integrating ISO 22000 with other management system schemes like ISO 9001 and ISO 14001 is advisable (Pinelli et al., 2018).

In our work frame, a parallel activity involves the characterization of goods through an analytical sampling scheme to define the qualitative and quantitative profile of bioactive molecules (such as polyphenolic compounds) and the determination of their concentration. The preferred technique for these analytical measurements is the UV-VIS spectrophotometry, with the application of tests for measuring antioxidant activity of plant extracts (Folin-Ciocalteu UV-Vis spectrophotometric assay) and anti-radical properties (DPPH radical spectrophotometric test). The results of these analyses contribute to the definition of product technical sheets and highlight the presence of bioactive substances, which may render the food matrix interesting for other uses, promoting multifunctionality. The analyses were performed on samples of a traditional Senegalese flour preparation and a sample of a semi-industrial infant flour.

Samples preparation

A quantity of 1 gram of each sample was dissolved in 20 mL of a hydroalcoholic solution consisting of EtOH (ethanol) 70% and acidic water at pH 3.2 by formic acid (30%). After 1 night extraction at room temperature, in the dark, the extracts were centrifuged at 5000 rpm for 5 min in a centrifuge at temperature control (18°C) to separate the hydroalcoholic supernatant from the residue. Samples were prepared in triplicate.

Spectrophotometry assays

Total polyphenols were determined by a Folin-Ciocalteau method following a previous study (Pinelli et al., 2018). The amount of total phenolics is expressed as Gallic Acid Equivalents (GAE, mg of gallic acid per 100 g of sample, on weight basis), through the calibration curve of gallic acid. The calibration curve range was 10 - 120 µg/mL (R^2=0.995). The antiradical capacity was estimated by DPPH test, according to a a previously reported procedure (Heimler, 2005: 3053–3056), with slight modifications (ISDRS 2018). The IC50 of the extracts was determined by using the five-point linearized curves [AR%-ln (concentration in polyphenols)], built determining AR% for five different dilutions of each extract and, then, by calculating the concentration in polyphenols (in ppm) of the solution that inhibits the DPPH activity to 50%. The antiradical efficiency (AE) was calculated following a previous work with slight modifications (Mansouri et al., 2005: 411–420), using the formula 1/IC50*100.

Results and Discussion

Quality management system

During the site visit to the transformation unit, the women of RFPT simulated a complete cycle of two characteristic productions (fruit juice production and jam production) using mango as raw material for both. The use of compliance checklists for prerequisite programs in production facilities, prepared according to the ISO 22000 standard, allowed for the generation of detailed report. The observation revealed some procedural weaknesses. Table 1 reports the main identified issues, categorized as structural (requiring structural, plumbing, or electrical interventions) and production related, with high or medium priority of intervention. The issues follow the internal layout of the transformation unit. For each issue, a proposed solution and a priority level for intervention are provided.

***Table 1**. Transformation unit assessment: main issues emerged and proposed solutions.*

STRUCTURAL ISSUES			
Ref. #	Issue	Proposed solution	Priority
SI.1	Holes in the corridor walls leading to the changing rooms and laboratory allow the entry of dirt, dust, and animals, creating potential sources of biological and physical contamination.	Overlay a fine-mesh net that prevents dust and animals from entering the facility while allowing ventilation.	High
SI.2	Bathrooms lack proper ventilation.	Install a metal duct connected to the outside, equipped with a fan to allow air circulation and ventilation.	Medium

SI.3	The sinks at the entrance of the laboratory and production areas have faucets that can re-contaminate hands after sanitization.	Replace the faucet with a pedal-operated or long-lever faucet to eliminate contact with dirty surfaces after hand sanitization.	High
SI.4	Glass doors pose a risk of physical contamination and injury if broken.	Apply plastic film to the glass to prevent glass dispersion in case of breakage.	High
SI.5	Gaps between tiles on the production room floor hinder effective cleaning.	Purchase and apply floor coating to create a completely smooth surface.	Medium
SI.6	Consider the adoption of insect capture lamps.	Purchase and install insect capture lamps in production and storage areas.	High
SI.7	Unprotected neon lights in the production area pose a contamination risk if broken.	Install covers/fittings on lights.	High
SI.8	Sharp corners on workbenches in the production area pose safety hazards for operators.	Install plastic or silicone corner guards on all workbench corners.	Medium
SI.9	The absence of rounded corners in the facility makes thorough cleaning difficult, increasing contamination risks.	Install rounded plastic corners on masonry surfaces, as baseboards and wall corners.	High
SI.10	Exterior doors permit the entry of dirt, insects, and crawling creatures, posing contamination risks.	Install brushes at the bottom of the doors.	High
PRODUCTION ISSUES			
PI.1	The use of wooden ladles poses a risk of cross-contamination. Wood is not allowed in production areas.	Purchase and use stainless steel ladles.	High
PI.2	Chemical products do not have a designated space when not in use, potentially leading to chemical risks or inappropriate use.	Purchase a cabinet for storing chemical products (consider multiple cabinets in different rooms for chemicals used in that room).	High
PI.3	Materials for production placed on the floor, posing a potential physical and biological contamination risk.	It is recommended to place the cabinets at a distance of 50-60 cm from the wall to prevent dirt buildup and the possibility of insects and rodents nesting.	High
PI.4	Food products placed directly on the floor, posing a potential physical and biological contamination risk.	Purchase plastic pallets. It is recommended to place the pallets at a distance	High

The assessment of the hygiene conditions of the premises and the observation of the processing cycles carried out by the women provided input for the definition of operational procedures and good manufacturing practices for the transformation unit. To ensure the effectiveness of an HACCP management system, it is first essential to define and formalize the Prerequisite Programs (PRP). Without a robust implementation of PRPs, the quality controls planned according to HACCP may lose their effectiveness, and the process may not be under control.

The definition and implementation of a Keur Moussa Transformation Unit Quality Manual (QM) followed evidence and inputs emerged during the field mission, with accordance to the level of awareness of the women of RFTP. To enhance the management aspects of the women social enterprise, the action-research for the development of a Quality Management System (QMS) for the cooperative began with the requirements of both HACCP and ISO standards (i.e. ISO 9001 and ISO 22000). Sections and paragraphs of the QM manual, prepared in French and appropriately adapted to the structure of the target cooperative, are therefore:

Table 2. *Index of Keur Moussa Transformation Unit Quality Manual*

Keur Moussa Transformation Unit Quality Manual	
0.0	**Revision History and Approval**
1.0	**RFTP Cooperative**
2.0	**About the Manual**
3.0	**Terms and Definitions**
4.0	**Context of the Organization**
4.1	**Understanding RFTP and Its Context**
4.2	**Understanding Needs and Expectations of Interested Parties**
4.3	**Determining the Scope of the HACCP Management System**
4.4	**HACCP Management System and Processes**
5.0	**Leadership**
5.1	**Leadership & Commitment**
5.2	**Policy**
5.3	**Organizational Roles Responsibilities and Authorities**
6.0	**Planning**
6.1	**Actions to Address Risks and Opportunities**
6.2	**Quality Objectives and Planning**
6.3	**Planning of Changes**
7.0	**Support**
7.1	**Resources**
7.2	**Competence**
7.3	**Awareness**
7.4	**Communication**
7.5	**Documented Information**
8.0	**Operation**
8.1	**Operational Planning and Control**
8.2	**Requirements for products and services**
8.3	**Design and Development of Products and Services**
8.4	**Control of Provided Processes, Products and Services**
8.5	**Production and service provision**
8.6	**Release of products and services**
8.7	**Control of nonconforming outputs**
9.0	**Performance Evaluation**
9.1	**Monitoring, Measurement, Analysis and Evaluation**
9.2	**Internal Audit**
9.3	**Management Review**
10.0	**Improvement**

10.1	**General**
10.2	**Nonconformity and corrective action**
10.3	**Continual improvement**
Appendix A:	**Overall Process Sequence**
Appendix B:	**Prerequisite Programs (PRP)**

The list of PRPs outlined and detailed in the QM is as follows: PRP 01 - Building construction and layout; PRP 02 - Premises and workspace design; PRP 03 - Utilities management (air, water, energy); PRP 04 - Waste disposal; PRP 05 - Personnel management; PRP 06 - Equipment suitability, cleaning, and maintenance; PRP 07 - Management of purchased materials; PRP 08 - Cross-contamination prevention measures; PRP 09 - Personnel hygiene and employee facilities; PRP 10 - Cleaning and sanitization; PRP 11 - Pest control; PRP 12 - Analysis. The action-research facilitated the co-creation of a hygiene and quality management system tailored to their processing unit and production processes, addressing specific identified needs. In international cooperation settings, donor or partner interventions often involve layered efforts that may duplicate previous actions, sometimes starting from scratch. This approach fails to build on the procedures already established by the training and interventions of beneficiaries. In this instance, we began with direct observation to identify strengths and weaknesses in the production process and current practices. These observations were then discussed during training sessions to enhance existing compliant procedures and introduce new ones. The new procedures must be supported by an effective, though streamlined, documentation system that includes descriptive, prescriptive (procedures and operational instructions), and record-keeping functions. Accompanied by formally assigned responsibilities within the organization, the QM will evolve in a continuous improvement framework, aligning with the level of awareness achieved by the RFPT women.

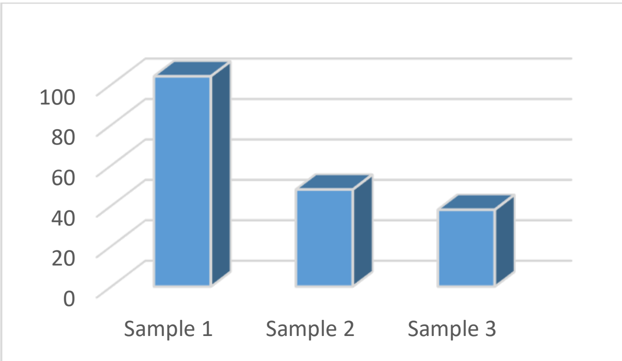
Antioxidant properties of selected flours

In evaluating the antioxidant properties of the enriched flour, it's essential to consider its primary ingredients. Millet, a key component, is a gluten-free grain rich in polyphenols, vitamins, proteins, and dietary fibers. It shows positive effects on diabetes, cancer, and cardiovascular diseases and is known for its drought resistance and antioxidant properties, especially when germinated or fermented (Tongshuai, 2022; Ajiboye et al., 2017; Shan Liang and Kehong Liang, 2019). Corn, another significant grain in the flour, also provides dietary fiber, vitamins, minerals, and phytochemicals. The flour includes legumes like peanuts and cowpeas, enhancing its nutritional profile. Peanuts contribute proteins, polysaccharides, polyphenolics, and vitamins, with notable antioxidant activity (Prodic et al., 2023). Cowpeas are rich in phenols and flavonoids, offering significant antioxidant benefits and potential as a functional food ingredient (Zia-Ul-Haq et al., 2013; Djifaby Sombié, 2018; Nassouroua et al., 2016). Moringa, promoted by WHO for its nutritional value, adds further antioxidant properties. All parts of the plant are nutrient-dense and used in traditional medicine and food supplements. Moringa extracts, especially from leaves, exhibit strong antioxidant, antimicrobial, and anticancer activities due to their high phenolic and flavonoid content (Fitriana et al., 2016; Prabakarana et al., 2018; Rabiu Abdulkadir et al., 2015).

A preliminary evaluation of antioxidant properties of Senegalese enriched flour was carried out in comparison with organic flours made with a single grain (millet and corn, respectively) taken from two Italian supermarkets. The average total polyphenol content assessed by the Folin-Ciocalteau test was 104 mg GAE/100g of DW for Senegalese enriched flour (Sample 1); 48 mg GAE/100g of DW for organic millet flour (Sample 2) and 38 mg GAE/100g DW for organic corn flour (Sample 3). Hence, the investigated Sample 1 showed a quite higher antioxidant potential with respect the other two samples and this is in accordance to its composite nature and in particular to the presence of high antioxidant ingredients, such as moringa and cowpeas. Folin-Ciocalteau results are shown in Figure 1.

Figure 1

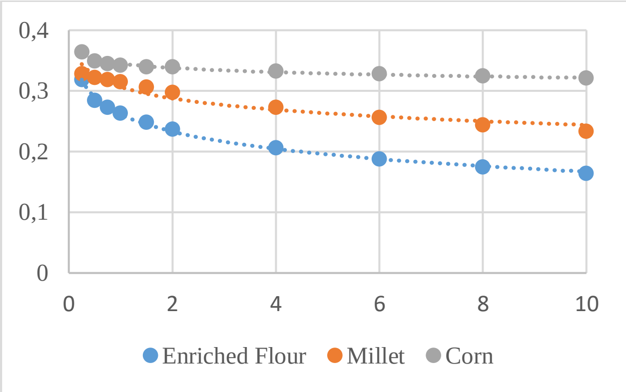
Contents of total phenolic antioxidants of the flour extracts. Data are expressed as mg of GAE in 100 g of dry sample.



Concerning the DPPH test a preliminary assay was made, measuring the kinetics of the three flour extracts diluted 1:4, with the exception of sample 3 that was measured without dilution (Figure 2). As it can be observed in Figure 2 for corn flour extract without dilution, despite the total phenolic content, not so far from that measured for millet flour extract, the kinetics of scavenging of the DPPH radical was extremely poor (4.6%) in comparison with the antiradical effect of the other two samples with a 1:4 dilution (57% enriched flour extract, and 37% millet flour extract). For this reason, the antiradical power of Sample 3, expressed as IC50, was not calculated.

Figure 2

DPPH radical scavenging kinetics(first 10 minutes) of flour samples: Sample 1 (Senegalese enriched flour) and Sample 2 (millet flour) with a 1:4 dilution, and Sample 3 (corn flour) without dilution.



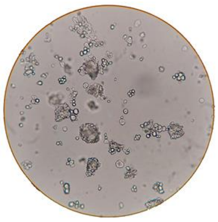
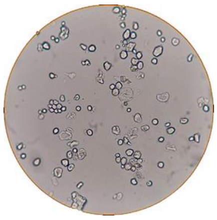
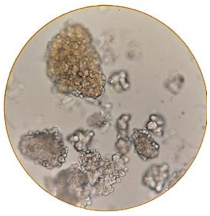
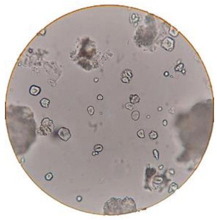
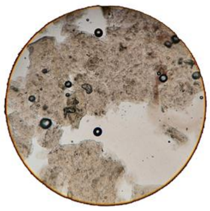
The antioxidant efficiency through the IC50 parameter is independent of the sample concentration, and for having a better evaluation of the interesting functional properties of flour extracts, the data of IC50 are reported as the quantity in mg of flour that inhibits 1 mg of radical.

Hence, the IC50 of the hydroalcoholic extracts average value for Samples 1 was 337 mg, much greater than the average value of Sample 2 (744 mg). These data, corresponding to the quantity of flour that inhibits the 50% of the radical molecule (DPPH), confirm the higher antiradical activity of the Sample 1 (Senegalese enriched flour) with a higher concentration and diversified composition of phenolic antioxidants.

The antiradical efficiency of the enriched flour (AE = 0.29) is more than double of that of the millet flour (AE = 0.13), confirming a direct relationship of antioxidant activity with the total polyphenol content (104 and 48 mg GAE/100g DW, respectively). However, the measured phenolic content of the enriched flour is comparable with data reported in literature for multigrain breads (Angioloni and Collar, 2011: 90-96), therefore, the process of grinding and mixing the different vegetal components will probably have to be implemented, given the great antioxidant potential of some plant species, in particular moringa and cowpeas. Finally, the Senegalese enriched flour was compared with a sample taken from the local market, a Senegalese semi-industrial infant flour, composed by cereal flours (millet, maize, corn, rice), niébé flour, milk powder, sugar, baobab powder, palm oil, iodized salt, calcium carbonate, vanilla flour, folic acid, iron. Despite the complex formulation of the second sample, the Folin results confirm the higher antioxidant power of the enriched flour, which shows a content 1.8 times higher (approximately double) of bioactivity compared to that of the infant flour. This finding can be due to the presence of the functional ingredient of Moringa extract, but further analyses are necessary, even because the optical microscope analysis (reported in Table 3) shows the second flour sample (infant flour formula) has the highest degree of grain refinement, which could affect its nutritional properties, for example for the heat generated during grinding.

Table 3*. Optical microscopy of the investigated flour samples*

Flour sample	*Microscopic Morphological Description*	*Magnification 400X*

Millet	Small starch granules, gathered in clusters. Single granules of polyhedral shape, hilum not visible.	
Corn	Granules of polyhedral shape, larger on average, visible hilum, also elongated. Less presence of clusters.	
Enriched (Pic 1)	A cluster of orange corn granules is visible. The presence of clusters is linked to non-excessive grinding.	
Enriched (Pic 2)	Another sample of flour, where the starch granules typical of legumes are visible, with a lenticular shape and linear hilum.	
For infant	The flour is sticky, indicating the presence of fatty substance and the formation of air bubbles. In general, the flour mass does not highlight the characteristics of the individual granules and appears to be more processed with a finer grinding degree.	

Conclusions

The introduction of a newly designed hygiene and quality manual for the women's cooperative represents a significant step towards fostering more sustainable practices and enhancing their commitment to standardized procedures. The transformation unit in Ker Moussa, though recently constructed, requires further improvements, both structurally and in terms of managerial organization at cooperative level. This includes for the cooperative defining key roles, implementing documentation for production records, formalizing quality procedures and controls, all of which were addressed during the action-research intervention conducted by ARCO as part of the SB-AGROIN project. RFPT now faces significant challenges: While transitioning towards a more professional and profit-oriented management, the company must secure funding for its daily operations and further improve profitability. Although RFPT has received substantial grants for equipment, it lacks the necessary funds to purchase sufficient raw materials and hire competent staff, such as an administrative manager, a commercial manager, salespeople, and to implement its promotion strategy. Additionally, it is essential to further enhance the skills of the women involved, particularly in marketing and fund management. Furthermore, it plans to sell products in local supermarkets, develop new business relationships with other female producers in the area, and structure partnership networks with regional representatives in Thiès and Dakar. In conclusion, despite initial difficulties and those still to be faced, the work done has marked a positive change in RFPT, now more capable and motivated to undertake actions for improving and developing its commercial activities.

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Beyond the nutritional quality of Made in Italy Space Food: Motivational and Performance Implications on Astronautic Teams

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Abstract

This study explores the influence of Italian-made space food on the well-being, motivation and performance of astronauts during the recent 'Axiom 3' mission. The objective is to examine the relationship between the consumption of high-quality Italian-made food and the organisational behaviour of space teams. While previous organisational literature has established connections between perceived well-being, motivation and high performance in various work contexts, there is a paucity of research specifically addressing these factors in the context of space missions and the peculiar impact of Italian cuisine. This research aims to expand the theoretical understanding of the organisational dynamics of space teams and to test, on an empirical level, the hypothesis that consuming high-quality Italian food alleviates perceived sensory hunger in space, thereby improving the psychological well-being, motivation and high work performance of astronauts. A combination of questionnaires and in-depth interviews was conducted with the astronauts of the Axiom 3 crew, as well as with innovation managers from a number of Italian Space Food companies. The results were then analysed using a set of selected theoretical organisational and qualitative constructs. Given the distinctive nature of the research, the findings, both theoretical and empirical, offer potential for intriguing generalisations and comparisons, thereby stimulating both scientific discourse and the work of experts from the various domains involved, including aerospace, food, organisational studies, and quality management.

Keywords: space food, space team, well-being, motivation, high performance

Introduction and Background

The Italian Air Force is the Italian organization that, more than any other, has been projecting itself into the space dimension, the so-called aerospace, for several decades.

The years in which the Italian General Luigi Broglio, an engineer and professor, conceived the first Italian space programme and dreamed of becoming a cosmonaut, are precisely the years in which the first human flight into space was made by Major Yuri Gagarin on board Vostok 1 on 12 April 1961, followed by those of the Americans Alan Sheppard on 5 May 1961 with a suborbital flight (Mercury-Redstone 3) and John Glenn, the first American in orbit, on 20 February 1962 (Mercury Atlas 6),

These were the glorious 1960s, when the first brilliant Russian and American cosmonauts began to confront each other against the backdrop of a profoundly dual world, divided by the competition between the two opposing blocs, the USA and the USSR.

It took seven years and a titanic investment of more than a hundred billion dollars before NASA succeeded in taking the first men to the moon on 20 July 1969 with the famous Apollo 11 mission. It was an event that changed humanity's perception of itself and of a hitherto almost unexplored universe that suddenly became less vast.

In those years there was no Space Europe: the first European astronaut (the German Ulf Merbold) would not fly until 1983, while the first Italian would wait until 1992, with the "Tethered" programme, the famous "satellite on a leash" proposed by Italy to demonstrate the concept of Prof. Mario Grossi.

Since then, the team of Italian astronauts has continued to grow, with eight cosmonauts having flown into orbit to date, in a context that is still in a state of flux, involving not only the country's military and strategic interests, which have always accompanied development and investment in the sector, but also technological, operational, security and economic implications, in a hyper-complex and ecosystemic logic (Volpe and Castaldo, 2021; Volpe and Castaldo, 2024; Zanda and Castaldo, 2023).

This is the backdrop to the latest space mission organized by Axiom Space to the International Space Station, using SpaceX's Crew Dragon Freedom as a vehicle.

The mission, called 'Axiom Mission 3', began on 18 January 2024 and ended after 21 days, following an orbital flight led by Italian pilot Walter Villadei, the only cosmonaut to have flown both in orbit and suborbital. Commander Michael López-Alegría led a crew of four to the International Space Station (ISS) on this commercial spaceflight mission, which cost an estimated $55 million per passenger and was designed to conduct more than 30 experiments and more than 50 outreach activities, making a significant contribution to scientific research and technology demonstration in microgravity.

Mission Axiom 3 includes the 'Italian Space Food Project', an initiative that forms part of the Italian government's submission to UNESCO in March 2024 to have Italian cuisine designated as an Intangible Heritage Site. This initiative has brought Italian cuisine into space.
Indeed, the Mission crew enjoyed Italian cuisine during the 14-day pre-departure quarantine and on board the ISS. The menus were prepared by selected companies, including Giovanni Rana, and products were created ad hoc by Barilla.

Objectives

This study examines the role of food for the Italian's Astronauts, specifically the role of the Italian Space Food in the context of the recent Axiom 3 Mission and its impact on the astronauts' well-being, motivation and performance, both as individuals and as a team.
In other words, the aim is to investigate the relationship between high-quality Italian-made food and the organizational behavior of cosmonauts.
In the organizational literature, the relationship between perceived well-being, motivation and high performance, both at the individual and team level, is well established (Cullen, 1997; Deci and Ryan, 2013; Donaldson *et al*., 2022; Herberg, 2017; Steers *et al*., 2004; Tay *et al*., 2023).
However, to the best of our knowledge, there are no studies on the organizational behavior of space teams and the relationship between Made in Italy food and high performance in sophisticated and hypercomplex environments such as those of space shuttles.
This research project aims to expand the theoretical knowledge base on the organizational behavior of space teams (Kanas, 2015; Palinkas *et al*., 2000). On a practical level, the goal is to test the research hypothesis (hp.0) that "*the high quality of made-in-Italy food, when consumed by astronauts, alleviates their typical sensory hunger and leads to psychological well-being, which in turn influences motivation and work performance*".

Research Design

To investigate the hypothesis that the high quality of made-in-Italy food, when consumed by astronauts, alleviates their typical sensory hunger and leads to psychological well-being, which in turn influences motivation and work performance (Zanda, 2016; Zanda, 2017), we need to define the variables and model for the research.

Variables

- **Independent Variables** (**IVs**):

- **Quality of Food**: This can be measured by the type and quality of food provided, specifically focusing on made-in-Italy food.
- **Sensory Satisfaction**: Levels of sensory satisfaction can be assessed through surveys or questionnaires focusing on taste, texture, and overall enjoyment of the food.

- **Dependent Variables (DVs)**:

- **Psychological Well-being**: This can be measured through standardized psychological well-being scales or assessments.
- **Motivation**: Levels of motivation can be evaluated using motivation scales or performance metrics specific to the tasks carried out during the mission.
- **Work Performance**: This includes both individual and team performance metrics, which can be assessed through mission logs, peer reviews, and objective performance data.

- **Proposed Research Model**

The research model can be framed using a causal path analysis, where the quality of food impacts sensory satisfaction, which in turn affects psychological well-being, leading to enhanced motivation and better work performance (Palermo and Castaldo, 2022; Zanda, 2016)

- **Hypothetical Path Model**

Path A: *Quality of Food → Sensory Satisfaction*

High-quality made-in-Italy food leads to higher sensory satisfaction among astronauts.

Path B: *Sensory Satisfaction → Psychological Well-being*

Higher sensory satisfaction results in improved psychological well-being.

Path C: *Psychological Well-being → Motivation*

Improved psychological well-being enhances individual motivation.

Path D: *Motivation → Work Performance*

Higher motivation leads to better work performance, both at the individual and team levels.

Overall Path: *Quality of Food → High-Performance Work*

The quality of food indirectly influences work performance through its effects on sensory satisfaction, psychological well-being, and motivation.

1. **Research Design and Methodology**

- **Principle Sample**: Italians astronauts participating several recent space missions, and the crew of the Axiom 3 Mission

- **Measurements**:
  - **Food quality**: Assessed by expert ratings and astronaut feedback
  - **Sensory satisfaction**: Measured by a sensory satisfaction survey
  - **Psychological well-being**: Assessed using scales such as the General Health Questionnaire (GHQ) or the Positive and Negative Affect Schedule (PANAS)
  - **Motivation**: Assessed using self-report questionnaires and performance measures.
  - **Job performance**: Measured through job performance records, peer evaluations and objective data.
- **Data collection**:

Surveys, questionnaires and in-depth interviews
Continuous collection of performance data during the mission and ex-post.

- **Analysis**:

Path analysis or structural equation modelling (SEM) to test proposed relationships between variables.

- **Focus on Methods**

To achieve our research objectives, we will employ documentary analysis of NASA and ESA materials, questionnaires and semi-structured interviews conducted with air force personnel and astronauts (in particular, the international crew members of the Dragon Freedom from the very recent *Axiom 3* (Ax-3) *Mission*, and with Italian pilot Walter Villadei, the only cosmonaut to have travelled both in orbit and in suborbital flight, that is our privileged witness.

Complementarily, to investigate aspects of perceived food quality, we will conduct 2 in depth interviews with innovation managers of Italian food companies to compare Italian-made space food with non-Italian-made space food.

Following the collection, analysis and comparison of the data from the interviews and questionnaires with other research and existing literature, a proposal for an optimized model will be generated. This will take into account both nutritional (Enrico, 2016) and psycho-motivational aspects, as well as those related to the high performance required in the space environment.

This proposal will subsequently inform more extensive future research, not only on the high quality of food made in Italy, but also on the organizational behavior and high work performance of astronauts. This may prove useful, for example, in contexts such as India, which is preparing to send its crews into orbit in the coming years.

Expected Results

The anticipated outcomes of this study are twofold. Firstly, the evidence gathered will contribute to filling the limited existing knowledge on organizational behavior in international space stations. Secondly, the relationship between research variables such as well-being, motivation, commitment and performance at both the individual astronaut and team level will be investigated, leading to the construction of an optimized model for future research on this topic.

Conclusions

Our analyses, which include the actors in space (the cosmonauts), but also government and defense personnel and the Italian manufacturing industry, are extended to the national systemic level. As a result, the implications will be significant at the level of the Italian national system and, ideally, will include comparative elements with respect to other countries, with a view to sustainable development (Castaldo, Porretta and Zanda, 2024). Given the complexity and uniqueness of the object of study, the study is likely to lead to further research on the subject, not only in academia, but also in industry and government.

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Track 8: Innovation Industry 4.0

AI Service Quality and Customer Experience: the case of students in Higher Education

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Abstract:

The use of Artificial intelligence (AI) and its fast dissemination has taken many industries by surprise. Since AI represents a form of disruptive innovation there are high expectations when it comes to impacting landscape of many industries. One of the industries that could be hit the most is higher education (HE). The research approach of this paper is to look at AI implementation in higher education through the lenses of service quality and its impact on customer satisfaction. As higher education students assume the mantle of early adopters, the imperative to discern and evaluate the quality of AI services within the higher education milieu becomes salient. In this paper a scale for measuring the quality of AI services from the standpoint of students was applied and used for testing its relationship to customer experiences. The primary goal of this research paper was to connect the quality of AI services namely Chatbots on one side and customer or in this case student experience on the other side. The research for this paper started with a development of a scale that could be used for measuring the AI service quality from student perspective. This part of the research process revealed that AI services from student perspective could be best described by four variables namely: AI service quality, negative aspects of AI implementation, usability of AI for studying and AI interactivteness. In the second part of the research these variables were connected to AI customer experience by using a Structural Equation Model (SEM). In the proposed research model customer experience was treated as a dependent variable.

Keywords: AI service quality, Chatbots, Customer experience, Higher education

Relevant Topic: Quality of services

Introduction

The implementation of artificial intelligence (AI) in higher education (HE) is expanding rapidly, bringing with it a myriad of new challenges and opportunities. Among the challenges are biases in datasets and algorithms, issues of plagiarism, and concerns over privacy. On the other hand, AI also presents significant opportunities, such as enhancing stakeholder satisfaction.

Hannan and Liu (2023) assert that AI has the potential to fundamentally reshape higher education institutions in various ways. One of the key changes AI brings is in the roles of students and teachers within the education system. Blau and Shamir-Inbal (2018), Niemi (2020), and Ali et al. (2021) have all discussed how AI can alter these roles, shifting the dynamics of teaching and learning.

Traditionally, students in higher education were viewed as passive consumers of knowledge. However, this perception has evolved significantly. Dužević et al. (2018) highlight a progression in which students' roles have shifted from passive consumers to active participants. Today, students are not only recipients of information but also integral players in the educational process. Their needs must be identified and satisfied, and they must be engaged as equal participants in all facets of teaching and learning. This new role for students is particularly important in the context of technological advancements and the evolution of new teaching and learning models driven by AI. AI-based services offer students various tools for learning and research, which, when coupled with proper preparation and guidelines, can enhance the effectiveness and productivity of educational processes (Liu et al., 2022).

As stated by pervious researcher's relationship between AI and customer experience should be further explored (Chen and Prentice 2024, Hoyer et al. 2020). Thus, understanding the student experience in relation to AI is crucial for improving the quality of services in higher education. By effectively integrating AI, institutions can create more dynamic, responsive, and engaging educational environments that better meet the needs of both students and educators. The primary goal of this research paper was to analyse the connection between AI services quality and customer or in this case student experience in the context of higher education. In order of achieving this primary goal several other goals needed to be met. The first one was to clearly define the dimensions constituting the variable AI service quality. The paper than determines three variables that are affected by AI services quality and can have significant impact on customer experience. They are: negative aspects of AI implementation, usability of AI for studying and AI interactivteness.

As for the use of Chatbots several remarks need to be made. First of all, the application of Chatbots in higher education has been addressed by researchers mostly in the manner in which institutions develop their own Chabot's that are than used for different purposes like service assistants or educational agents (Perez et al. 2020). The focus of this paper is on commercially developed Chatbots that can serve as learning tools for students for both academic and personal goals. The speed of adoption for AI tools used by student population will grow significantly in the future since knowing them will be a big contributor to their employability (Rudolph et al. 2023). Also many students identify AI products with Chatbots namely Chat GPT since all of their experience is derived from using these tools.

The impact of artificial intelligence AI on higher education HE is intricate and multi-dimensional. Despite AI's rapid advancement, the number of research papers utilizing concrete indicators to assess its effects remains limited. To comprehensively understand AI's influence on HE, additional research is necessary, integrating various research domains. Future developments in HE will undoubtedly incorporate diverse AI-based tools. Consequently, it is crucial to explore students' expectations and perceptions regarding these widely available AI tools. This understanding will facilitate monitoring and improving service quality performance within HE systems.

The paper starts with the brief overview of the connection between AI and customer experience. In this part of the paper the evolution of discussion on connection AI and customer experience is presented. It than turns to the topic of implementation of AI in higher education (HE). In this part special attention is given to Chatbots since they are the product students use the most and even identify as AI. That topic is followed with methodology description and descriptive statistics of primary data. The impact of AI services quality on customer experience was indirectly measured trough: negative aspects of AI implementation, usability of AI for studying and interactivteness. The paper uses SEM methodology for testing the proposed relationship between AI services quality and customer experience. The paper ends with conclusions that summarize paper contributions, limitations and recommendations for further research.

AI and customer experience: theoretical background

The topic of AI and its influence on customer experience has been debated in marketing literature for some time. When it comes to AI and services the most popular approach is to analyse how will AI effect current businesses, processes and consumers mostly by automating part of the work previously done by employees (Huang et al. 2018) or to treat AI as a tool for employees in order of improving their performance (Nguyen et al. 2021), or to investigate the options of customer engagement (Huang et al. 2020).

The old view on connecting AI and customer experience was primarily concerned with collecting data, processing the data and delegation of certain tasks to AI (Cukier 2020). It is usual to treat AI as an advanced tool for gathering and analysing data on costumer behaviour which in the end leads to increased customer experience (Cukier 2020). This "old paradigm" of AI is more related to Big Data analytics than to the contemporary role current AI tools are starting to play. The main benefits derived from using AI in this "old view" are that companies will understand customer needs better, develop products more efficiently, and innovate faster (Cukier 2020). Another research stream on AI and customer experience looks at comparisons between being served by a real person or an AI proxy. Prentice and Nguyen (2020) found employees were a preferable choice compared to AI.

The new view of connecting AI to customer experience emphasizes the concept of AI quality and takes into consideration a specific industry or a customer. Examples of this are linking AI quality performance to customer engagement in hotel context (Prentice et al. 2020), new technologies like Chabot's to shopping experience (Hoyer et al. 2020), AI in general to customer relationship management (Libai et al. 2020), AI enriching customer experiences in the context of FinTech industry (Arora et al. 2023), influence of AI namely Chatbots on on-line customer experience (Chen et al. 2021). Some of these studies offer different moderators between AI and customer experience such as: personality (Chen et al. 2021), emotional intelligence (Prentice and Nguyen 2020).

Top three factors influencing AI-powered customer experiences are service quality, perceived usefulness, and perceived convenience (Arora et al. 2023), there are other important factors such as: data collection, algorithmic output, task delegation and social interactions (Cukier et al. 2021). Service quality has been named as one of key factors affecting customer experiences by many authors (Arora et al. 2023, Trawnih et al. 2022). For this reason, the paper started with identifying the key elements of AI service quality and defining the characteristics of AI that were affected by AI services quality.

There were several conclusions drawn from this part of literature review. First of all, quality was the main factor affecting customer experience with AI. Second that it is possible to define and measure AI service quality but the definition and dimensions need to be adjusted to the context of higher education and AI services used there. Third is that the influence of service quality on customer experience is usually mediated by another variable. These conclusions were used for drafting the research proposal in the rest of the paper.

The use of AI Chatbots in Higher Education

Artificial intelligence (AI) applications in education have been growing significantly in the last couple of years (Zawacki-Richter et al. 2019). AI can be broadly defined as "Computers which perform cognitive tasks, usually associated with human minds, particularly learning and problem-solving (Baker 2016). Since AI encompasses a large range of technologies there are several ones that stand out from the aspect of higher education especially: machine learning, natural language processing, data mining and neural networks. In this paper the focus is primarily on Chatbots that rely mostly on natural language processing. The reason for choosing Chatbots was simply because for students they represent the AI product that has already been mass adopted. There are many ways to approach the application of AI in HE. According to Baker and Smith (2019) the AI tools in education can be divided into: learner facing, teacher facing and system facing. According to Chen et al. (2020) the role of AI can be classified into: administration, instruction and learning. Learner facing AI tools are software's that students use to learn a subject matter and Chatbots mostly associate with learning category.

Chatbots have been classified as one of the key technologies that will affect customer experience of the future (Hoyer et al. 2020). Chatbots are a type of virtual assistant software programs that conduct conversations with users through audio or text. They are designed to simulate human conversations Chatbots are commonly used in customer service contexts. The AI behind Chatbots uses natural language processing (NLP) algorithms (Hoyer et al. 2020). Another way of looking at Chatbot is to consider them as tools that combine artificial intelligence(AI) and natural language processing or other technology, which enables it to interact to a certain level of conversation with a human interlocutor through text or voice (Perez et al. 2020).

Previously mentioned research such as Zawacki-Richter et al. (2019), Chen et al. (2020), Baker and Smith (2019), etc. typically treat AI tools as the ones that are developed by HE institutions and then used as part of generic HE processed such as grading, advising and so on. In this paper the focus is on commercially developed AI tools that can be used for both private and study purposes. Chat GPT would be an ideal example. The main difference here is that these readily available tools are the ones that are really being mass adopted for all kind of purposes. There are studies demonstrating a significant adoption of AI Chatbots in Higher education (Subaveerapandiyan et al. 2024, Rudolph et al. 2023, Perez et al. 2020, Dempere et al. 2023) and these research names saving time and improving academic performance as main benefits of using AI. When it comes to AI impacting student experiences in Higher education Chen et al. (2020) found curriculum and content customization by machine learning algorithms improved learner's experiences and overall quality of learning. The second reason for choosing commercially developed products is that these tools are characterized as "disruptive innovations" which means they have the potential to radically influence the old model of learning in higher education.

There are some limitations for using the AI Chatbots in higher education that need to be mentioned. Previous studies tested the "intelligence" of most popular publicly available Chatbots and the results showed they still lack the intelligence of A and B graded students but Chat GPT-4 did show best results (Rudolph et al. 2023). Another warning is that Chatbots are excellent liars and that each Chatbot statement requires verification and proper referencing (Rudolph et al. 2023). There is also the problem of negative influence on the interactions between students and teachers (Kasthuri et al. 2021) and studies investigating the "dark side" of using AI in services, example of marketing (Barari et al. 2024). After investigating the role of AI Chatbots in studying process three key areas were defined. They were: use for studying, negative aspects of use and interactivteness.

Methods

The topic of analysing the components of AI services quality is present in literature (Subaveerapandiyan et al. 2024, Noor et al. 2022,) however this paper brings several key contributions. First of all, a list of key attributes associated with the quality of AI services was obtained by a series of focus groups done in the student population. A series of 48 mini focus groups were conducted at the Faculty of economics and business Zagreb in the winter semester of 2023 to understand key elements more deeply and complete the list of AI service quality factors. As a result of the literature review and focus group interviews, an online questionnaire was developed and spread to the students.

The questionnaire was focusing on the student experience of quality dimensions pinpointed by previously described research: accuracy, reliability, efficiency, scalability/objectivity, interoperability, adaptability, design and context, min. error or biases (8 questions – service quality dimensions: 'QUAL'). The 2nd area included problematic perception fields negatively worded (6 questions – negative aspects of the AI implementaion 'NEG'), while the next one highlighted the possible positive aspects, positively worded (8 questions – usability of AI for studying 'USE'). The last area concentrates on the application process of AI asking for the level of agreement with their relevance (5 questions – interactivteness 'INT').

The questionnaire was distributed to students from the Faculty of Economics and Business, University of Zagreb through an online platform, during the winter semester of the academic year 2023/2024. The sample included 1000 students from undergraduate and graduate study programs. In total, 310 students completed the questionnaire. There were 66% females and 89% of traditional students (age between 20 and 25). Descriptive analysis showed that data has a normal distribution. Based on the literature review and qualitative analsysis, the model has been developed to explore the impact of AI service quality dimensions on the student experience, through the negative aspects, usability and interactiveness (see Figure 1). Structural equation modeling (SEM) is a statistical approach to model testing (Hair et al., 2016). It combines factor analysis and multiple regression analysis and enables the researcher to test a number of hypothesised relationships simultaneously. The PLS-SEM method is very appealing to many researchers as it enables them to estimate complex models with many constructs, indicator variables and structural paths without imposing distributional assumptions on the data (Hair et al. 2029). Smart-PLS software has been employed to explore the relationships between variables and predict key constructs.

Results and Discussion

The Figure 1 presents the results of path analysis conducted using Smart-PLS. All hypothesised relationships are significant, and further analysis revealed god model fit.

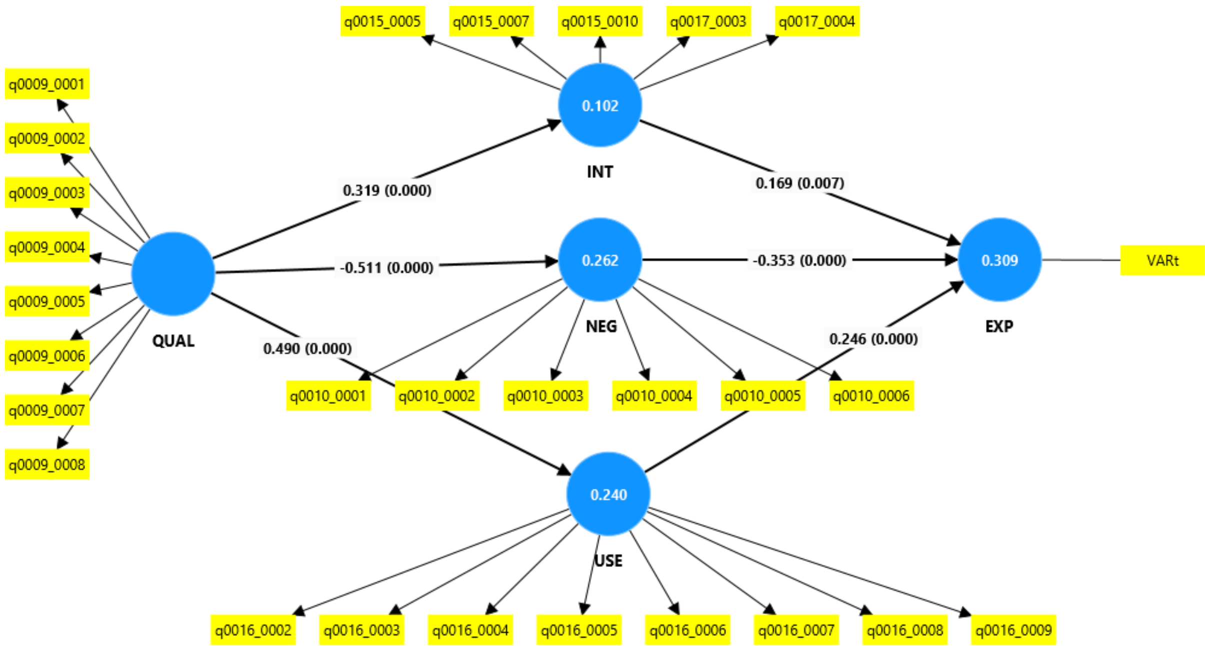

Figure 1. Path analysis of AI service quality dimensions and customer experiences in higher education

To evaluate measurement model, we analysed the convergent and discriminant validity. The convergent validity analysis showed that all factor loadings are above 0.544, while most of them are above 0.7 (see the Appendix 1). Since the study is exploratory, the Chronbach's alpha values are above 0.7, and Average Variance Extracted is higher than 0.5 we retain all the indicators.

Table 1. *Discriminant validity*

	EXP	INT	NEG	QUAL	USE
EXP					
INT	0.351				
NEG	0.464	0.182			
QUAL	0.567	0.375	0.588		
USE	0.432	0.613	0.277	0.556	

Note: EXP – customer experience, INT - interactiveness, NEG - negative aspects of the AI implementaion, QUAL - service quality dimensions, USE - usability of AI for studying

The HTMT criterion for discriminant validity is presented in the table 1. All constructs achieved values ranging between 0.182 and 0.613 that is less than 0.85 trashold based on the HTMT criterion. Moreover, Fornell-Larker criterion confirmed that disriminant validity has been established.

Table 2. Structural model assessment

Path	Path	T-Value	P-Value	R^2	Q^2	f^2	Decission
QUAL->INT	0.319	5.057	0.000	0.102	0.088	0.113	Supported
QUAL->NEG	-0.511	10.667	0.000	0.262	0.247	0.354	Supported
QUAL->USE	0.490	9.691	0.000	0.240	0.224	0.315	Supported
INT->EXP	0.169	2.689	0.007	0.309	0.250	0.031	Supported
NEG->EXP	-0.353	7.341	0.000	-	-	0.171	Supported
USE->EXP	0.246	4.103	0.000	-	-	0.063	Supported
QUAL->EXP*	0.355	9.448	0.000	-	-	-	Supported

Note: EXP – customer experience, INT - interactiveness, NEG - negative aspects of the AI implementaion, QUAL - service quality dimensions, USE - usability of AI for studying; * indirect effect

Table 2 presents the structural model assessment. Additionally, the confidence intervals have been checked and all data were between lower and upper level. Collinearity statistics (VIF) results confirmed no collinearity issues, since all values were below 3. With regard to customer experience, negative aspects of the AI implementation have the strongest effect (-0.353), followed by the usability of AI for studying (0.246), and interactiveness (0.169). In total, the service quality dimensions had significant indirect effect on the customer experience (0.355). It also significantly influences all other variables in the model with strongest relation to the negative aspects of the AI implementation (-0.511), then usability of AI for studying (0.490), and interactiveness (0.319). Therefore, it is advisable for the higher education institutions to focus on service quality dimensions to lower the negative aspects of AI implementation, and increase the level of interactiveness and usability of AI for studying. Consequently, it will increase the level of student experience with AI implementation. To assess if the relationships are significant, a bootstrapping procedure has been performed. Assuming a 5% significance level, all relationsips in the structural model were significant.

Regarding the model's explanatory power, the R^2 values of EXP (0.309), USE (0.240) and NEG (0.262) are considered acceptable, while INT (0.102) is considered weak (Zaarour & Melachrinoudis, 2019). The effect sizes (f^2) values are large for the relations between QUAL and NEG (0.354), and QUAL and USE (0.315), medium for relations between NEG and EXP (0.171), and QUAL and INT (0.113), and small for USE and EXP (0.063) and INT and EXP (0.031). Moreover, Q^2 values are larger than zero, and compared to RMSE values we found that PLS-SEM analysis produces smaller prediction errors than the LM for all indicators (Hair et al., 2022), confirming high predicitve power of the model.

Conclusions

The widespread adoption of commercially developed AI tools has significantly influenced various aspects of our lives, including education. Among these tools, Chatbots—such as Chat GPT—have gained popularity among students for both personal and academic purposes. This paper delves into practices that explore the quality of AI services, its impact on student experience, and the implications for higher education.

There are several contributions to the theory and practice made by the paper discussed in the following text. The focus of this paper is on commercially developed AI tools that can be used by students for both private and study purposes. Chatbots namely Chat GPT represent an ideal example of a technology that has been adopted by student population and whose adoption will have significant consequences for higher education. The paper uses the results of a survey conducted among student population in order of better understanding the concept of AI services quality. The list of key attributes associated with the quality of AI services was obtained by a series of focus groups done in the student population. The first theoretical contribution was in detecting several dimensions of AI services quality namely: accuracy, reliability, efficiency, scalability/objectivity, interoperability, adaptability, design and context. The second theoretical contribution consisted from developing a Structural equation model (SEM) that connects AI services quality to negative aspects of AI implementation, usability of AI for studying, interactivteness of AI and customer experience. The hypothesis that AI service quality will significantly influence customer satisfaction was supported by the data and SEM methodology. Also AI service quality has significant negative influence on negative aspects of using AI. The important practical implication is that raising AI service quality reduces negative aspects of its use and significantly contributes to increasing customer experience. All these relationships are supported in the context of higher education and student experiences with using Chatbots like Chat GPT. These findings are particularly relevant in educational settings where Chatbots like Chat GPT are widely used. As AI continues to shape education, understanding the quality of AI services and its effects on student experience and engagement is crucial. By addressing limitations and further exploring these dynamics, we can optimize AI tools for a more enriching educational experience.

However, several limitations need to be mentioned. The study did not account for students' expectations regarding AI service quality, and the research sample was limited to students from a single faculty. Future research should validate this model across different AI services beside Chatbots. Also it would be interesting to test the model for different commercially available Chatbots. One of the limitations is connected to the way of measuring student experience with AI services. In this paper a single indicator approach was used that has some disadvantages like limited coverage and reduced precision. Recommendation for further studies would be to use multiple indicators. Testing the SEM model for other AI services and adding some new options in the place of customer experience is also recommended. It would be interesting to use some objective measures of student study performance as dependent variables. Also moderating factors related to services, the student and the student performance can be investigated to uncover the boundary conditions under which AI service quality is likely to influence student experience. Another thing to consider is doing a comparison models for physical and on line teaching. It would be interesting to start with student expectations as a basis for measuring AI service quality in these two settings.

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Appendix 1. Convergent validity

Construct	Item	Loading	Cronbach's alpha	Composite reliability	AVE
QUAL	q0009_0001	0,798	0.867	0.876	0.521

	q0009_0002	0,838			
	q0009_0003	0,765			
	q0009_0004	0,659			
	q0009_0005	0,544			
	q0009_0006	0,630			
	q0009_0007	0,568			
	q0009_0008	0,746			
NEG	q0010_0001	0,801	0.802	0.816	0.505
	q0010_0002	0,678			
	q0010_0003	0,727			
	q0010_0004	0,779			
	q0010_0005	0,637			
	q0010_0006	0,626			
USE	q0016_0002	0,734	0.872	0.878	0.530
	q0016_0003	0,770			
	q0016_0004	0,766			
	q0016_0005	0,795			
	q0016_0006	0,738			
	q0016_0007	0,660			
	q0016_0008	0,600			
	q0016_0009	0,744			
INT	q0017_0003	0,813	0.787	0.810	0.539
	q0017_0004	0,832			
	q0015_0005	0,677			
	q0015_0007	0,625			
	q0015_0010	0,701			

Note: EXP – customer experience, INT - interactiveness, NEG - negative aspects of the AI implementaion, QUAL - service quality dimensions, USE - usability of AI for studying

Intended vs. actual use of Industry 4.0 technologies: A culture-driven survey

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Abstract:

This study empirically examines the impact of an integrated form of culture on the acceptance of Industry 4.0 (I4.0) technologies, both in terms of employees' intention to use them and their actual use. The beliefs and norms, habits and attitudes relevant to lean intertwined with the elements of digital culture, constitute an innovative construct that reflects the cultural antecedents of I4.0 technology acceptance. The Unified Theory of Acceptance and Use of Technology (UTAUT) was invoked to identify the intention to use and the actual use of I4.0 technologies as dependent variables. Data was collected using a 1-5 Likert scale questionnaire administered to 1285 employees in more than 70 Greek organizations and 452 valid responses were obtained. Partial least squares structural equation modelling (PLS-SEM) was used to test the research hypotheses. The results confirmed the significant role of culture in technology acceptance measured at both the intentional and the actual levels of use. Interestingly, the effect of measured intention to use on actual use of I4.0 technologies was found insignificant. Voluntariness of use and experience in using digital technologies were used as control variables. Facilitating conditions were also included in the model to test their effect on the intention to use and its predictors. For academics, this study combines the technical perspective of the actual use of I4.0 technologies with non-technical - cultural and behavioural – factors focusing on the human perspective of digitalization and offering novel insights to the extant body of knowledge. For practitioners, the empirical findings underscored the importance of culture in the successful implementation of new technologies indicating a clear managerial path. A limitation of this study was the heterogeneity of the sample as both manufacturing and service organizations were included operating in the private and public sectors. Future research may explore the validity of the identified relationships in sector-specific business contexts. Moreover, case study analysis will delve into the survey findings and explore the contingent nature of the relationships.

Keywords: Unified Theory of Acceptance and Use of Technology (UTAUT), culture, lean management, digital transformation, Intention to Use, Industry 4.0

Relevant Topic: TQM in the digital age

Introduction

In the total quality management (TQM) context, a quality-oriented organizational culture is emphasized as a key success factor. The intrusion of Industry 4.0 technologies has an inevitable impact on Quality creating the Quality 4.0 wave of change (Glogovac et al., 2023; Sony et al., 2021). As organizations face the challenge of incorporating the Industry 4.0 technologies into their daily operations, lean and quality management practices need to adapt to the new scenery. People interact with modern influential technologies such as the blockchain, the artificial intelligence, and the Internet of Things. The long-lasting debate on the hard and soft elements of TQM comes to the foreground with a new understanding (Lim et al., 2024). Digital transformation of TQM is now eminent in an adapt-or-die mode. In this line of thinking and revising the quality status quo, fostering culture to accept new technologies is the main point of interest in this study. It is hypothesized that a new TQM culture, integrating lean and digital perspectives can transform people's mindset and lay the groundwork for the Quality 5.0 paradigm shift where human-machine interaction reaches a higher level of communication and interaction (Frick and Grudowski, 2023). In order to explore the human behavioural aspects that influence the adoption of digital technologies by the employees, this study draws on the theories of technology acceptance. According to these theories, individual reactions to use have a direct impact on the intentions to use and, in turn, actual use (Venkatesh et al., 2003). The Unified Theory of Acceptance and Use of Technology (UTAUT) model considers four direct determinants of user acceptance and behaviour: performance expectancy, effort expectancy, social influence, and facilitating conditions (Venkatesh et al., 2003). Facilitating conditions reflect the employees' perspectives on their organizational and technical support in using digital technologies and capture the objective factors in the environment that affect the potential use of technologies. By merging the cultural and behavioural elements into a conceptual model, this study aimed to test potential causal relationships between the two main constructs of lean-digital culture and the intention to use as well as with the actual use of digital technologies. The effect of certain contingency factors, such as the voluntariness of use and the experience with use, was also examined.

Methods

An empirical survey was initiated for the purpose of data collection. The measurement instrument consists of validated sets of questions corresponding to each variable of the conceptual model. The organizational culture is analysed in two dimensions - the digital and the lean - and measured using the scales proposed by Martínez-Caro et al. (2020) and Bortolotti et al. (2015), respectively. The intention to use is a construct devised by Venkatesh et al. (2003) that is predicted by performance expectancy, effort expectancy, and social influence. To assess actual use, an indicator comprising 25 I4.0 technologies was developed. The questionnaire was distributed via Google Forms to employees of both private and public Greek organizations over a three-month period last year. Partial least squares structural equation modelling (PLS-SEM) was employed to test the research hypotheses. Additionally, moderation tests were conducted using the Hayes process module in SPSS.

Results and Discussion

Figure 1 shows the structural model and the bootstrapping testing results for the model and the effect of facilitation conditions. Lean-Digital Culture has a significant (p-value <0.001) impact on both the Intention to Use and the Actual Use, with coefficients of 0.428 and 0.341, respectively. The high factor loadings of both Digital Culture (0.864) and Lean Culture (0.939) on Lean-Digital Culture underscore the critical role of the proposed composite form of organisational culture in digital transformation.

It is noteworthy that there is a discrepancy between the intention to use and the actual use of digital technologies. This finding is corroborated by prior research that interprets the intention to use as a perceptual estimation of acceptance in contrast to the actual use, which is measured in factual terms (Tao, 2009). Similarly, contingency factors, such as the facilitating conditions, influence the intention, rather than the actual use. This finding suggests the potential influence of other factors on the actual use that are missing from the model. In line with previous research (Maruping et al., 2017; Venkatesh et al. 2008), facilitating conditions alone are not expected to have a direct effect on the use of technologies.

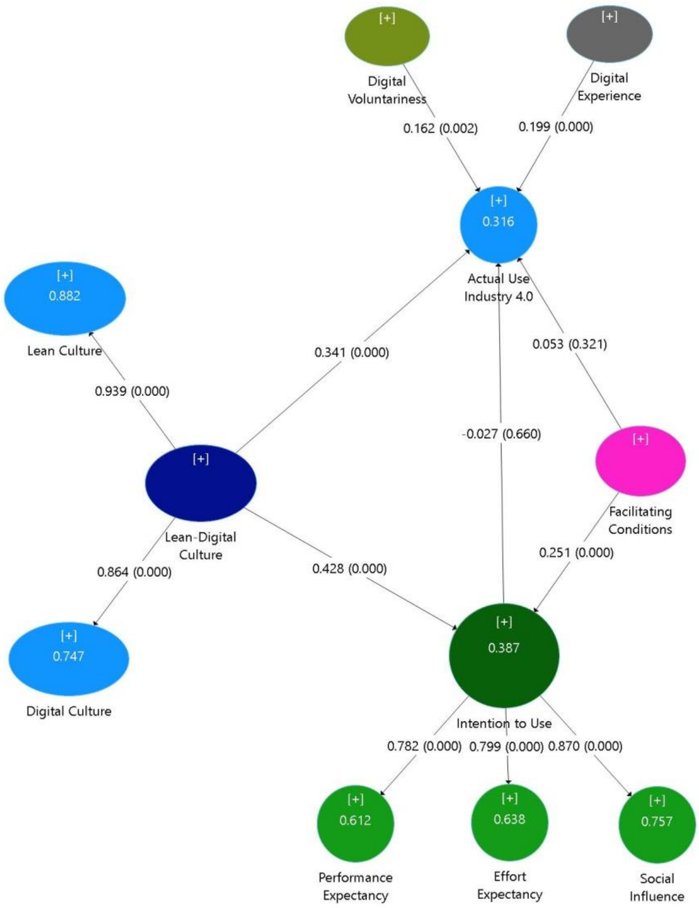

Figure 1. *The effect of lean-digital culture on the intention to use and the actual use of Industry4.0 technologies*

An alternative approach has also been tested using the three dimensions of the Intention to Use, i.e. performance expectancy, effort expectancy, and social influence, as first-order variables. Voluntariness of use, experience in digital technologies and facilitating conditions were tested as control factors. Results indicate differences in the effect of the three control factors on the three dimensions of the Intention to Use. Voluntariness affects only social influence, facilitating conditions affect effort expectancy and social influence, while experience in digital technologies affects performance and effort expectancy.

The results of the moderation testing indicated that the facilitating conditions exert a moderating influence on the relationship between lean-digital culture and the intention to use. The combined moderating effect of experience and voluntariness on the relationship between facilitating conditions and lean-digital culture was also confirmed. The results of this study align with the UTAUT model's conceptualization of facilitating conditions as a distinct factor from the three dimensions of the intention to use (Venkatesh et al., 2003; 2008). This underscores the pivotal role of resource availability, knowledge, training, and assistance in the adoption of technologies.

Conclusions

The potential for revolutionary changes in lean and quality management brought about by industry 4.0 technologies remains largely theoretical. This is particularly the case in Greek organizations and in SMEs globally, where resources are limited and innovation and change within organizations proceed at a slow pace. This study presents a human-centred perspective on the challenge of technology acceptance. Despite the widespread recognition and implementation of the UTAUT model by researchers across various disciplines, it has never been employed in this particular context. Results emphasised organizational culture as an enabler of technology acceptance among employees and identified strong causal relationships between culture and both the intention to use technology and the actual use of technology. The impact of specific contingency variables, such as facilitating factors, voluntariness, and experience of use, on the aforementioned relationships was also investigated highlighting the importance of resources, experience and volition. Future research could employ this approach and focus on other people-related factors, such as leadership in advancing digital transformation and fostering a lean-digital culture. A limitation of this study was the heterogeneity of the sample as both manufacturing and service organizations were included, operating in the private and public sectors. Future research may explore the validity of the identified relationships in sector-specific business contexts. Moreover, case study analysis could delve into the survey findings and examine the contingent nature of the relationships.

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ACKNOWLEDGEMENTS

This work is part of a project that has received funding from University of Macedonia Research Fund under the Basic Research 2023 funding programme.

Differences in Kansei Evaluation between Real Products and Product Images in Virtual Reality: A Case Study of Personal Watercraft

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Abstract

Kansei quality refers to the product quality evaluated based on customer impressions and feelings, such as comfort and luxury. One approach to designing attractive products is to improve their Kansei quality, which involves evaluating customer impressions or product desirability. With the advancement of digital technology, the possibility of evaluating customers' Kansei based not only on actual products but also on product images in virtual reality (VR) has emerged, nd the findings are used to inform product design. However, it is possible that customers experience different Kansei when they see a product in reality or VR. Eliminating the differences between the two would improve the utility of the VR evaluation results in accurately informing product design. This study examined a personal watercraft case study to clarify the nature of differences in customers' Kansei evaluations when they observed the same product in reality versus in VR. One hundred and ten participants observed a personal watercraft model in real and VR environments, and evaluated the differences in Kansei from six evaluation aspects. Based on the results, criteria were established to determine whether there was any difference in Kansei evaluation between the two. To confirm their applicability to other evaluation aspects, as well as to small-scale participant surveys, a similar investigation was conducted with 23 participants using ten evaluation aspects. After modifying some of the criteria based on the results, the set of criteria was deemed suitable for small-scale surveys. Additionally, the differences in Kansei evaluations observed across evaluation aspects were standardized into ten patterns.

Keywords: Kansei Quality, Customer Impressions, Virtual Reality (VR), Paired Comparison Method, Product Evaluation, Product Design

Introduction

Kansei quality refers to the product quality evaluated based on customer impressions and feelings, such as comfort and luxury. One approach to designing attractive products is to improve their Kansei quality, which involves evaluating customer impressions or product desirability.

With the advancement of digital technology, the possibility of evaluating customers' Kansei based not only on actual products but also on product images in virtual reality (VR) has emerged. Nagamachi et al. (2021) stated that Kansei evaluation using VR was sufficiently effective. Matsushita et al. (2004) used 3D CG models to study the Kansei evaluation of glass used in buildings. Thus, there is a shift towards using VR to evaluate customers' Kansei for target products, and the findings are used to inform product design. VR is also expected to be useful in product marketing.

However, whether users experience the same Kansei feelings when they see a product in reality or in VR is unclear. Fujiki et al. (2012) stated that the texture quality of a 3D model influences the sense of reality. Kajihara et al. (2022) used a personal watercraft as a case study and analyzed the differences in Kansei evaluations when viewing the same model in reality and VR. They found a difference between the two and identified the need to adjust the observer's viewing angle and distance in VR to reduce this difference. Thus, it is possible that customers experience different Kansei when they see a product in reality or VR. Eliminating the differences between the two would improve the utility of the VR evaluation results in accurately informing product design.

Kajihara et al. (2022) identified a difference in Kansei evaluations between reality and VR; however, they did not specifically mention what that difference is. Furthermore, the criteria for determining whether a difference exists were not clarified.

This study examined a personal watercraft case study with the aim of clarifying the nature of the differences in customers' Kansei evaluations when they observed the same product in reality versus in VR. Specifically, we analyzed the results of a comparative evaluation of the same model in real and VR environments and identified patterns in the appearance of the graphs of the differences in the Kansei evaluations. We then derived criteria for classifying the graph patterns.

Section 2 describes the process of drafting the graph patterns and criteria based on the results of a comparative study of 110 participants. Section 3 describes the results of validating the draft based on the results of a survey with 23 participants. Section 4 discusses the significance of this study, and Section 5 presents the conclusions and future issues.

The graph patterns of differences in Kansei evaluations that this study identifies will make it easier to consider effective measures to reduce these differences.

Drafting of evaluation graph patterns and criteria for determining patterning

Large-scale survey methodology

To obtain data to derive patterns and examine judgment criteria, we surveyed more than 100 people at the 2022 Japan International Boat Show, where marine leisure products were sold and exhibited. In this survey (hereafter referred to as "Survey 1"), participants were asked to observe the same model in real and VR environments and to evaluate the Kansei of the model at that time. Figure 1 shows the real model used in this survey and Figure 2 shows the model images created using VR. The PC and VR headset used to create and view the VR images were the "OMEN by HP 17-cb1002TX" and "VIVE Pro 2," respectively.

Figure 1. *Real personal watercraft model*

Figure 2. *Model image of personal watercraft in VR*

Because the participants intended to visit the boat show, it was not possible to allow much time for each person to complete the survey. Therefore, to reduce the burden on the participants, we decided to use the one-pair comparison method. The evaluation scope was the seat of the watercraft. From the aspect of evaluation, we selected six aspects of the seat: glossiness, texture, tension, softness, stylishness, and ride comfort, referring to Kajihara et al. (2022).

However, the participants could not simultaneously observe the models shown in Figures 1 and 2 because the VR was a goggle-wearing survey. This study focused on the degree of difference in Kansei evaluation when observed in VR compared with a real product. Therefore, we asked the participants to look at the VR model first and then at the real product, and asked them to evaluate their Kansei at that time. Table 1 shows the questionnaire used in Survey 1.

***Table 1**. The questionnaire used for Survey 1*

VR model ⟷ **Real model**

(1-1) Glossiness				
Strongly VR	Slightly VR	No difference	Slightly real	Strongly real
☐	☐	☐	☐	☐

(1-2) Texture				
Strongly VR	Slightly VR	No difference	Slightly real	Strongly real
☐	☐	☐	☐	☐

For example, if the participant felt that the model was shinier when observed in VR for the aspect of "glossiness", they were asked to fill in a mark on the left side of Table 1; if they felt that there was no difference between the two, they were asked to fill in a mark in the middle of Table 1.

Survey 1 results and draft evaluation patterns

The evaluation results were obtained from 110 participants using the method described in subsection 2.1. The age breakdown of the participants was as follows: 7 were in their teens, 32 in their 20s, 18 in their 30s, 20 in their 40s, 23 in their 50s, 9 in their 60s, and the age of 1 participant was unknown.

Using the data collected in Survey 1, the number of participants per point was tabulated, and a histogram was created for each aspect. Figure 3 shows the corresponding histograms. For ease of tabulation and analysis, we converted the variables into dummy variables: 1 = strongly VR, 2 = slightly VR, 3 = no difference between the two, 4 = slightly real, and 5 = strongly real.

Looking at the shape of the graph in Figure 3, the number of responses of 3, which corresponds to "no difference," is the highest for the two aspects of "tension" and "stylishness," and is in the form of a normal distribution. If the graph has this shape, it can be concluded that there is no difference in the evaluation between the actual product and VR model.

However, "softness" and "ride comfort" were skewed toward the real object, with the shape of the mountain drawn to the right. With regard to these two aspects, it was possible to determine that the participants felt more strongly when they saw the actual product. Two mountain peaks were formed for "glossiness." "Texture" was a flat graph.

The fact that there were graphs with mountain peaks closer to the actual product suggests that there were also graphs closer to VR that did not exist in the results of Survey 1. These graphs show the shape of a mountain drawn to the left. In this case, the peak value of the graph is on the left side.

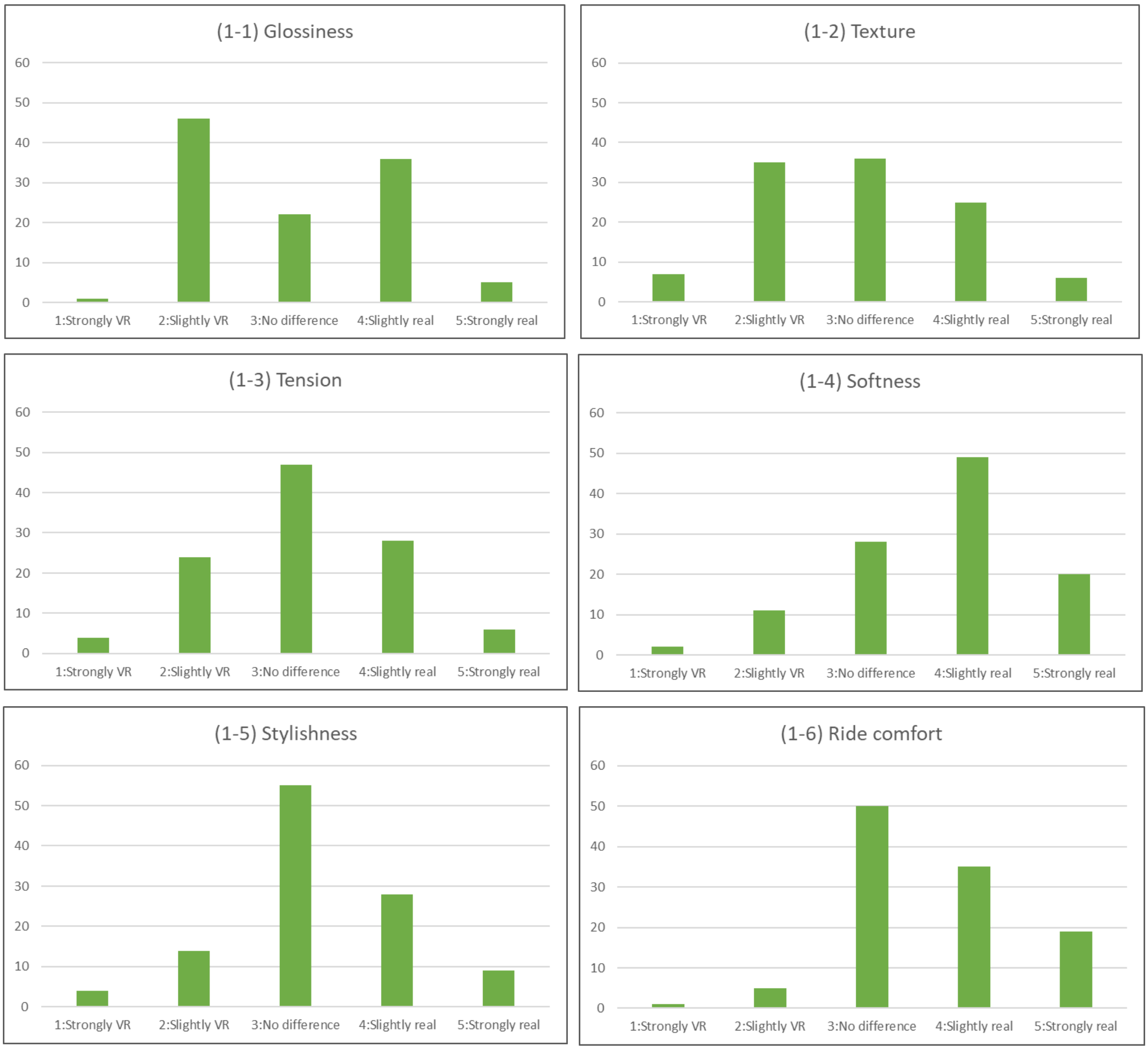


***Figure 3**. Histogram of Survey 1 results*

Thus, the differences in Kansei evaluations can be roughly classified into four patterns. Pattern 1 had a normal distribution, and it can be concluded that there was no difference in the evaluation. Pattern 2 had the peak value of the graph on the right side, and it can be concluded that the actual product is perceived more strongly. Pattern 3 had the peak value of the graph on the left side, and it can be concluded that VR was perceived more strongly. Pattern 4 is a twin-peak or plateau type, and it can be concluded that there is a large variation in the evaluation among the participants. This is the draft of the graph patterns.

Draft criteria for pattern classification

If the graph of the evaluation results is similar to Pattern 1 of the four patterns, it can be concluded that there is no difference in the Kansei evaluation between reality and VR for this aspect. Therefore, we decided to establish objective criteria to determine whether the evaluation results correspond to Pattern 1.

Pattern 1 has a normal distribution, with a score of 3 at the center. Therefore, we set two criteria to judge the graph: (1) the graph is normally distributed, and (2) the mean of the graph is three.

For criterion (1) that the graph must be normally distributed, we decided to use the "kurtosis" and "skewness" of the graph. Kurtosis indicates how sharp the graph is or to what extent the base of the graph is extended. The higher the sharpness of the graph, the higher the kurtosis, and the smoother the graph, the lower the kurtosis. Skewness indicates whether a graph is symmetrical. It is zero when the distribution is perfectly symmetrical, positive when the data are skewed to the left, and negative when the data are skewed to the right.

The kurtosis and skewness of each of the six aspects in Survey 1 were calculated, and the criteria were defined by comparing the values of "tension" and "stylishness," which were in Pattern 1, with the values of the other aspects. As a result, the criterion for (1) was defined as a kurtosis of -0.5 or greater and an absolute skewness of 0.1 or less.

As a criterion for (2), to confirm that the mean of the graph is 3, we decided to utilize the t-test, which is a test of the population mean. The criterion for (2) was set as follows: the null hypothesis was set to mean = 3 ($\mu = 3$), the significance level was set to 1%, and the null hypothesis was not rejected, confirming that the mean of the graph was 3.

The same model was compared with the real and VR models, and the results of the Kansei evaluation were graphed for each aspect. It was decided that if it satisfied both criteria (1) and (2), the Kansei evaluation for that aspect would be Pattern 1, that is, there was no difference between the two. Conversely, if the graph did not correspond to Pattern 1, a difference between the two was considered. These were the draft criteria for pattern classification.

Verification of drafts and proposal of evaluation pattern table

Verification of drafts

We tested whether the draft criteria established in subsection 2.3. could be applied to other evaluation aspects and small-group surveys. To test this, an additional survey (hereafter referred to as Survey 2) was conducted with 23 participants in the same manner as Survey 1, with a total of ten evaluation aspects, including seven aspects that were not used in Survey 1.

Using the data for each aspect collected in Survey 2, histograms were created for each aspect, and drafts of the criteria were applied. The results of applying these criteria are listed in Table 2. The symbols in Table 2 are as follows: (○) denotes that the criteria are satisfied, (×) denotes that the criteria are not satisfied, and (-) denotes that the evaluation is not possible. Figure 4 shows the histograms for each aspect in Survey 2.

Table 2. Results of applying the draft criteria

Aspect	Kurtosis	Skewness	T-test	Pattern
(2-1) Vividness of colors	×	○	×	4
(2-2) Glossiness	○	×	○	4
(2-3) Texture	×	×	×	4
(2-4) Softness	○	×	×	2
(2-5) Seat area size	○	×	×	2
(2-6) Toughness	○	○	○	1
(2-7) Fashionable	○	×	○	—
(2-8) Stability	○	×	○	—
(2-9) Luxury	○	○	○	1
(2-10) Preference	○	○	○	1

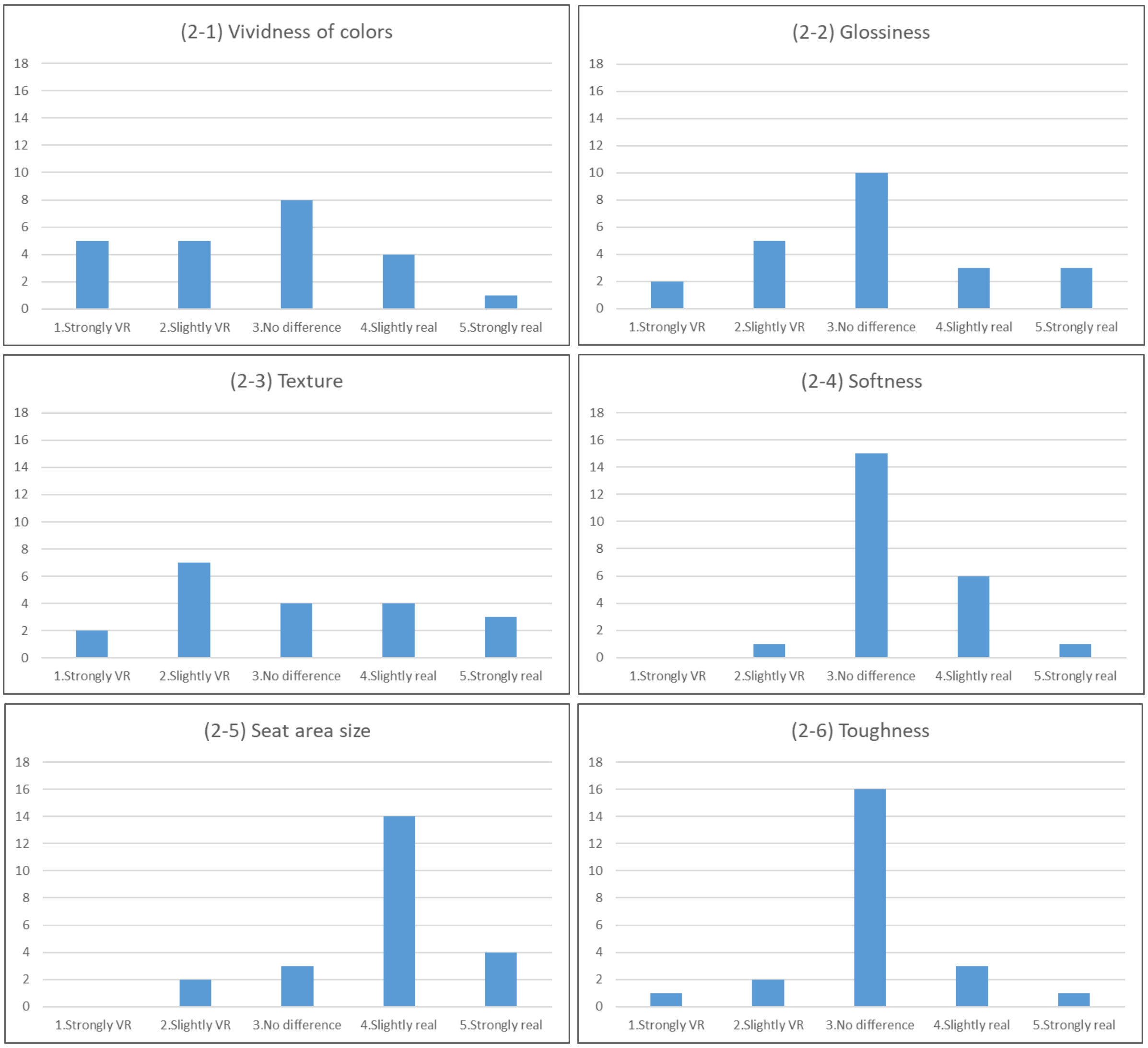


Figure 4. *Histograms for each aspects in Survey 2 (1/2)*

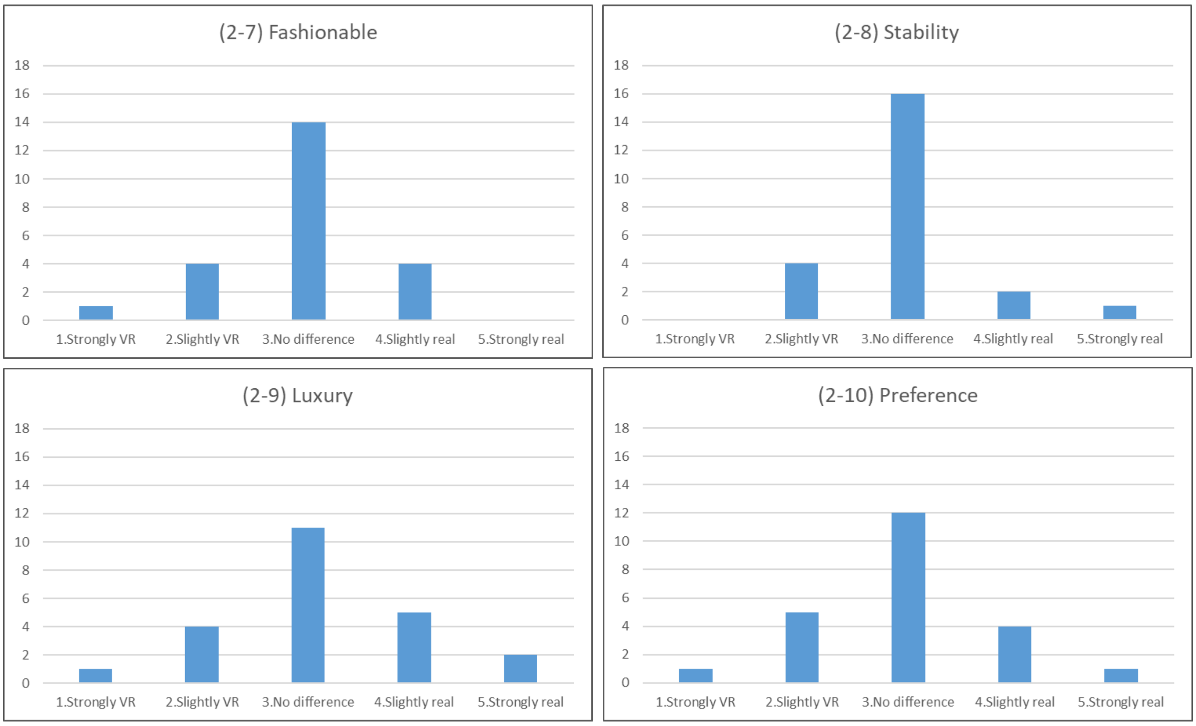


Figure 4. *Histograms for each aspects in Survey 2 (2/2)*

Consequently, the draft criteria could be applied to eight of the ten aspects, and patterns could be identified. However, it was necessary to reconsider the graphs for "fashionable" and "stability." The graphs for these aspects show that the skewness criterion was not met, despite the overwhelming number of respondents who answered "3," meaning no difference. This is thought to be because the number of participants in Survey 2 was smaller than in Survey 1, which covered more than 100 participants, and thus a single vote had a greater effect on the skewness. Therefore, it was decided to include a criterion that if the overwhelming majority of the respondents stated that there was no difference and the "kurtosis is greater than 1.0," the pattern would be considered to be Pattern 1 even if the skewness criterion was not met. Table 3 shows the criteria for determining that there is no difference in the Kansei evaluation between reality and VR.

Table 3. *Criteria for determining that there is no difference in Kansei evaluation between reality and VR*

Item	Criteria
(1) kurtosis, skewness	(a) kurtosis greater than -0.5 and absolute skewness within 0.1 (b) kurtosis greater than 1.0 (no skewness criteria at this time)
(2) test of the population mean	The null hypothesis in the t-test is set to mean=3 (μ=3), the significance level is set to 1%, and the null hypothesis is not rejected.

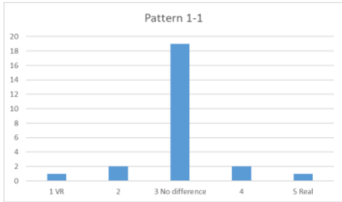
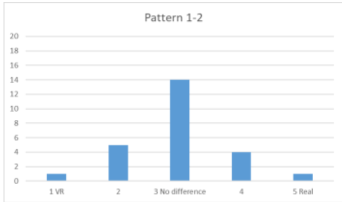
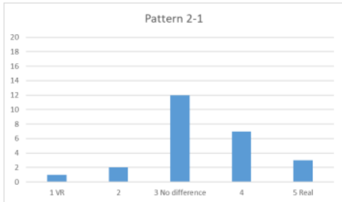
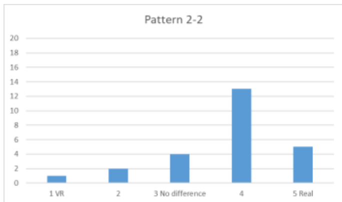
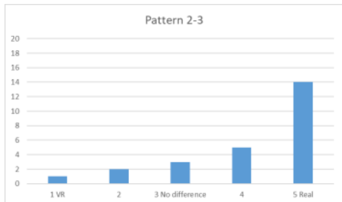
Using the revised criteria, the patterns of the evaluation results from the 10 aspects were examined. As a result, five aspects were classified as Pattern 1, two as Pattern 2, and three as Pattern 4. No aspects fell into Pattern 3.

Subdivision of patterns and proposed evaluation pattern table

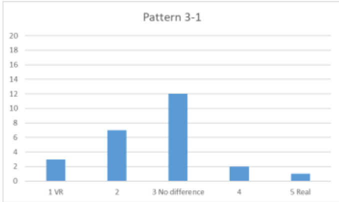
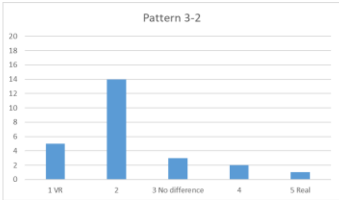
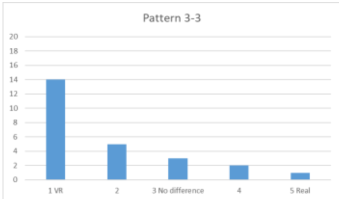
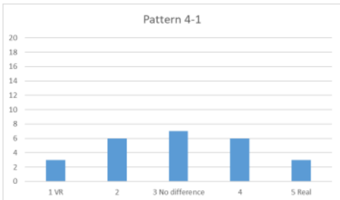
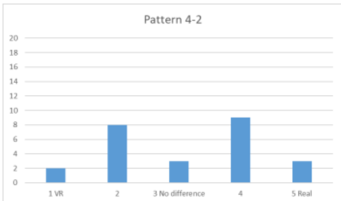
From Figure 4, it is clear that graphs with different peak heights exist, even if they are classified into the same pattern. From this, it was concluded that the four patterns in subsection 2.2. can be further subdivided. Therefore, each pattern was subdivided according to the shape of the graph. Pattern 1 was subdivided into two, Pattern 2 into three, Pattern 3 into three, and Pattern 4 into two, for a total of ten patterns.

The criteria presented up to this point were intended to confirm whether the pattern fitted Pattern 1. Therefore, we set classification criteria for the other patterns using the number of peaks, mode, and kurtosis of the graph. These criteria were combined with the previously established criteria listed in Table 3 to obtain the final criteria. The results were summarized, and the evaluation pattern table shown in Table 4 was created.

Tabel 4. *Evaluation pattern table (1/2)*

Pattern		Criteria	Explanation of Pattern	Example of Histogram
1	1-1	・Kurtosis ≥ 1.0 ・Test of population mean	There is no difference between the two.	
	1-2	・1.0 > Kurtosis ≥ -0.5 ・Absolute skewness within 0.1 ・Test of population mean	There is no difference between the two, but the evaluation results include individual differences compared with Pattern 1-1.	
2	2-1	・The mode (peak value of the graph) is "3".	Generally, there is no difference between the two, but many people have a slightly stronger impression of the actual product.	
	2-2	・The mode (peak value of the graph) is "4".	Many people have a slightly stronger impression of the actual product.	
	2-3	・The mode (peak value of the graph) is "5".	Many people have a stronger impression of the actual product than the VR model .	

__Tabel 4.__ Evaluation pattern table (2/2)

Pattern		Criteria	Explanation of Pattern	Example of Histogram
3	3-1	・The mode (peak value of the graph) is "3".	Generally, there is no difference between the two, but many people have a slightly stronger impression of the VR model.	
	3-2	・The mode (peak value of the graph) is "2".	Many people have a slightly stronger impression of the VR model.	
	3-3	・The mode (peak value of the graph) is "1".	Many people have a stronger impression of the VR model than the actual product .	
4	4-1	・A flat graph with one peak	The evaluation results are scattered.	
	4-2	・A graph with two peaks	The evaluation results are scattered.	

Discussion

Significance of this study

This study focused on the differences in the evaluation of real and VR personal watercraft, which were not mentioned in Kajihara et al. (2022). In this study, when the results of the pairwise comparisons were graphed, we found that the shape of the graph had characteristics, and we thought that we could create a pattern. Therefore, we focused on the characteristics of the positions and shapes of the peaks in the graph to create patterns of the difference trends.

Statistical criteria such as skewness, kurtosis, and tests of population means were used to derive objective criteria for patterning. By applying these criteria to small-scale surveys and revising them, we believe that we were able to establish criteria that can be applied to a large number of surveys.

The fact that the differences in Kansei evaluations were patterned indicates that the reasons for the differences between seeing the same model in actual products and VR were subdivided. This will make it possible to consider policies that reduce the differences in each pattern.

Research methods for comparing real and VR

In this study, the one-pair comparison method was used instead of the five-point method as the evaluation method for comparing the real object and the VR model. This was done to reduce the burden on the participants in Survey 1. As a result, compared with the 5-point method, the difference between the real object and VR could be visually confirmed in a single graph. This allowed us to derive a graph pattern. This indicates that the pairwise comparison method is easier to handle when comparing the difference in Kansei evaluation between two objects.

In Surveys 1 and 2, the participants were asked to view the VR after viewing the actual object and to respond verbally to the results of the pairwise comparison while observing the VR. This was done to ensure that the impression of the 3D model would not fade by having the participants evaluate the model while observing the VR. In addition, participants who provided extreme answers, such as a score of 1 or 5, were interviewed regarding the reasons for their evaluation. This allowed for the subdivision of the pattern.

Conclusions and future issues

This study examined a personal watercraft case study to clarify the nature of differences in customers' Kansei evaluations when they observed the same product in reality versus in VR. One hundred and ten participants observed a personal watercraft model in real and VR environments, and evaluated the differences in Kansei from six evaluation aspects. Based on the results, criteria were established to determine whether there was any difference in Kansei evaluation between the two. To confirm their applicability to other evaluation aspects, as well as to small-scale participant surveys, a similar investigation was conducted with 23 participants using ten evaluation aspects. After modifying some of the criteria based on the results, the set of criteria was deemed suitable for small-scale surveys. Additionally, the differences in Kansei evaluations observed across evaluation aspects were standardized into ten patterns. Subsequently, we proposed the evaluation pattern table summarizing the results of these analyses.

In future, it will be necessary to consider policies that reduce the differences in each pattern and confirm its effectiveness. It is also necessary to verify whether the criteria proposed in this study can be applied to parts other than the seats of watercraft and to other products.

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Leveraging Generative AI: Enhancing Employee Engagement and Performance in the Workplace

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Introduction

The introduction underscores the profound effects of emergent technologies such as Chat GPT 3.0 on both productivity and the transformation of industries, while also considering the associated concerns about privacy, control, and the potential for job obsolescence (Acemoglu et al., 2023; Young et al., 2021). It addresses the ambivalent role of generative AI, which can both exacerbate inequalities and amplify productivity gains. The discussion is enriched by insights from diverse disciplines, recognizing the advantages and challenges of Chat GPT, including issues of privacy and algorithmic bias. The study explores the adoption of generative AI in the workplace, emphasizing the critical role of trust in boosting productivity and the impact of engagement on performance. It stresses the need for an all-encompassing approach that combines views on technology readiness, user perceptions, and trust, particularly pointing out the opaque nature of AI algorithms as a hindrance to trust. Engagement is analyzed through its cognitive, emotional, and behavioral dimensions and their effect on performance. The paper seeks to link the deployment and utilization of AI tools with trust and its influence on employee engagement and performance, particularly examining the mediating role of trust. It also outlines the structure of the paper, including theoretical underpinnings, methodology, findings, and conclusions.

Methods

Hypotheses propose that optimism and innovativeness enhance user experience; user experience boosts trust; trust improves work engagement; and work engagement leads to better employee performance (Llorens et al., 2007). This framework aims to understand GenAI's impact on the workplace, highlighting the synergistic effects of technology readiness, acceptance, trust, and engagement on performance. These hypotheses all together merges into the research model in Figure 1.

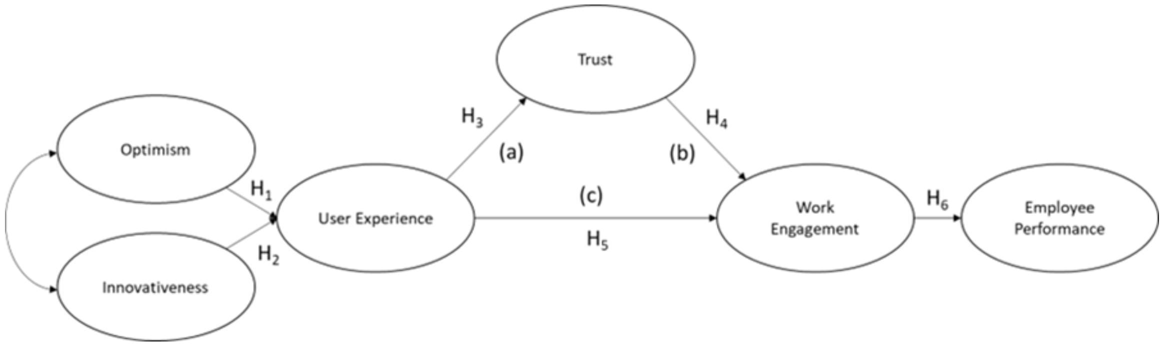

Figure 1.- Research model

Questionnaire Design

To evaluate the impact of generative AI tool usage in workplace settings, a comprehensive questionnaire was developed. This survey comprised various sections that covered aspects such as technology readiness, acceptance, user experience, trust in AI tools, work engagement, and overall workplace performance. The questions were carefully selected or modified from established studies to maintain precision and relevance. Table 1 presents the constructs examined, the specific items included in the questionnaire, and their sources, offering a systematic method to investigate the role of generative AI in shaping workplace dynamics.

Table 1*.- Items proposed for the questionnaire.*

	Construct	Code	Item	References
1	Optimism	OPT1	Gen AI tools contribute to a better quality of my life	(Parasuraman, 2000; Parasuraman & Colby, 2015)
2		OPT2	Gen AI tools give me more freedom and flexibility	
3		OPT3	Gen AI tools give me more control over my work tasks	
4	Innovativeness	INN1	Other people come to me for advice on new Gen AI technologies	
5		INN2	In general, I am among the first in my circle of friends to acquire new Gen AI technology when it appears	
6		INN3	I can usually figure out new Gen AI tools without help from others	
7		INN4	I keep up with the latest Gen AI technological developments in my areas of interest	
8	Usefulness	USE1	I find gen AI useful in my job	(Davis, 1989)
9		USE2	Using gen AI makes it easier to do my job	
10		USE3	Using gen AI in my job would enable me to accomplish tasks more quickly	
11	Easy to Use	EAS1	I think that Gen AI is easy to use	
12		EAS2	Learning to use Gen AI was easy for me	
13		EAS3	I find it easy to get Gen AI to do what I want it to do	
14	Trust	TRU1	In my work, I feel comfortable depending on the information provided by Gen AI	(McKnight et al., 2002)
15		TRU2	I trust that I can rely on Gen AI in my work	
16		TRU3	I feel that I can count on responses of Gen AI to help me in my work	
17		TRU4	If I have a challenging problem in my work, I use Gen AI	
18		TRU5	I feel assured about data protection on the gen AI-tools	
19		TRU6	I feel adequately protected from problems on the AI-tools used in my company	

20		TRU7	I trust that gen AI-tools used in my company comply with established legal structures	
21	Work Engagement	WEN1	Time flies when I am working	(Wijayati et al., 2022)
22		WEN2	I am enthusiastic about my job	
23		WEN3	When I am working, I forget everything else around me	
24		WEN4	At my work, I always persevere, even when things do not go well	
25		WEN5	My job inspires me	
26		WEN6	At my job, I am very resilient	
27	Employee Performance	EPE1	My tasks are completed as per the specifications and standards	(Wijayati et al., 2022)
28		EPE2	The units of output meet organizational expectations	
29		EPE3	My tasks are generally completed on schedule	

Survey Administration and Demographics

Data collection was conducted in December 2023 by a survey company, yielding 251 responses from Spanish professionals experienced with generative AI tools at work. Analysis showed a balanced gender distribution and a youthful respondent profile, with over half under 35 and only 19.5% aged 46 or older. High engagement was noted, with 13.9% using AI tools intensively and 21.1% daily. Education sector professionals were the most frequent users at 27.09%. ChatGPT by OpenAI was the most used tool for text generation, with 51.79% of respondents, and 8.37% used other chatbots, totaling 60% utilizing chatbot technology. Image and video generation tools were the second most used.

Assessment of the Research Model

This study aims to examine the pathway from an employee's readiness to use generative AI tools in the workplace to their performance, passing through factors such as technology acceptance, trust in these technologies, and work engagement. A two-phase analytical approach was adopted for this analysis.

Initially, to identify and refine the most representative items for each variable, five Exploratory Factor Analyses (EFA) were conducted using principal component analysis and varimax rotation. This procedure confirmed that the variables were statistically robust and aligned with the objectives of the study.

Following this, the research model depicted in Figure 1 was analyzed using Structural Equation Modeling (SEM), utilizing robust maximum likelihood estimation from the asymptotic variance-covariance matrix via EQS software. This step involved a thorough evaluation of the constructs' psychometric properties, including reliability (assessed with Cronbach’s alpha and composite reliability) and convergent validity (evaluated through average variance extracted). Additionally, discriminant analysis was undertaken to ensure the distinctiveness of the constructs, comparing the square of each construct's average variance extracted with its inter-construct correlations.

Lastly, the suitability of the model was determined through various metrics such as the Bentler-Satorra chi-square, its coefficient and degrees of freedom, the Comparative Fit Index (CFI), and the Root Mean Square

Error of Approximation (RMSEA). Once the model's validity was confirmed, the standardized coefficients were analyzed to elucidate the relationships among the variables.

Results and Discussion

The study began with five Exploratory Factor Analyses (EFA) to reveal key insights. The initial EFA focusing on the optimism and innovativeness dimensions of the Technology Readiness Index (TRI) scale confirmed their distinctiveness. Subsequent EFAs on other constructs each resulted in a single dimension, aligning with the standards set by Ladhari (2012) and Wolfinbarger & Gilly (2003). These standards required that items have loadings of 0.7 or higher on their respective factor, do not load above 0.50 on multiple factors, and maintain an item-to-total correlation above 0.50. Although two items, EAS3 and WEN1, showed slightly lower loadings of 0.698 and 0.696, they were retained in the analysis due to their significant contributory value.

The discriminant validity assessment was conducted by comparing linear correlations or standardized covariances among latent factors, yielding satisfactory results. This involved ensuring that inter-factor correlations did not surpass the square root of the Average Variance Extracted (AVE), as recommended by Fornell & Larcker (1981). The results confirmed discriminant validity, with the square roots of the AVEs for each construct exceeding their corresponding off-diagonal elements.

The model fit indices demonstrated a successful alignment of the variables with the predefined factors in the research model. The Satorra–Bentler chi-square value was 577.75, with 317 degrees of freedom and a p-value of 0.000; the chi-square to degrees of freedom ratio ($\chi 2/df$) stood at 1.82, comfortably within the acceptable limit of 5. The root mean-square error of approximation (RMSEA) was 0.057, and the comparative fit index (CFI) reached 0.913. Although interpreting the robust chi-square statistic requires caution, the overall model fit was considered acceptable according to the criteria established by Hair JF, Black WC, Babin BJ, Anderson RE (2010).

All path coefficients were significant at a 0.05 level of significance, except for the path from "User Experience" to "Engagement," resulting in the acceptance of five out of the six hypotheses, with the fifth hypothesis being rejected.

Conclusions

This study sheds light on the complex dynamics involved in adopting generative AI tools and their impact on workplace performance, emphasizing the critical interplay between technology readiness, user experience, trust, and work engagement. It highlights trust as a key mediator between user experience and work engagement, underscoring its essential role in the successful utilization and integration of generative AI tools to boost employee performance.

Three main insights are drawn from the analysis: First, optimism plays a more significant role in shaping user experience than early adoption of pioneering technology, emphasizing the importance of a positive outlook toward technological advancements. Second, trust serves as a vital link between user experience and work engagement, indicating that trust in generative AI is crucial for enhancing work engagement. Third, the study confirms that work engagement significantly boosts employee performance.

The managerial implications of these findings suggest focusing on building trust in generative AI technologies, fostering a positive technology culture, and implementing strategies to enhance employee engagement with these tools. Future research should explore these relationships across various cultural and organizational settings and examine the effects of related constructs like job satisfaction on the established theoretical framework.

The opening quotation from Acemoglu provides a backdrop for exploring the nuanced effects of technological progress on stakeholders, indicating that while technology can enhance productivity, the benefits are not uniformly distributed, which points to a need for more empirical research into these dynamics.

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Quality 5.0 in Higher Education: A Literature Review

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Abstract

The world is currently undergoing a process of rapid change in all aspects of human living. The progressive digitalization of the industrial sector is promoting the creation of a sustainable Society 5.0, where humans and machines cooperate to achieve shared production goals. However, this new paradigm is still surrounded by a limited understanding and is yet to be defined, particularly regarding higher education institutions.

This paper aims to contribute to the scientific comprehension and definition of the role of Quality 5.0 in higher education institutions, by exploring how the implementation of a social-oriented quality management approach influences the university environment. A literature review was conducted to study previous papers regarding this novel topic. Using the Web of Science, Google Scholar and Scopus databases, articles were obtained based on the following string of keywords present in the abstract: (university OR “higher education” OR “higher education institution”) AND (“smart university” OR “university 4.0” OR "quality 5.0” OR “social-oriented quality” OR “society 5.0” OR quality-centric OR sustainability) considering only articles published from 2018 to 2024.

The results outline the main pillars of Quality 5.0, the potential benefits of its implementation in universities, and finally the obstacles that may be encountered in the process. The study is limited by the databases referenced and by the consideration of articles written only in English. This paper's findings can be helpful to university practitioners, managers, and other stakeholders as a guide for implementing a Quality 5.0 approach into the strategic goals of higher education institutions.

Keywords: higher education, quality management, smart university, society 5.0, sustainability, literature review

Relevant Topic: Quality Management in Service Industries

Introduction

Originating in Germany in 2011, the Industry 4.0 (I4.0) concept has connected the boundaries between the physical and the digital world. Together these two worlds have shaped the novel cyber-physical complexes that form a digital ecosystem, characterised by machine intelligence, affordable storage, pervasive computing, and robust connectivity (Salimova et al., 2020; Efimova & Briš, 2021).

As a matter of fact, these new I4.0 technologies, techniques, tools, skills, training, and education are generating new concepts, disciplines, and business opportunities such as Services 4.0, Products 4.0, Workers 4.0, and Education 4.0 (Salimbeni et al., 2023). It has led also to the inception of Quality 4.0, which is the alignment of quality management methods and tools with I4.0 principles and technologies, building and improving upon traditional quality management approaches (Barsalou, 2023; Ramezani & Jassbi, 2020). In fact, quality has been one of the critical factors for organisations to remain competitive and sustain market dominance in today's world (Huang et al., 2022).

I4.0 has also prompted the necessity to construct a Society 5.0. Although it has only been consolidated at a theoretical level by the Japanese government, Society 5.0 aims to utilise I4.0 technological developments for ameliorating the quality of life of the population by solving socio-economic issues and acting as a driving force in redefining lifestyles for the better welfare of humanity (Biswas et al., 2023). This next development of I4.0 has already begun with the recent conception of a new paradigm, known as Industry 5.0 (I5.0) (Salimbeni et al., 2023). The I5.0 paradigm represents the fifth stage of industrial production evolution, that is, a kind of people centric I4.0 where human operators work in close collaboration with smart machines with a much greater proactive emphasis on environmental sustainability. This fifth industrial revolution is predicted to generate digitised manufacturing industries with advanced product innovation capabilities, a more informed decision-making process, greater flexibility, increased productivity, and improved machine quality and efficiency (Singh et al., 2023).

Naturally, the visionary notions of Society 5.0 and Industry 5.0 require the integration of supplementary facets into the Q4.0 concept, which leads to the formation of the fifth evolution of quality management principles, known as Quality 5.0 (Q5.0). This novel theoretical concept encompasses environmental sustainability, spanned across the global landscape, by adopting a proactive stance towards continuous improvement and defect prevention. The Q5.0 paradigm plans to go beyond the limitations of traditional quality control processes, by adopting a holistic approach which focuses on social responsibility, employee engagement, sustainability, and societal satisfaction (Frick, 2023).

These fifth-generation paradigms, which will have the capacity to integrate all actors of innovative sustainable ecosystems and democratic values, have also brought about the formation of new approaches in higher education. In fact, technology and academia have been running in parallel to each other for decades to favour the continuous transformation of the higher education sector. This sector is now in dire need of an integration of innovative cyber-physical-social technologies into operational systems and processes (Alharbi, 2023). This development, which attempts to establish better quality education standards, has been attributed the name of

Education 5.0 and, in the case of higher education, University 5.0 (U5.0). A smart University 5.0 must understand and continuously improve not only its internal environment, but also the ambient external to its boundaries. The U5.0 paradigm attempts to address the present ongoing sustainable and digital transitions, with the scope of establishing a new contemporary system which systematically promotes the unfastened, "glocal", digital, and social innovations for the overall well-being of humanity and the planet (Carayannis & Morawski, 2023). Therefore, the Q5.0 concept closely ties in with the implementation of this new educational paradigm, as in order to obtain the betterment of higher education from the triplex sustainability perspective, the implementation of an adequate updated quality assurance system is a fundamental prerequisite.

The aim of this paper is to provide a possible delineation of the theoretical construct that is the Q5.0 paradigm and its potential application in higher education institutions (HEIs). A state-of-the-art literature review was undertaken to explore the main characteristics, possible benefits, and challenges of a potential implementation of the Q5.0 concept, as well as the possibility of applying it in the university environment.

Methods

A state-of-the-art literature review on the development of the Q5.0 concept and its potential role in higher education was conducted following the six-stage methodology established by Barry et al. (2022). Tab. 1 presents the review protocol utilised.

The search was carried out using Scopus, Web of Science, and Google Scholar databases. The keywords used (see Table 1) were searched based on the article abstract in the different databases. Although some experts have recommended excluding conference proceedings, this study has included them in order to extract all possible insights on this emerging research field. The references of the identified papers were also used to extend the selection process. The reviewed papers were selected according to whether they contribute to the development of the Q4.0 or Q5.0 paradigms and their application in higher education. The resulting number of papers does not include research works that were not written in the English language and all other forms of grey literature were disregarded. Papers were also excluded if they did not focus on the implementation of all three sustainability aspects in HEIs or if there was a poor research design and unclear arguments presented.

Table 1: Review protocol

Item	Description
Keywords	university, higher education, higher education institution, smart university, university 4.0, quality 5.0, social-oriented quality, society 5.0, quality-centric, sustainability
Inclusion	Papers applying qualitative, quantitative methods and conceptual studies; conference proceedings; papers focusing on the development of the Q4.0/Q5.0 paradigm, quality mangement in HEIs, the implementation of TQM, Q4.0, or Q5.0 in HEIs, sustainable development goals and HEIs, integrating practices regarding the three aspects of sustainability in HEI strategic planning and quality management, digital transition in HEIs.
Exclusion	Papers not written in English; all other forms of grey literature; papers focused solely sustainability education, climate change in HEIs, environmental sustainability in HEIs.
Publishers	Springer, Taylor & Francis, Elsevier, MDPI, Wiley, IEEE, Emerald, ACM
Time Period	January 2018 to March 2024

Conceptual studies and studies implementing qualitative or knowledge-based methods that focused on broader questions were included. There were very few papers that focused on Q5.0, however, articles dealing with Q4.0, social-oriented quality, and all three aspects of sustainability, applied to the higher education sector, were considered for evaluation as many of these papers dealt with the future developments of these concepts. Two of the authors critically evaluated the studies collated based on the chosen review protocol (see Tab. 1) which was verified previously through a pilot review of ten articles in which the findings were assessed via a brief comparative analysis. This was done in order to align the interpretations of the two reviewers and account for a certain degree of subjectivity. A total of 270 papers were reviewed.

Results and Discussion

The evolution of the concept of quality

Global competition has enhanced the role of quality in the business world. In today's highly competitive market, with escalating demands of consumers for getting better products and services, the emergence of quality plays a vital role in the survival of companies. Corporate economic success, alongside the need for improvement in productivity, customer satisfaction, profitability, innovativeness, an ever-changing organisational culture, and the globalisation of world trade have also contributed to making quality a top priority for companies worldwide. In other words, these challenges and pressures have placed a renewed focus on quality improvement which favours the company in gaining competitive advantage for the long-term survival of the organisation (Martin et al., 2020).

However, the issue lies in how to define the concept of quality, as it possesses a multi-faceted, intangible nature, thus meaning that it is subject to many different interpretations and perceptions. In fact, over time different meanings have been assigned to the notion of “quality”. For example, Shewhart and Deming (1986) defined quality as an expectable degree of dependability and uniformity, as well as being at a cost convenient for the market, and Juran (1989) gave a customer-oriented feature to the concept defining it as “fitness for use”. Crosby (1996) also considered quality as the “conformance to requirements or specifications” and supporting customer wants.

Before the first industrial revolution, quality was considered insignificant. However, as Industry 1.0 progressed, the importance given to quality gradually increased, leading to the development of the first quality control methods. This timeframe is referred to as Quality 1.0 (Q1.0) in the evolution of the quality concept and lasted approximately until 1890. Q1.0 revolved mainly around the inherent characteristics of a product and predominantly focused on craftsmanship, raw materials, and functionality. Back then, a high-quality item was considered as being skilfully made, functional, unique, durable, and reliable. This early interpretation of quality was quite subjective, and varied significantly based on culture, geographic area, and individual perceptions (Frick & Grudowski, 2023).

The second stage of evolution is known as Quality 2.0, which took place between 1890 and 1940, and was greatly influenced by the advent of the second industrial revolution which gave life to mass production. It marked the initiation of systematic standardisation of quality goods, gaining greater importance among both manufacturers and consumers. In this period, the meaning of quality began to mutate from being associated solely with individuality and craftsmanship to also comprehending uniformity and consistency, particularly for mass-produced products. Companies began to understand that in order to construct solid customer loyalty and remain competitive on the market, it was crucial to supply products considered of a high-quality standard. Quality control processes in factories began by focusing on defect detection and elimination, for example statistical process control, in order to favour the creation of quality goods that met a certain standard and were possible to replicate on a larger scale. Many American and European companies began establishing a special quality department, in charge of conducting quality controls just as the final task before shipping. However, they soon learned that leaving defect control to the last minute generated a lot of extra costs. The new quality improvement methods developed then, form the basis of today’s modern quality management systems (Hattinger & Stylidis, 2023).

From 1940 to 1995, a significant change in the concept of quality occurred as an immediate consequence of Industry 3.0, which saw the development of new technologies, a more globalised market, and the inspiration of quality gurus such as K. Ishikawa, P. Crosby, W. E. Deming, and J. Juran. Also known as the Quality 3.0 (Q3.0) period, during this time quality was becoming an all-inclusive organisational philosophy, shifting towards a more proactive quality assurance approach with a focus on continuous process improvement. Defect prevention was no longer just part of the final production phase but incorporated in the whole process from the very beginning. All operators were to be responsible for checking the quality output of their own work. Customer feedback grew in importance and was now considered also during the product development phases, in order to embed a high level of quality in each manufacturing stage with the aim of exceeding customer expectations. Thanks to the creation of computers and the internet, companies were capable of storing and utilising vast quantities of data to favour the improvement process. This nascent philosophy was named the Total Quality Management (TQM) approach (Frick & Grudowski, 2023; Hattinger & Stylidis, 2023).

In the era of the fourth industrial revolution (I4.0), from the beginning of the new millennium to the present day, technological and industrial advancements are currently being implemented into manufacturing procedures. These events have caused the development of the fourth generation of quality management, called Quality 4.0 (Q4.0). The Q4.0 refined approach shows a greater adaptability in dealing with these new disruptive information technologies, in catering for the demands of the supply network, and in managing and using increased quantities of data (Chiarini & Maneesh, 2022). This fourth quality revolution has a unique potential to implement automation and digitization effectively in the production ecosystem, incrementing organisation competitiveness and profitability through the enhancement of customer experience. In this sense, quality is not only about creating a product that meets basic standards; it also encompasses the consideration of the level of convenience, the after-sales services, and the overall user experience, making transparency and information accessibility fundamental in quality perception. (Antony et al., 2023).

Starting from 2020, the concept of quality is becoming ever more interlaced with innovative and sustainable business practices, constructing a holistic approach which spawned from the initiation of Industry 5.0. In fact, Quality 5.0 (Q5.0) reflects a new era marked by the completion of digital transformation, a boost in sustainability levels, augmented automation, and increased awareness regarding environmental and social issues. In this context, quality is being modernised according to the circular economy principles, which emphasise the importance of waste reduction, recycling, and reducing the environmental impact of manufacturing processes. Q5.0 is characterised by a change in model from being traditionally reactive to adopting a more proactive approach, by entrenching quality control into every phase of production with the aid of advanced technologies (Frick & Grudowski, 2023).

Principles of Quality 5.0

The Q5.0 concept is a combination of elements from Sociology, Science and Technology, all centred around the inclusive development and progress of humanity and civilization. It is a blend of social, environmental, and cultural factors, in which the idea of customer is expanded to include society as a whole. The definition of stakeholder satisfaction is broadened to include social satisfaction with a major prospect on sustainability according to which future generations are considered customers of today. Particular focus is placed on guaranteeing psychological well-being and quality work life, enhancing morale, as well as encouraging character development, empowerment, and knowledge-sharing, all in integration with technology advancements (Biswas et al., 2023; Deleryd & Fundin, 2020). The Q5.0 approach, which strives for distinctiveness and creativity, considers predominantly the human factor which has become crucial in production in terms of product/service personalization and innovation, unlike in previous revolutions. In fact, customers today are searching for unique products and services that have the personal marks of creators and craftsmen (Tadić, 2022). For these reasons, future business development strategies should not be centred only around customers and competition but must necessarily integrate social and environmental concerns as priorities (Deleryd & Fundin, 2020). In synthesis, Q5.0 is a comprehensive, proactive, end-to-end approach, leveraged by the newest technology, that guarantees high standards of quality assurance and customer satisfaction (Frick & Grudowski, 2023).

The key elements of this new paradigm include (Frick & Grudowski, 2023):

1. Design: thanks to advanced design software, companies will have the possibility to create digital prototypes on which to conduct tests in order to highlight any potential faults before constructing physical ones. In this way, the design phase undergoes a more accurate and effective quality control procedure.

2. Production & Inspection: Industry 5.0 technologies, including the Internet of Things (IoT), smart devices, automation, artificial intelligence, and robotics, can be implemented to facilitate a continuous inspection of the manufacturing process. This means that errors can be swiftly rectified in real-time, favouring a reduction in downtime and waste production, as well as making sure the product outcome complies to high quality standards.

3. Data Analysis: great amounts of data can be stored, analysed, and used throughout production, thanks to advancements in data analytics software and machine learning. Consequently, this can aid in the identification of trends or patterns of underlying quality errors.

4. Delivery: Products get delivered in perfect condition thanks to the implementation of an IoT-enabled supply chain which permits the tracking and monitoring of products in real-time.

5. Feedback: the processing and evaluation of customer feedback becomes much more efficient through the use of AI systems that have the capacity to identify emerging trends. This in turn, favours the implementation of continuous improvements in order to constantly ameliorate product quality and increase customer happiness.

These elements not only apply to the manufacturing of goods but can also be extended to the offering of services. The main processes involved in Q5.0 comprise predictive analytics, process optimization using AI, human-machine collaboration, and real-time monitoring (Arsovski, 2019). These will favour a thorough comprehension of the manufacturing and service offering processes, the prediction of potential issues, the optimization of operations, and a more collaborative decision-making process, in order to amplify product and service quality and reliability, process proficiency and customer happiness (Frick & Grudowski, 2023).

The potential of Quality 5.0

When integrated into the I5.0 framework, Q5.0 will combine the use of digital technology and automation with quality assurance while maintaining human intuition, decision-making skills, and creativity as a central focal point. It predicts and proactively addresses any maintenance and quality issues that may arise, bringing about significant advancements in product and service quality and customer happiness, while favouring waste and cost reduction (Frick, 2023). This approach enables the optimization of asset lifecycle, enhancement of operational resilience and excellence, maximisation of quality issue detection and resolution, and the promotion of an organisational culture of continuous improvement (Frick & Grudowski, 2023).

Thanks to the new advancements in technology, tedious tasks can now be completed in less time and in a more reliable and practical way. Robots can perform the time-consuming physical tasks, AI can easily collate and analyse large amounts of data, machine learning algorithms can monitor production data to identify possible quality issue patterns, human-machine communication and collaboration empowers workers and operators with the necessary knowledge and tools required to solve issues, sensors will help to avoid the manufacture of poor-quality goods, and in the meantime, people will have the opportunity to focus on more creative jobs. In fact, this will favour the realisation of ideas that could not have been imagined before (Tadić, 2022). The human factor plays a crucial role also in the resolution of issues, as people are needed to fully understand the context in order to take appropriate actions. However, an adequate organisational culture is necessary to allow continuous improvement and learning to flourish in the workplace (Frick, 2023).

The Q5.0 quality management system results in the manufacturing of superior quality products and deployment of outstanding services, which enhances process transparency, boosting customer trust and loyalty and incrementing profits. Profits are also increased through improved operational efficiency and resource utilisation, which places major importance on waste reduction and the elimination of inefficiencies. Additionally, it allows for the futureproofing of the organisation, as the Q5.0 forward-thinking style can help to avoid regulatory issues and prepare for possible shifts in consumer demand, which protect profits. The positive impacts that Q5.0 would have on the environment include placing a strong focus on sustainability and environmental stewardship, through reducing energy consumption, resource usage, etc.; reducing waste by adopting better quality control practices which means fewer defects will appear; complying with environmental regulations. Regarding employees, adopting a fifth-generation quality approach would favour employee engagement and empowerment, encouraging them to be more committed, creative, and productive in their work. Workers and operators would have the opportunity to enhance their skill set and grow professionally, thanks to Q5.0 training. A Q5.0 inspired workplace is one that guarantees safety, diversity, inclusion, and wellness for its staff, which helps to improve the work environment and job satisfaction, attract new talented professionals, and reduce the turnover rate (Frick & Grudowski, 2023).

Furthermore, future Q5.0 professionals must possess high levels of system thinking, evidence-based decision-making ability, a continuous improvement perspective, leadership in organisational learning, as well as the ability to comprehend how decisions affect the various aspects of human lives and society (Radziwill, 2018). These professionals must acquire the skill to understand how to give products a unique touch in order to attract customer attention (Tadić, 2022).

Challenges and future prospects

Considering the new era that is at hand, sustainability has occupied a place of priority on society's agenda, thus, a fifth quality generation is expected to utilise societal satisfaction as the new way of measuring the performance of an organisation. However, the challenge here is to understand how to measure societal satisfaction, as it includes not only the economic and environmental dimensions, but also that of social responsibility. The idea of "consumer" should no longer involve only one individual or segment of the population, but incorporate social responsibility principles also, which should be of equal importance. However, for it to be attained, sustainable social development must first be outlined and accepted by all actors of the service or product supply chain (Delyryd & Fundin, 2020). For a great number of companies and institutions, this requires a drastic shift in the organisational mindset and a conversion to a forward way of thinking on how to maintain long-term survival through a combination of values that apply to a vaster number of stakeholders. This challenge has also been extended to researchers and academics of the sector, as they are faced with the issue of applying a multidisciplinary approach to quality management, by taking into consideration theories from sociology, psychology, business ethics, and change management. Furthermore, a great number of monetary resources are deemed necessary to favour an efficient and effective transition to the new Q5.0 paradigm in all sectors (Arsovski, 2023).

As it is a complex mission to complete, for an organisation to make this transition happen, the design and development of an action plan is fundamental. It is also important to remain consistent to the plan as much as possible and to have full participation on behalf of the staff. To favour participation all aspects of the plan must be explained in detail in terms of why and how the tasks will be undertaken. Management must keep a close eye on employees that tend to not be open to change or that may create discontent among the staff group. This kind of behaviour is quite often due to a lack of understanding of the new approach being implemented, fear of what may be deemed as unknown, or even fear of losing their job. These issues must be dealt with as soon as possible, otherwise other employees may begin to lose faith in the plan, sabotaging the success of its development. Even if managers know all about the implementation of Q5.0, if they are not capable of passing this knowledge on to their colleagues, motivating them into action, and establishing a spirit of togetherness, the chance of a positive outcome will be quite scarce (Tadić, 2022).

Another challenge that is presented is the acquisition of the ability to handle modern technologies, as I4.0 technologies will be upgraded and continued to be used even throughout I5.0. Hence, it is essential for all types of organisations to adapt and apply these new tools in their daily operational processes, as quality performance strictly depends on this adaptation. In fact, the key to success for any organisation lies in the upgrade of existing technological assets and the acquisition of other modern advancements (Frick & Grudowski, 2023).

Furthermore, the role of quality professionals must be modernised to include competencies that will be of greater assistance to the requirements of current stakeholders, in order to achieve greater societal satisfaction. Thus, Q5.0 professionals must possess the following characteristics: flexibility, courage, passion and drive for change, and creativity to allow for the organisation to reach its full potential. On top of this, management teams must assume the role of co-producers and collaborators of the business development, alongside consumers and stakeholders. Consequently, this leads to the necessity of developing new management models that favour the adaptation to a market environment in continuous evolution. These models must promote awareness of the current technological advancements, an inclination towards new business habits, and encourage employees to embrace change. This is critical for the successful introduction of the Q5.0 approach (Delyryd & Fundin, 2020). Other potential challenges that may arise during the implementation process include concerns regarding data management and privacy issues, and the risk of technology dependence arising.

The potential role of Quality 5.0 in the higher education sector

Despite there being little or no evidence in current literature of a potential implementation of a Q5.0 paradigm in the university environment, there has been much talk of incorporating various principles in strategic processes, which are directly linked to this novel paradigm.

Having committed to the contribution and development of education, research and cooperation with the societal environment, HEIs have been faced with drastic changes in society. They must rapidly adapt to these revolutions by initiating a transformation of the institutional organisation and internal environment. This renovation of the higher education sector is, in fact, part of the fifth-generation revolutions and is beginning to be associated to the terms „University 5.0“(U5.0) and „smart university“. The effective realization of these so-called „smart universities" is predicted to commence by the 2030s. HEIs must undertake a radical transition to the U5.0 paradigm in order to provide future graduates with the adequate skills and knowledge for which the fourth and fifth industrial revolutions have created a necessity. In today's world, technological innovations have favoured the spread of the digital transformation to all parts of everyday life. With these, new challenges have arisen which cannot be simply resolved by adopting a unilateral approach. These complex challenges require universities to employ innovative, open, and socially inclusive approaches. They must aim to go beyond their traditional operations and begin assuming a proactive role in transformative change and in generating real social impact. In fact, one of the key roles of U5.0 is to form qualified human resources that will contribute proactively and through innovative ways to this positive digital transformation and change of the societal ambient (Akturk et al., 2022; Andres et al., 2022). It can be noted that, proactivity and continuous improvement are two characteristics of the U5.0 approach, which are also common to the Q5.0 approach, thus creating another linkage between these two innovative concepts.

The achievement of a high quality third-level education is the basis of sustainable development from all aspects. As part of the U5.0 approach, HEIs must necessarily instil a balance between environmental, societal, and economic sustainability in order to navigate successfully through uncertain geopolitical times and complete digitization. These institutions have the fundamental role of being society's developers and advocates of new knowledge. Thus, the future development of society depends upon the quality of education received by current and future graduates. Additionally, the implementation and improvement of processes which guarantee higher educational quality will support future citizens and favour social development. A sustainable HEI can be defined as one that nurtures a high quality of teaching, carries out processes that ameliorate academic quality of life, and optimizes its consumption of natural resources. By combining digital technological tools with sustainability concepts, academic professors will have the opportunity to enrich the student learning experience. Furthermore, educating students in sustainable development is fundamental for the instauration of a Society 5.0 and for the accomplishment of the UN's sustainable development goals. (Olmos-Goméz et al., 2020; Islam & Khan, 2023). This pursual, on behalf of HEIs, of sustainability in its various forms is in fact one of the focal points of the Q5.0 paradigm.

The U5.0 paradigm also comprehends the continuous cooperation between the following five dimensions: industry, government, university, society, and the natural environment. Experts define it as an innovative, „evergetical", eco-system, with a human-centric approach, in which institutions can collaborate in the creation and divulgation of information, necessary for the development of innovative change. To safeguard this eco-system of innovation, distinct vision and mission statements must be established and, subsequently, incorporated into the HEI's organisational strategy, while considering all legal, social, and ethical aspects that may be implied. Universities must be capable of comprehending what competencies their graduates require and align their teaching and assessment operations in order to place students at the centre of education. Studies have shown that allowing students to create and govern their own personalised learning paths, suiting their individual needs, aspirations and creativity, favours the betterment of their academic performance and success. In fact, by implementing the digital U5.0 approach students take on a more central, proactive and independent role, while teachers and lecturers act as mediators and facilitators of this process. This leaves educators with the responsibility of developing adequate curriculums which rotate around digital skills, green literacy, cognitive and metacognitive abilities, social and emotional skills, as well as practical and physical skills which incorporate the new communication technologies (Eskinat & Teker, 2023; Vieira et al., 2023). These elements of cooperation, inclusivity, and human-centricity are shared principles central to both the U5.0 and Q5.0 approaches.

Conclusions

In this article a state-of-the-art literature review on the potential role of Quality 5.0 in HEIs was conducted, offering an overview of its main characteristics, principles, the potential benefits of its implementation, any possible challenges that may be encountered, and how this approach could be applied in the university environment.

Quality 5.0 is a relatively new theoretical approach which has attracted much attention from academics, as shown by the increase in the number of papers published in the last few years. The literature review exposed various aspects related to Q5.0. Firstly, the concept of quality has undergone various evolutionary stages over time, with the fourth generation of quality being currently in action. In order to favour the transition from Q4.0 to Q5.0, many changes are necessary, thus it is fundamental to comprehend all aspects of this new approach. Q5.0 can be defined as a proactive quality management approach that leverages advanced technologies in order to increase manufacturing efficiency, elevate the quality standards of goods and services, and exceed customer expectations. It places the human being at the centre of the paradigm and the aim is to not only obtain economic sustainability, but also give priority to environmental and social sustainability. In fact, a sustainable organisation must adopt an inward- and outward-mindset in terms of innovation, in order to survive in a fast-changing world. Q5.0 principal values must be internalised in companies and institutions, in order to shift from a consumer satisfaction perspective to a societal satisfaction perspective.

Despite the potential of Q5.0, its future remains uncertain as there are many challenges to overcome and issues to resolve regarding the effectiveness of the implementation process. The main difficulty is that of encouraging society as a whole and organisations to adopt an open mindset that is focused on sustainability and that welcomes change. Implementing this new paradigm would require redefining the organisation's culture, values, mission, and production processes or service offering in order to incorporate environmental stewardship and social responsibility principles. However, these issues could be an opportunity for the academic community to conduct further research and investigations, in order to favour the realisation of Q5.0 at its full potential not only in industry but also in higher education.

The findings of the review highlight many gaps in the literature regarding realistic implementation of the approach and concrete developments of the actual advantages and disadvantages of its adoption in the higher education sector. However, there are many hey elements of the Q5.0 approach that have been considered individually and analysed. In fact, fundamental principles, including proactive approach, continuous improvement, the various aspects of sustainability, external cooperation, inclusivity and human-centricity, have been studied in great detail and attributed to the innovative concept of U5.0. Despite not having been associated directly to Q5.0, it is obvious from the literature review that the principles of U5.0 are strictly tied to those of the fifth generation of quality.

The study is limited by the lack of quantitative data and case studies currently present in the literature, by the databases referred to, and finally by the consultation of papers written only in the English language. Hence, future research is required in order to develop quantitative and practical evidence of the successful application of Q5.0 in the higher education sector and its influence on the overall performance of HEIs. For the time being, the Q5.0 paradigm remains merely a theoretical conception in need of further development.

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Track 9 : Quality Management

On the Interpretation of Total Quality Management. TQM – On its last legs or still going strong?

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Abstract

Interest in quality-related questions increased at the end of the twentieth century, when industrialization deepened and stronger international competition emerged. Quality became a high-priority management area in its own right, partly due to the influence of quality gurus, who represented the influencers of their time. Concepts such as companywide quality control, total quality control, and total quality management (TQM) were introduced, often by consultants, and used as Western approaches that could respond to the quality success attained by Japan following World War II. Quality-related research is ongoing, but a clearer theoretical base is needed to improve our understanding of the existing position of TQM. The purpose of this paper is to explore the content of TQM and the ways in which it can be interpreted in terms of its values, methodologies and tools. A review of the concept of TQM, including its history, was conducted, and the relationships among quality, Quality Management (QM), and TQM were clarified. An interpretation of TQM and the corresponding content is presented in this paper.

Keywords: Total Quality Management, TQM, Quality Management, QM, Emergence Paradigm

Relevant Topic: Role of quality management in industry 5.0

Introduction

Quality has fascinated humans for eons (Juran, 1995). This concept has been in common currency for a long time, but it began to receive extensive discussion and widespread acceptance in the 1980s (Brown, 2013). Interest in quality-related questions increased at the end of the twentieth century, when industrialization deepened and stronger international competition emerged (Brown, 2013; Coleman, 2013). Quality became relevant to many leaders, especially in Japan, because of the damage resulting from World War II and the corresponding need for technological, social, and managerial improvements (Kanji, 1990). This situation progressively gave rise to a trend that has often been identified as ‘the quality revolution’ or ‘the quality movement’ (Dahlgaard-Park, 1999, 2011). One component of this movement consisted of researchers and practitioners seeking to establish a scientific basis for quality management (QM) (Zairi, 2013). In the twentieth century, quality became a high-priority management area, in large part due to the teachings of influential quality gurus (Zairi, 2013). Several concepts, such as companywide quality control, total quality control, and total quality management, were initiated during the later decades of that century. According to Hackman and Wageman (1995), TQM became a social movement when it expanded from its industrial origins to health care, public organizations, nonprofit organizations, and the educational sector. To examine this concept scientifically, one must first define it (Dale et al., 2001). However, such epistemic concerns have rarely been prioritized within the quality movement (Cole and Scott, 2000). One reason for this gap might be the close relationship between quality and practical work (Fisher and Nair, 2009). Another reason pertained to the multitude of national and regional quality awards that emerged due to various stories of success; however, a great deal of research on this phenomenon was also conducted at this time, and several journals with a specific focus on quality were launched (Brown, 2013). These quality award models have also had stronger impacts on practical work with TQM than have articles published in academic journals (Hellsten and Klefsjö, 2000).

Regardless of time and context, quality has been the subject of multiple definitions, which have often been vague, and this notion has come to describe a wide variety of phenomena (Reeves and Bednar, 1994). This complexity and the multiple perspectives on quality that have emerged historically have made theory development in this context difficult (ibid). It is essential to describe various philosophies concerning quality, such as TQM, clearly and to identify the similarities and differences among them for purposes related to scientific progress and university teaching (Fredriksson and Isaksson, 2018). A deep understanding of how central research topics have developed and evolved over time can promote development in the field of science and simultaneously ensure that practices remain up to date (Carnerud and Bäckström, 2021). TQM-related issues such as implementation, performance and culture received increased interest in the late 1980s and 1990s, which peaked in approximately 1995. Subsequently, studies in the area slowly decreased (ibid). The main reason for this decrease was probably the fact that the organizational changes initiated during this time did not result in the anticipated successes. Some reasons for this failure, in turn, were that the TQM concept was developed based on vague definitions such as “a culture which …”, “a strategy for …”, or “a way to…” (Bergman et al., 2022, p. 53) and that difficulties pertaining to practical application were overlooked (ibid). One problem in this context is that a great deal of the literature on TQM was written by consultants, and the issue of what TQM “really is” has largely not been a main area of focus for academic researchers (Hellsten and Klefsjö, 2000).

Furthermore, in an attempt to clarify the existing position of TQM, van Kemenade and Hardjono (2019) declared that a new paradigm is required to explain current directions and future needs in this field. These authors called this paradigm the emergence paradigm and argued that systems thinking must be incorporated into QM theory and practice as well as into leadership training (ibid). Deming's (1993) perspective on leadership is based on what he calls 'profound knowledge', which is now often referred to as 'improvement knowledge' (Bergman et al., 2022). This notion includes four elements: knowledge about variation, psychology, theory of knowledge, and appreciation of a system (ibid). As early as 30 years ago, Hackman and Wageman (1995) claimed that the diversification of work has been accomplished under the name 'total quality' and that it has become unclear whether TQM still has an identifiable theoretical core. Quality-related research remains ongoing, but researchers such as Dahlgaard-Park et al. (2018) have argued that a clearer theoretical base is needed to improve our understanding of the existing position of TQM. This claim is in line with Hellsten and Klefsjö (2000), who reported that only limited definitions of what TQM truly is have been developed, and many unclear descriptions of this notion have been presented. Additionally, QM and TQM are sometimes treated as identical, which exacerbates such confusion. Thus, the purpose of this paper is to explore the content of TQM and the ways in which it can be interpreted in terms of its values, methodologies and tools.

Methods

A review of the concept of TQM, including its history, was conducted. Since 1990, two of the authors have engaged in continuous discussion regarding and examination of what TQM is and should be, and in the first edition of the book, Quality: From Customer Needs to Customer Satisfaction (Bergman and Klefsjö, 1991), they presented six values as part of 'the cornerstone model of TQM'. The version of the values presented in the latest edition of this book as well as the version presented in this paper were developed based on in-depth discussions among the four authors of this paper. TQM, which represents a system featuring various values, methodologies, and tools, was developed and discussed by Hellsten and Klefsjö (2000) and has since been accepted and included in the book. Additionally, the content of TQM was examined by exploring previous research and the descriptions provided in the literature.

The relationships among quality, QM and TQM

TQM and its relationships to QM and the concept of quality can be viewed in many ways. Before we can explore the content of TQM and the ways in which it can be interpreted, we must clarify these relationships. We identify quality management (QM) as the scientific subject or the field of science exploring quality-related concerns, in which context the concept of quality is foundational. It corresponds to other fields of science such as, for example, logistics management and financial management. TQM is, on our interpretation, a management system within QM that aims to improve quality. This relationship is illustrated in Figure 1.

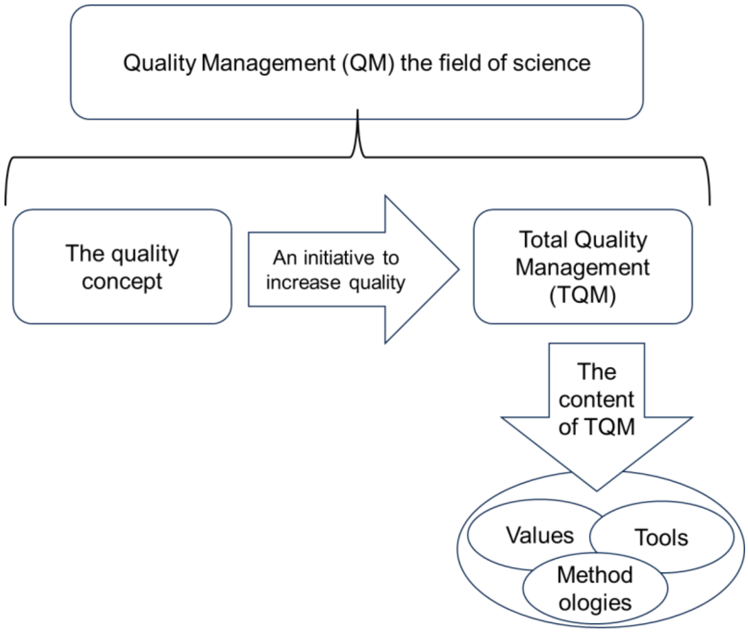

Figure 1. *The relationships among quality, QM and TQM*

The history and development of TQM

It is not known when or by whom the phrase total quality management (TQM) was created (Bergman et al., 2022). Some have claimed that this term was established in 1984 when NALC (Naval Aviation Logistics Command) was on the verge of applying an approach to quality improvement based on the ideas in the book 'What is Total Quality Control' by Ishikawa, (1985) but wanted to avoid using the term 'control' (Bergman et al., 2022). Nancy Warren is said to have proposed the term 'management' as a substitute. "Deming is talking about management, why don't we call it Total Quality Management?" (ibid). Some have argued that the origin of the term is a mistranslation from Japanese; see Xu (1994). In the Japanese language, there is no difference in meaning between the terms for 'control' and 'management'. Park Dahlgaard et al. (2001) suggested that the term may have been coined by Armand Feigenbaum. William Golomski reported that Koji Kobayashi, a former executive at NEC (Nippon Electric Company), was the first to use the term total quality management in the acceptance speech he delivered when he received the Deming Prize for Individuals in 1974.

Martínez-Lorente et al. (1998) reported that the phrase TQM became popular in the mid-1980s. According to Lo and Chai (2012), later developments in TQM resulted in a shift towards the provision of quality service and the measurement of the success of this process. Dahlgaard-Park et al. (2013) claimed that the total number of articles on the topic of TQM has been decreasing since it reached a peak in 1995. On the other hand, Bajaj et al. (2018) conducted a literature review of 102 research articles published between 1995 and 2015, which revealed that research on TQM has increased nearly threefold over the past decade. In contrast to Bajaj et al. (2018) and in line with Dahlgaard-Park et al. (2013), Carnerud and Bäckström (2021) found that the mid-1980s was the starting point of research on TQM, which exhibited an intense increase and reached a peak in the mid-1990s. Subsequently, the topic of TQM entered a 5-year recession, which was followed by a 5-year revival.

Beginning in the new millennium, publications on TQM have exhibited a decreasing trend (ibid). The fourth TQM paradigm is obvious from approximately 2005, in line with Weckenmann et al. (2015). Additionally, the review of research on TQM practices and their impact conducted by Bajaj et al. (2018) revealed that various scholars have labelled and defined practices in their own ways.

How should TQM be defined?

Hackman and Wageman (1995) claimed that TQM is rooted in four linked assumptions "about quality, people, organizations, and the role of senior management" (p. 310), which enable this notion to realize the associated normative outcomes. According to Hellsten and Klefsjö (2000), TQM is a management system that consists of three related components: values, methodologies, and tools. Dahlgaard-Park et al. (2018) emphasized the facts that TQM is characterized by management theories related to customer orientation and long-term thinking and that the core values of TQM were developed based on the input of numerous studies of organizational practices (ibid). These authors describe TQM as based on a foundation of "core values & concepts, components and focal points/main thoughts" (p. 1119). It could be argued that definitions of TQM should be based on a system view that keeps customers in focus, thereby acknowledging the importance of a preventive and proactive culture, focusing on continuous improvements through strong employee engagement and providing support for efforts to achieve and maintain such a culture through various methodologies and tools (Bergman et al., 2022). To ensure that such a culture can be successfully established and enhanced, organizations must have good knowledge of different areas, for example, variation, psychology, theory of knowledge, and system thinking (ibid). This context was referred to as the knowledge system or profound knowledge by Deming (1993). Our view of TQM is that it is a management system that consists of various values, methodologies, and tools that are used in "an endless endeavour to fulfil, and preferably exceed, customer needs and expectations in a cost-effective way by continuous improvement work, to which all involved are committed, focusing on the processes in the organization and its customers" (Bergman et al., 2022, p. 54). From this perspective, TQM is viewed as a way of proactively searching for ways to delight customers, i.e., a "holistic concept, where values, methodologies, and tools are combined to attain ever higher customer satisfaction with less and less resource consumption" (ibid, p 59). The corresponding values are strengthened through the use of various methodologies and tools to form a whole. "This whole can be described as a management system. This means that we both have a system consisting of parts working together towards a common goal and that it is a system to support management with quality improvements. The methodologies and tools are needed to support the shared values of the people in the organization, acting as a foundation for the principles of the management system and making them part of the culture" (p. 500).

The content of TQM in terms of its values

TQM is occasionally described using quality award criteria, such as those pertaining to the Malcolm Baldrige National Quality Award or the European Quality Award (Hellsten and Klefsjö, 2000). However, the relationship between such award models and TQM is unclear (ibid). These quality award models themselves have been described in terms of different core values and include different numbers of core values, thus exacerbating this confusion (ibid). Hackman and Wageman (1995) added four change principles to the content of TQM, which they viewed as influencing organizational interventions with the goal of improving quality (ibid). These principles are as follows: 'focus on work processes', 'analysis of variability', 'management by fact' and 'learning and continuous improvement' (ibid). Different authors have used various terms to refer to the content of TQM, for example, 'factors', 'key elements', 'values', 'cornerstones', and 'principles' (Foster, 2004; Dale, 2003; Sila and Ebrahimpour, 2002; Lagrosen, 2006). Various literature reviews conducted by Hellsten (1997), Sila and Ebrahimpour (2002), Motwani (2001), and Lagrosen (2006) have all identified similar values, such as 'Focus on Customers', 'Continuous Improvement', 'Focus on Processes', 'Fact-Based Decisions', 'Everybody's Commitment' and 'Management Commitment'. Dahlgaard-Park et al. (2018) described eight core values of TQM in a more descriptive form: 'Top management responsibility', 'Employees have a strategic approach for continuous improvement', 'Customer-need orientation', 'Produce quality work from the first time', 'Encourage mutual respect, communication & teamwork', 'Behaviour of leaders and employees need to change at the beginning of the implementation of TQM core values', 'Cooperation with supplier', and 'Concern for social and environmental context' (ibid). These values are similar to those described above, with the exception of the final two values, which pertain to suppliers and social and environmental contexts; however, these thoughts are embedded in, for example, the value 'focus on customers'. Descriptions of the core values of TQM have differed among various authors (Hellsten and Klefsjö, 2000). Bergman et al. (2022) expressed the values of TQM in an active way that emphasized "the importance of relentless, systematic, and consistent work to create and develop a strong culture" (p. 73):

- focus on customers,
- develop committed leadership,
- let everybody take active part,
- improve continuously,
- focus on processes, and
- base decisions on facts. (ibid)

Bergman et al. (2022) claim that these six values are all linked to each other and must be viewed as a whole; see Figure 2. Together, these values create something that is more than the sum of its individual parts. These six values are described in further detail below.

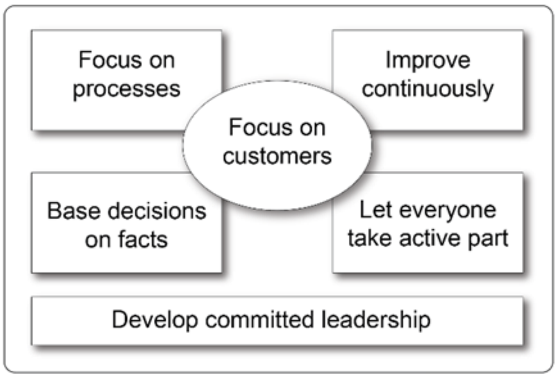

Figure 2. *The values that serve as the basis of total quality management. This representation has been referred to as the Cornerstone Model, (Bergman et al. 2022, page 60).*

Focus on customers entails "1) finding out who the organization's customers are, now and in the future, 2) finding out the needs and expectations of these customers, and 3) making sure to meet, and preferably exceed, customer needs and expectations" (Bergman et al., 2022, p. 35). It is essential to reflect on the needs and expectations of both external and internal customers. The value, **base decisions on facts** focuses on the attempt to make well-founded decisions and "not let random factors, bias, or prejudice play a decisive role" (ibid, p. 37). Through a **focus on processes,** we can improve how we work instead of focusing solely on the results. "To facilitate learning, we can divide the study into several parts, each focusing on a sub-process that contains fewer activities. By focusing on improving our processes, we can work in a better, smarter, and more cost-effective way, which can create products with a higher ratio of customer value per total cost" (ibid, p. 65). Continuous quality improvement is crucial for all organizations that want to survive, which is why **improve continuously** is a value associated with TQM; this value focuses on both small and large systematic improvements. **Let everyone take active part** highlights the task of guaranteeing that all employees can be committed to and actively participate in decision-making and improvement efforts. The value known as **develop committed leadership** assumes a management style that is based on "visibility, clarity, and personal commitment" (ibid, p. 72).

The content of TQM in terms of its methodologies and tools

The TQM concept does not merely comprise of the values, the values are strengthened by methodologies and tools to form a whole (Bergman et al. 2022). To continuously uphold the values appropriate methodologies has to be used to let the values permeate activities in the organization, and thereby making it a part of the corporate culture. There is also a need for hands-on tools to systematize and facilitate the work in the different methodologies and make them effective (ibid).

Most methodologies are not defined as there are variations that could and should be used, depending on which values are to be strengthened. There are several other methodologies and tools than those shown in Figure 3, it is only examples. Different methodologies and tools are needed to support a given set of values, and one methodology may strengthen various values.

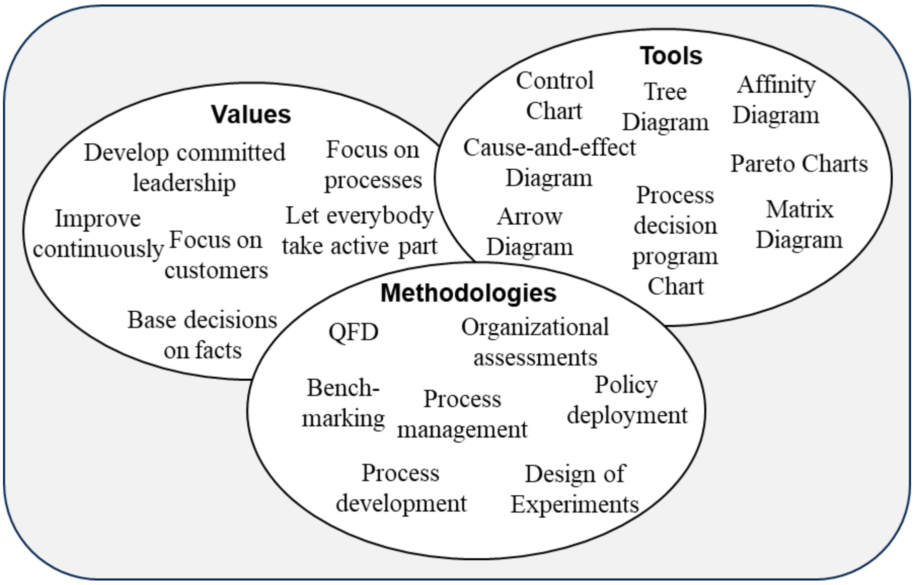

Figure 3. *Total Quality Management seen as a system made up of values, methodologies, and tools. The methodologies and tools in the figure are just examples, not a complete list. Also, as time passes, they tend to change. (After Hellsten & Klefsjö, 2000)*

A matter worth noting is that the management system, TQM, is an open system i.e., it is constantly influenced by and interacting with the surrounding world. For example, values obtain new meanings as time passes and new methodologies and tools suitable for the TQM system appear in other fields and sciences (ibid).

Conclusions

Many scholars have called for a stronger theoretical foundation for defining the concept of TQM. We can conclude that TQM has been explored for theoretical and academic purposes, although the descriptions of practical ways of working with TQM remain diverse. TQM is and has been defined and described; the problem is that this interpretation has been defined in many ways, and it seems to be difficult to reach a common agreement regarding content and the way in which it is interpreted in terms of its values, methodologies, and tools. We conclude that TQM should be interpreted as a whole, i.e., as a management system that consists of various values, methodologies, and tools. This management system is an endless endeavour to fulfil, and preferably exceed, customer needs and expectations in a cost-effective way by continuous improvement work, to which all involved are committed, focusing on the processes in the organization and its customers. TQM, not least because of its holistic view, is relevant in all areas of society, both private and public sector. Our conclusions are also that TQM is one of several quality initiatives within QM and that TQM is constantly developing and is therefore still going strong.

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Action Certainty in Complaints HandlingDefining Action Certainty in Complaint Handling. A Comprehensive Approach for Enhancing Consistency and Decision-Making

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Abstract

The concept of action certainty is critical to professionalism and productivity in the workplace. However, the term is rarely used in engineering disciplines and lacks a consistent definition. The need to address this topic is particularly evident in manufacturing companies, where dealing with complaints can be challenging. Especially when the distinction between different legal bases and responsibilities is necessary. Therefore, this paper examines existing definitions of action certainty and derives criteria necessary for definition in engineering terms. It also presents a specific definition of action certainty in complaint handling and suggests factors and solutions to improve safety. Based on these general criteria, a definition of safety of action in complaint processing is presented as well as factors and solution approaches that can enable an improvement regarding such certainty. It presents one possible solution to the posed problems by developing an algorithm to automatically identify different failure criteria based on customer complaints from the product usage phase.

Keywords: Action Certainty, Complaint Management, Skill Development

Introduction

The world of work is in constant change (Hoonakker & Korunka, 2014; Korunka & Kubicek, 2017). As classic work structures and hierarchies are increasingly being replaced by new models and methods, new challenges and problems constantly arise too (Dean, 2007; Hekkala et al., 2017; Schwer & Hitz, 2018). One challenge that the modern workplace is facing is how to motivate employees and grant them greater autonomy and responsibility. This shift aims to eliminate outdated control systems and prevent issues such as micromanaging. (Almeida, 2017; Hekkala et al., 2017; Pussella & Bandara, 2020). The increasing complexity of products and supply chains often poses a challenge to this fostering of independence and sense of responsibility, especially in manufacturing companies (ElMaraghy et al., 2012; Myrodia & Hvam, 2015; Schuh et al., 2017). Particularly when dealing with customer complaints arising from the product usage phase, it can be a challenge for the employees responsible to gain an overview of the situation and possible consequences. To counter this problem, this paper looks at how employees can be given greater confidence in handling complaints – we call it “Action Certainty”. However, there is no fixed definition of this term and what it signifies in the international arena, particularly in the engineering disciplines. It is therefore first necessary to clarify what is understood by confidence in action, which aspects influence it and which options can be used to strengthen employees' confidence in action in general and in the specific context of complaints handling.

In order to achieve this objective, Chapter II initially identifies the challenges and issues associated with the handling of complaints, with a particular focus on the manufacturing industry. In order to facilitate the development of solutions to the identified problems, Chapter III presents a definition for the term 'action certainty'. This is achieved by deriving key criteria from previous definitions of action certainty or related terms. In Chapter IV, the derived criteria are integrated into a separate definition of action certainty, specifically regarding the handling of customer complaints. The chapter also deals with the solution approach of the AlGeWert research project, which aims to support employees in complaints processing with the help of an algorithm for handling customer complaints. Chapter V draws a conclusion and looks at the research outlook, which will be dealt with in the further course of the project.

Challenges in Complaints Processing

Prior to addressing the question of how the work of complaints handling can be improved and supported, it is first necessary to identify the prevailing challenges in this area. To this end, a literature review identified various core challenges that arise in connection with complaints handling.

Helmy et al. (2023) look at the importance of efficient complaints management from the point of view of sustainability for companies. They find that the fast and effective processing of complaints has proven to be an increasing challenge in recent years. Filip (2013) assesses the importance of complaint management in terms of the added value that complaints can provide for the improvement of services and products. She emphasizes that a particular lack of standardized processes can lead to inadequate complaint management. Hake et al. (2021) look at complaint management in the specific context of the medical technology industry and examine the 8D report – a widely used method for handling complaints – for automation potential. The authors also emphasize the need for standardized, ideally automated, processes to improve the efficiency and accuracy of complaint handling.

Muskan,Ravi Singh Rana,Savita (2023) emphasize the need for a structured complaints management system in order to gain an appropriate perspective for the effective handling of such complaints. They emphasize the need to systematically extract and store information provided by complaints in order to quickly find appropriate solutions. Haghi et al. (2018) examine various challenges from the perspective of German companies of different sizes. They find that a uniform database and the effective extraction of relevant data are the main challenges for companies. Effey and Schmitt (2012) highlight the challenges of complaints processing from both a marketing and quality management perspective. They highlight the need to successfully prioritize incoming customer complaints as one of the main challenges. Among the problems to be overcome are the differentiation between safety-related and monetary risks.

The results of the literature research presented above reveal many obstacles that can arise in the processing of complaints and complaint management on the company side. For example, standardized processes must be established to ensure a rapid response to and processing of incoming customer complaints. Further challenges arise in the extraction of relevant information from customer complaint texts. In addition, the correct prioritization of complaints, especially regarding the legal framework and compliance with various regulations.

The aspects mentioned above are therefore all currently relevant obstacles that employees encounter in complaints processing and that influence action certainty. To determine how this certainty can be improved in complaints handling, the following two chapters will now deal with the main aspect of this paper - the definition and criteria for improving action certainty.

Comparison on Definitions of Action Certainty and Derivation of General Criteria

In order to develop our own definition of action certainty, this chapter presents a number of existing definitions of the term. As previously explained in the introduction, there are few meaningful descriptions of what action certainty entails in previous research work in engineering disciplines. For this reason, definitions from other disciplines are presented and examined for generally valid interfaces that characterise action certainty. Consequently, following the respective presentation of the different definitions, general criteria are derived with the intention of narrowing down what is understood by action certainty and how it is to be assessed. As there is no concrete definition in the English language of what the authors understand by action certainty – not even in specialist areas outside engineering – definitions of various terms are compared that have a similar statement of what we want to describe with action certainty.

Rau (1996) uses the term of "human reliability" in her work. She interprets the phrase in such way that people (in this case, employees) can act correctly in complex situations. This correct action or the making of this correct decision must take place within a specified period of time. It is clear from these descriptions that, for there to be certainty of action, it must first be specified what can be considered "correct" behavior in the respective situation. The requirements for the tasks and expectations of the employees must therefore be clearly formulated so that the extent to which they (can) meet these requirements despite the complexity and novelty of a situation can be checked accordingly.

Pomeroy and Oliver (2021) introduce the term "action confidence" to describe the certainty and courage to act in uncertain situations, even if you might have hesitated beforehand. It is clear from the definition that action confidence is about overcoming fears and being able to better understand the actual effects of one's own actions. Confident behavior is not associated with performing well. It is about acting with the knowledge you have. The key message that can be derived from this description is that action certainty is not contingent on the individual competencies of individual employees. Rather, it is about creating an environment and establishing methods of work that facilitate the ability of employees to discern the appropriate course of action at the opportune moment and to identify the information they require to successfully complete complex and challenging tasks.

Another term that is used in various publications about teaching and educational science is action competence. Although the application of the term differs thematically according to the area under consideration, there are some aspects that can certainly be included in the definition of action certainty that we are looking for. Sass et al. (2020) emphasize the distinction between action competence and teaching approaches. They describe it as the interplay of the necessary knowledge and awareness, the will to contribute to a cause and the self-confidence that one's own actions will help bring about change. Although they use this description in connection with environmental change and in relation to social coexistence. However, the core aspects can also be applied to the subject of this paper. Namely, that the goal is to be a "qualified participant" who has the necessary knowledge to correctly assess a situation and contribute to its solution.

According to the definitions presented above, various characteristics or criteria can be derived that are intended to represent what is understood as action certainty in the context of this paper. The three main points are as follows:

1. It must be clearly defined which behavior is considered correct for the situation in question.
2. Employees must be aware of the correct behavior in the regarded task.
3. Employees must be able to assess the situation themselves and select the correct behavior to gain control over the situation.

Before diving further into the transfer of the overall definition of action certainty into the domain of complaint management, an important distinction must first be made: The action certainty described here stands between the different aspects of employee competences, but it not to be used synonymously to the term. Employee skills can be divided into professional, methodical and personal competencies, further abbreviated as Knowledge, Know-How and Behavior (Russo, 2016). These include strategic working specialist knowledge, methods, and soft skills such as negotiation or moderation skills. Self- confident behavior is also one of a person's personal skills. Although these aspects border on the definition of action certainty, they cannot be equated with it, as the focus is on different points. Action

Certainty is not about methods that give employees the necessary psychological support to behave confidently in their work. Nor is it about ensuring that they have the necessary basic knowledge to carry out their work conscientiously. Rather, the objective is more about which "technical" solutions can be used to support employees in performing certain tasks "correctly" and which aspects need to be considered. The importance and interaction of employees and the company in this approach is also important. While the employee is largely responsible for the development of their own competencies, action certainty in the sense of our definition is something that can be influenced and ensured more by external functions. Companies and employers therefore have a greater influence on ensuring the action certainty of their employees through suitable documentation, processes and tools. A pictorial distinction between Employee Competences and Action Certainty is shown in Figure 1.

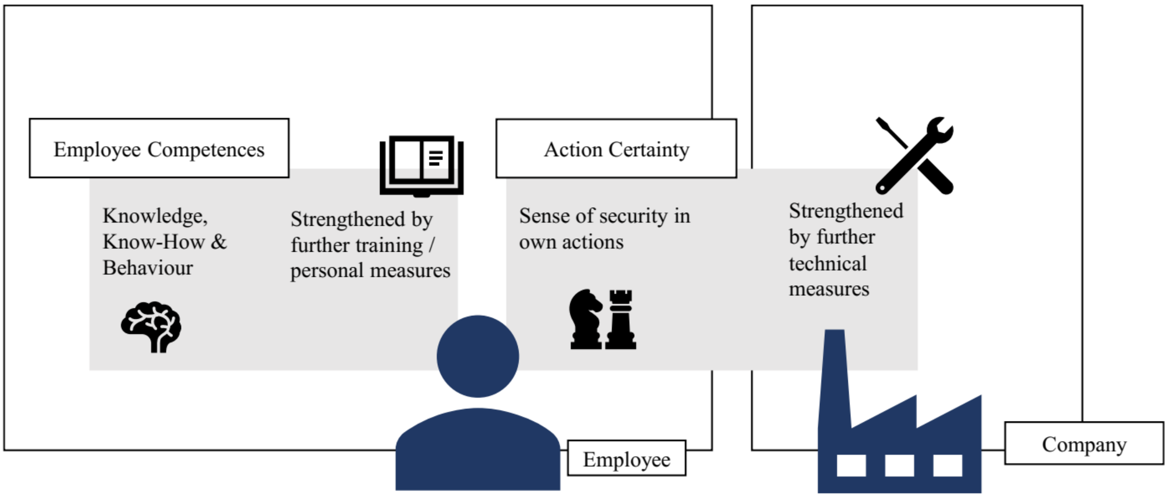

Figure 1: Differentiation of action certainty and competence

As a second delamination, the measurability of the presented term needs to be determined. As mentioned above, three aspects to define action certainty were derived from the research. Based on the previous research, these three aspects are seen as decisive for the assessment of action certainty. As no quantitative model was developed during this study, it is initially assumed that action certainty can at least be assessed qualitatively. However, a concrete measurement based on a scale, or comparative values is not yet possible. The definition of the specific criteria for the use case presented thus represents an initial check of the transferability of the definition developed. Furthermore, the evaluability of action certainty should also be assessed. For this purpose, a specially developed algorithm solution will then be examined to determine the extent to which it fulfills the criteria previously set for action certainty. These two aspects are discussed in the following chapter.

Definition of certainty of action in the context of consideration and presentation of a proposed solution

The general criteria derived in the previous chapter for evaluating Action Certainty are now to be transferred to a concrete consideration of the processing of complaints. To this end, the three main aspects are first transferred to the specific case of complaint handling in order to determine the corresponding criteria for solution approaches. Based on these criteria, a possible solution approach is presented that can support employees in complaint processing with an algorithm-based solution.

The specific criteria for action certainty for action certainty in complaints processing are to be formulated based on the in-depth literature research regarding two specific problems. Firstly, the uncertainty regarding the legal framework and consequences should be resolved. This means that the employees who receive and process the incoming complaint should quickly gain clarity about the legal situation in which the complaint situation is to be classified and what consequences or further action needs to be taken. To this end, it is also essential that it is clear to what extent responsibilities are regulated when processing complaints and which information chain must be followed should a case arise, that could be based on legal liability principles.

The following criteria result from the three main points:

1. Clear categorizations and delimitations must be established that clearly categorize the present complaint into the various (legally) relevant aspects.
2. The employees must, after identification of the case at hand, know a clear assignment of further action steps and all responsibilities of parties that may be involved.
3. The information needed to perform the right actions must always be clearly accessible to employees.

As indicated in the preceding chapter, a potential solution strategy will now be presented in the context of this definition with a view to enhancing the certainty of action in complaints processing, specifically regarding the three factors outlined above. One potential avenue for fulfilling the criteria described in terms of ensuring and improving the reliability of action is the possibility of utilizing an algorithm- supported interface for complaints processing. The deployment of automatic text recognition and processing should facilitate the further processing of complaints by employees. As part of the AlGeWert project, a corresponding application was developed to support users in processing customer complaints. The result is the so-called AlGeWert algorithm (AGWA for short), which will be presented shortly.

The main task of the AGWA is to extract information from written customer complaints to determine the risk of a possible liability claim on the part of the customer. For this purpose, a tool was written using Python that links to an SQL database containing information about customers, orders and products. The user then has the option of having the AGWA check complaint texts via a graphical user interface.

Customer complaints are checked in accordance with the basic German legal principles, which may apply depending on the circumstances in which the error occurred and the type of error. These three legal bases are as follows:

1. warranty law - concerns the liability of sellers for the sale of knowingly defective products.
2. producer liability according to the German Civil Code (BGB) - Covers the liability of manufacturers and suppliers for the marketing of defective products that can be knowingly prevented.
3. product liability law - consideration of the liability of manufacturers for placing defective products on the market in accordance with the European Product Liability Directive

An incoming complaint can be entered in a text field (which currently still has to be done manually) and the text can then be processed by the algorithm. The algorithm extracts information about the customer and order, if available, from the text and compares it with the database. If the associated order can be identified, the origin of the customer and the date of purchase are compared. These two criteria already represent objective differentiating factors for the various legal cases. The customer's error description is then analyzed using an NLP model. For this purpose, the pre-trained SpaCy pipeline is used, which was manually trained for the different error categories based on Amazon complaints of various household products. After the type of defect underlying the complaint has been assessed, the algorithm uses a stored decision scheme to make a statement as to whether there is a risk of a liability case under German law. If such a liability risk has been identified, the user is notified, provided with initial instructions for action and has the opportunity to view information about suppliers and other parties involved in the value chain. A schematic diagram of this procedure is shown in Figure 2.

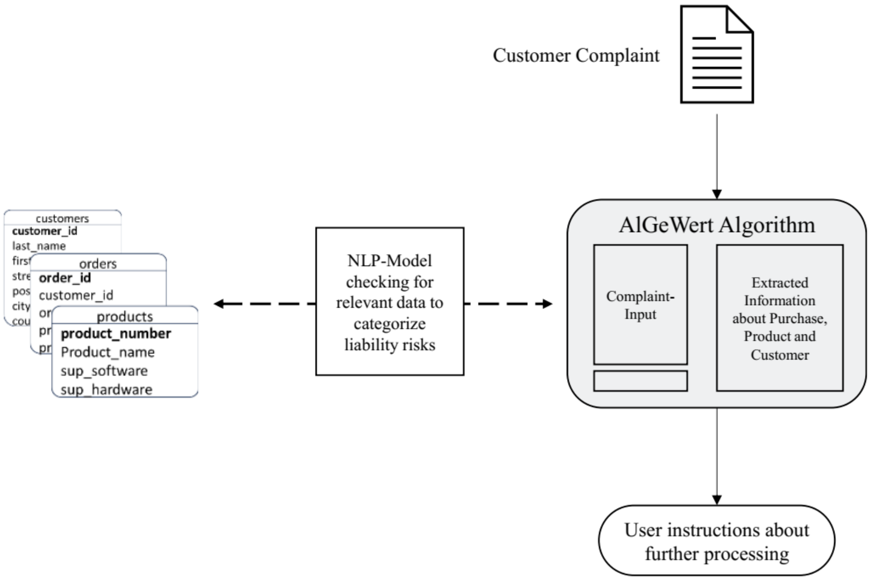

Figure 2: Scheme of the AlGeWert Algorithm

Both the product and customer information as well as the information on suppliers of the respective products are taken from the linked database. Meticulous database maintenance and the upkeeping of the information contained therein are therefore essential for the accuracy of the information provided by AGWA.

As can be seen from the description above, the AGWA already offers a way of automatically assessing complaints and providing the user with specific information. However, it is now necessary to determine the extent to which the use of this tool also has a positive influence on the previously specified action certainty criteria. To assess the different action certainty criteria, the three aspects are considered as applicable requirements for the AGWA and checked for their degree of fulfillment.

Regarding the clear categorization and delimitation of legal and other important factors, the criterion is almost completely fulfilled. The AGWA can evaluate the information provided to it and make a clear statement about the risk of a liability event occurring under German law. The second criterion, which considers clear instructions to employees, can be regarded as fully met. The AGWA clearly guides the users using the tool and issues clear user instructions to the users when assessing the complaint. This not only includes a risk assessment and any necessary forwarding to the relevant (legal) departments. Users are also provided with information about any suppliers involved. The last criterion states that all relevant information should always be accessible to employees. This point is assessed as partially fulfilled. The reason for this is that the algorithm accompanies all processes with information. However, the underlying decision paths are not displayed at all points and do not allow complete insight into all underlying decision-making structures, which is why this point is not considered to be fully met. Despite this, the AGWA is largely able to fulfill the criteria for ensuring certainty of action. An assessment of all three characteristics is summarized in Table 1.

Table 1: Degree of fulfillment of the criteria for Action Certainty by the AGWA

1	Clear categorizations and delimitations must be established that clearly categorize the present complaint into the various (legally) relevant aspects.	◕
2	The employees must, after identification of the case at hand, know a clear assignment of further action steps and all responsibilities of parties that may be involved.	●
3	The information needed to perform the right actions must always be clearly accessible to employees.	◑

Two things can therefore be seen from the assessment and the overview in the table. Firstly, it is possible to evaluate the definition-determining categories by identifying the degree of fulfillment. This makes it easy to check the example presented to see to what extent employees' confidence in their actions can be promoted. On the other hand, it can be seen from the example that the tool already offers a way of ensuring or at least positively influencing safety of action. However, there is still room for improvement.

To place these results once again in the context of the task and the objective of the work, the following chapter will critically discuss the results.

Discussion

After defining the term action certainty in the previous chapters, both in a general context and in a context specific to complaints handling, the authors have presented a possible proposal to improve the action certainty of employees in complaints management. The results presented here will now be put into context and discussed. Based on a literature review, the authors developed their own definition of the term action certainty. This proved to be relevant for the authors to evaluate the success of the AlGeWert project in an appropriate context. A suitable definition consisting of three relevant criteria could be developed for the area of consideration presented in this paper. These criteria, in the form of requirements, can be evaluated and assessed. However, it should be emphasized that the definition of action certainty, as well as the differentiation from other relevant terms, is initially only theoretical. For this distinction to be established and used in the engineering field, it seems essential to further develop the definition by observing real scenarios. Both personal surveys and experiments with employees with different competence profiles will be relevant in the future, especially to differentiate the concept of competence and to prove that action certainty can be improved by using suitable tools.

Considering the current context of research and the theoretical definition of action certainty developed here, the AlGeWert algorithm presented here already offers a solution to support action certainty in complaint processing. It does this by providing users with a clear procedure and unambiguous instructions for action as well as relevant information for further processing. However, it does not yet fully cover all the problem areas identified in the literature research. Complaints can already be easily categorized based on relevant criteria. The prioritization of incoming customer complaints is also considerably improved by the NLP-supported error assessment. This means that the aspect of quickly identifying legal risks and liability risks can be seen as improved. For an all-encompassing complaint management solution, however, the AGWA should rather be seen as an element that should be supplemented by an overall framework model and embedded in a more comprehensive software system.

Conclusion and Outlook

To improve employees' sense of security when dealing with complaints, the term Action Certainty was introduced in this thesis. As there is no clear definition of the term in the engineering environment, a definition was developed based on a literature search. For this purpose, definitions of various related terms were checked for their applicability to the scenario under consideration and criteria for an own action certainty definition were derived from the definitions. The resulting general criteria were then adapted to the specific example of complaint processing and compared with a possible solution for improving action certainty. The AGWA is a tool that is specifically designed to support users in considering the liability risks that can arise for a company because of defective products. To this end, NLP can be used to read out customer complaints and check for the occurrence criteria of various liability cases. Although the AGWA initially only covers one aspect of complaint processing, it already shows that the established criteria for action certainty can have a positive influence. Putting the tool in a more holistic context and creating a more comprehensive solution that guarantees action certainty in the processing of complaints should be part of future research work. However, it is equally important to make the theoretical definition of action certainty verifiable in practice. It is particularly important to conduct further research to establish and use the term to differentiate it from a person's methodological and personal skills.

Acknowledgement

The authors appreciate the German Research Foundation (DFG) for the support of the Project "AlGeWert" (funding code: SCHL 2225/7-1).

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Mission statements as an indicator of the strategic business approach: analysis and perspectives of the manufacturing sector in Barranquilla

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Abstract

This study analyses the strategic approach of small and medium-sized companies in the manufacturing sector of Barranquilla by studying the issues that appear in the formulation of their mission statements, with the purpose of understanding the dynamics of business development based on the importance of these as indicators of strategy and organizational identity. First, a database of 22,057 companies with current registration in the Barranquilla Chamber of Commerce in 2023 was downloaded, extracting data from the manufacturing sector, corresponding to 8.64% of the total companies, and then a sample of 205 small and medium-sized organizations that have a web presence and business mission available to the public. The processing and analysis of these missions allowed the identification of the main keywords that revealed the existence of six (6) approaches as the axis of the business development strategy in the sector: competitiveness focused on quality, innovation, and technological development; customer orientation; emphasis on social and environmental responsibility; focus on operational efficiency and process optimization; and human resource development. Finally, the missions were evaluated qualitatively with the purpose of determining their depth and coherence in relation to the strategy, approach, values, and behaviour, finding that these are, in general, shallow, and despite allowing the identification of a sectoral strategic approach, at the individual do not adequately reflect a profile that allows guiding the definition of the identity and the business development strategy.

Keywords: Strategy, Sustainability, Quality, SMEs

Relevant Topic: Quality, innovation and corporate social responsibility

Introduction

Mission statements are more than just declarations of intent (Pearce & David, 1987); they present a company's purpose, values, and strategic direction, providing insights into how businesses perceive their market role, approach competition, and commit to stakeholders (Leuthesser & Kohli, 1997). In the manufacturing sector, where innovation, quality, and sustainability are crucial, mission statements can reveal significant information about a company's priorities and alignment with industry trends (Caferra, y otros, 2023).

The articulation of a company's mission statement is a key element in defining its strategic approach and organizational identity (Abdullah, Anumudu, & Hassan, 2022). This research examines the strategic business approaches of small and medium-sized enterprises (SMEs) in the manufacturing sector of Barranquilla, Colombia, through the analysis of their mission statements. While this study focuses on a specific region, its findings have broader implications for understanding how mission statements can serve as indicators of strategic orientation and business identity, particularly in relation to innovation, quality, and sustainability (Fitzsimmons, Sunny, & Heffron, 2022).

This study is significant because it offers a comprehensive analysis of the manufacturing sector in Barranquilla and provides a methodological framework that can be applied to other sectors and regions. By examining a dataset of 22,057 companies and focusing on a sample of 205 SMEs with publicly available mission statements, this research identifies key strategic themes prevalent in the sector. These themes include competitiveness focused on quality; innovation and technological development; customer orientation; social and environmental responsibility; operational efficiency and process optimization; and human resource development.

The findings contribute to the existing knowledge in strategic management by highlighting the role of mission statements as strategic tools. The identification of six distinct strategic approaches within the sector demonstrates the diversity of business strategies among SMEs. Additionally, the application of correspondence analysis provides a detailed understanding of how these strategies manifest across different subsectors, revealing commonalities and unique strategic orientations.

For practitioners and researchers focused on innovation, quality, and sustainability, this study offers valuable insights into how these elements are reflected in the mission statements of manufacturing SMEs. The qualitative evaluation of the mission statements shows that many lack the depth needed to effectively guide the identity and development strategy of individual businesses. This finding emphasizes the importance of crafting mission statements that articulate a company’s strategic intent and reflect its commitment to innovation, quality, and sustainability.

Methods

Data collection: This study employed a quantitative approach to analyse the mission statements of small and medium-sized enterprises (SMEs) in the manufacturing sector of Barranquilla, Colombia. The data collection process involved several steps:

- Database Compilation: A comprehensive database of 22,057 companies with current registrations in the Barranquilla Chamber of Commerce as of 2023 was compiled. This database included various sectors of the economy.

- Sector Filtering: From the total database, companies belonging to the manufacturing sector were filtered out. This filtering process resulted in a subset of 1,905 companies, representing 8.64% of the total companies.

- Sample Selection: To ensure the relevance and availability of data, a sample of 205 SMEs with a web presence and publicly accessible mission statements was selected.

Data processing and analysis: Text Extraction: The mission statements of the selected companies were extracted from their websites. This extraction was done manually to ensure accuracy and completeness.

- Keyword Analysis: The extracted mission statements were processed with Microsoft Excel and Phyton to identify recurring keywords and themes. This analysis aimed to reveal the strategic orientations present within the mission statements.

Correspondence Analysis: A correspondence analysis was applied to detect groups of companies with similar strategic approaches. This statistical method helped in understanding the distribution and relationships between different strategic orientations across the subsectors.

Results and Discussion

Descriptive analysis of the companies

In 2023, the business sector in the city of Barranquilla comprised a total of 75,634 registered companies, established between the years 1931 and 2023. Of these, 42% were commercial establishments, 24% were sole proprietorships, and 32% were corporations. Within the corporate group, 3,492 companies, representing 14%, belonged to the manufacturing sector. Among these manufacturing organizations, 1,905 were classified as small and medium-sized enterprises (SMEs).

Regarding its existence, the first company in this sector registered corresponds to 1943, although 80% of the existing companies were created in the last 10 years, which shows a recent surge in the establishment of manufacturing business in the city as evidenced in Figure 1.

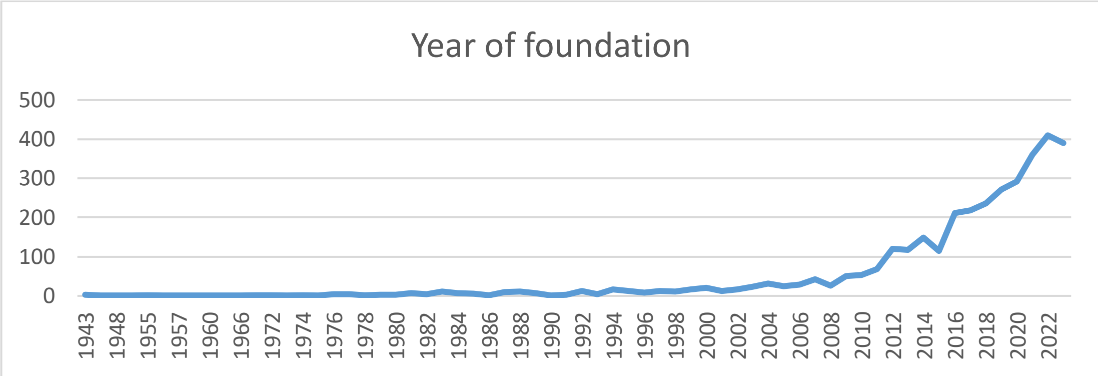

Figure 1. *Time evolution of companies founding.*

In this group of companies analysed, a total of 821 had a declared web presence at the time of the review, however, of these, only 483 had a functional website and in this group, 205 dedicated a section of it to share their strategic aspects publicly.

In terms of the activity they perform, 20% of the companies are concentrated in the following productive functions:

Table 1. *Main economic activities of manufacturing firms*

ISIC Activity	Description	Percentage
C33	Specialized installation, maintenance and repair of machinery and equipment	9,7%
C10	Manufacture of food products	3,8%
C25	Manufacture of processed metal products except machinery and equipment	3,8%
C14	Garment making	2,5%
C18	Printing and production of copies from original recordings	1,5%

As shown in Table 1, the most prevalent primary economic activity among manufacturing firms in Barranquilla is the specialized installation, maintenance, and repair of machinery and equipment, accounting for 9.7% of the total. This highlights the importance of operational efficiency and the critical role of maintenance services in supporting industrial activities. Other significant activities include the manufacture of food products (3.8%), reflecting the region's focus on catering to both local and export markets and contributing to food security and quality control. The manufacture of processed metal products, except machinery and equipment (3.8%), emphasizes the sector's diversity and its capacity to supply high-quality components to various industries such as construction and automotive. Garment making (2.5%) plays a significant role in job creation and economic diversification, with potential for innovation in sustainable practices. Printing and production of copies from original recordings (1.5%) supports various sectors by providing essential services for packaging, labelling, and marketing. The distribution of these economic activities reflects a manufacturing sector that is both diverse and strategically positioned to support various industrial and consumer needs, demonstrating a balanced mix of foundational industries and growth-oriented sectors, which not only supports economic stability but also provides a platform for future development and innovation.

Strategic approaches

The 205 missions analysed contained a total of 1442 individual descriptors (words) that express the identity of the organizations evaluated in the study after eliminating common words (such as connectors) and carrying out a process of lemmatization and grouping of descriptors by synonyms. These descriptors are used a total of 5096 times, and the first step of the analysis corresponds to counting the frequency of the most common words so that they represent the ideas and strategic choices of companies in the description of their identity. Table 2 shows the descriptors that represent 30% of the missions analysed.

Table 2. *Main descriptors for manufacturing firms' missions*

Word	Frequency	Percentage
customers	164	3,2%
quality	145	2,8%
services	125	2,5%
product	89	1,7%
needs	72	1,4%
solution	70	1,4%
growth	57	1,1%
process	52	1,0%
support	49	1,0%
industrial	43	0,8%
market	42	0,8%
environment	40	0,8%
human	40	0,8%
meet	40	0,8%
standard	37	0,7%
equipment	35	0,7%
manufacture	31	0,6%
offer	31	0,6%
design	28	0,5%
satisfaction	27	0,5%
work	27	0,5%
value	26	0,5%
efficient	25	0,5%
expectations	24	0,5%
technology	24	0,5%

The analysis of mission statements revealed key strategic orientations. By examining the most common words used in these statements, it was possible to identify six primary strategic approaches that serve as the axis of business development in the sector: competitiveness focused on quality, innovation and technological development, customer orientation, emphasis on social and environmental responsibility, focus on operational efficiency and process optimization, and human resource development. This section delves into each of these strategic approaches, highlighting their significance and the insights derived from the keyword analysis.

Competitiveness focused on quality: The word "quality" appeared 145 times, accounting for 2.8% of the total word count, indicating a significant focus on maintaining high standards. Quality is one of the key factors in competitiveness, especially in the manufacturing sector where product reliability and excellence are paramount (Chikan, Czakó, Kiss-Dobronyi, & Losonci, 2022). Companies emphasize quality to differentiate their products and services, build customer trust, and comply with industry standards (Rane, Achari, & Choudhary, 2023). This focus on quality reflects a strategic commitment to delivering superior value and achieving long-term success.

Innovation and technological development: Innovation and technological advancement are essential for staying competitive in a rapidly evolving market (Mckinsey & Co, 2020). The keywords "innovation" and "technology" appeared frequently, with "technology" mentioned 24 times (0.5%). This highlights the sector's dedication to embracing new technologies and fostering innovation. Companies prioritize research and development to enhance product features, improve manufacturing processes, and create cutting-edge solutions. This strategic approach ensures that firms remain agile and responsive to technological advancements, cultural and social changes, and market demands (Elali, 2021).

Customer orientation: Customer orientation is evident from the prominence of the word "customers," which was the most frequently used word, appearing 164 times (3.2%). Additionally, terms like "needs" (72 times, 1.4%), "support" (49 times, 1.0%), and "satisfaction" (27 times, 0.5%) underscore the importance of understanding and meeting customer needs. This approach involves focusing on customer satisfaction, building strong relationships, and providing exceptional service. By prioritizing customer orientation, companies aim to enhance loyalty, drive repeat business, and create a competitive edge (Rane, Achari, & Choudhary, 2023).

Emphasis on social and environmental responsibility: The keywords "environment" (40 times, 0.8%) and "human" (40 times, 0.8%) reflect a strategic emphasis on social and environmental responsibility. Companies recognize the importance of sustainable practices and the impact of their operations on the environment and society (Vetroni, Salvador, do Prado, de Francisco, & Moro, 2021). This approach involves adopting eco-friendly processes, reducing carbon footprints, and promoting corporate social responsibility initiatives. Additionally, valuing human resources and fostering a positive work environment are crucial components of this strategy, aligning with global trends towards sustainability and ethical business practices.

Focus on operational efficiency and process optimization: Operational efficiency and process optimization are highlighted by words such as "efficient" (25 times, 0.5%) and "process" (52 times, 1.0%). These terms indicate a strategic focus on maximizing resource utilization, streamlining operations, and enhancing productivity. Companies aim to reduce waste, lower costs, and improve overall efficiency to remain competitive (Agyabeng, Ahenkorah, Afum, & Owusu, 2020). This approach involves continuous improvement methodologies, such as Lean and Six Sigma, to optimize manufacturing processes and achieve operational excellence.

Human resource development: Human resource development is another critical strategic approach, evidenced by the word "human" (40 times, 0.8%) and related terms like "support" (49 times, 1.0%) and "growth" (57 times, 1.1%). Companies prioritize developing their workforce through training, skill enhancement, and career development programs. This approach recognizes employees as valuable assets and focuses on fostering a motivated, skilled, and engaged workforce. Investing in human resource development not only enhances productivity but also drives innovation and supports long-term business growth (Surya, y otros, 2021).

Cluster analysis

The clustering and PCA analysis reveal distinct strategic orientations among the companies, highlighting the diversity in approaches within the sector. Each cluster represents a unique combination of strategic priorities, ranging from quality and customer satisfaction to environmental responsibility and continuous improvement. This detailed understanding can help stakeholders in the sector tailor their strategies to align with industry trends and best practices. Figure 2 shows the distribution of business strategies across the two principal components after a PCA and a clustering analysis to identify and label the clusters representing the six strategic approaches.

Figure 2. *Clusters for company strategic approach*.

- **Cluster 0. Quality and customer satisfaction:** Companies in this cluster prioritize the quality of their services and products and emphasize customer satisfaction and support.
- **Cluster 1. Meeting needs and providing services:** This cluster focuses on understanding and meeting the needs of customers, providing excellent services, and ensuring product quality.
- **Cluster 2. Customer service and support:** Companies here emphasize providing services and support to customers, ensuring quality and efficient processes.
- **Cluster 3. Solution and manufacturing standards:** The focus in this cluster is on offering solutions and maintaining high standards in manufacturing and industrial processes.

- **Cluster 4. Continuous improvement and environmental responsibility:** Companies in this cluster emphasize continuous growth and improvement, with a significant focus on environmental responsibility and market presence.
- **Cluster 5. Customer and market-oriented growth:** This cluster focuses on customer needs, market growth, environmental considerations, and the human element in business operations.

Conclusions

The analysis of the mission statements from small and medium-sized manufacturing companies in Barranquilla provides significant insights into the strategic orientations prevalent in the sector. The research identified six primary strategic approaches: competitiveness focused on quality, innovation and technological development, customer orientation, social and environmental responsibility, operational efficiency, and human resource development. These strategies reflect a comprehensive understanding of the diverse elements that drive business success in the manufacturing sector. This study's novelty lies in its systematic evaluation of mission statements to uncover strategic priorities, offering a unique perspective on how these companies articulate and implement their strategic visions.

The findings highlight that while mission statements serve as a useful tool to gauge strategic priorities, there is often a gap between the declared missions and the depth of strategic alignment in practice. Many mission statements were found to be superficial, lacking the coherence and specificity needed to effectively guide organizational identity and strategic direction. This indicates a need for companies to invest more in developing mission statements that are not only reflective of their strategic goals but also actionable and deeply integrated into their operational frameworks. By bridging this gap, companies can enhance their strategic clarity and better align their organizational behaviours with their declared missions.

Moreover, the study contributes to the state of the art by demonstrating the importance of mission statements as a diagnostic tool for strategic orientation in the manufacturing sector. The clustering and PCA analysis revealed distinct strategic orientations among the companies, highlighting the diversity and specificity of strategic approaches within the sector. This methodological approach can be replicated in other sectors and regions to assess strategic orientations and improve business strategies. By providing a clear understanding of the strategic priorities, this research offers valuable insights for policymakers, business leaders, and stakeholders aiming to foster a more strategically coherent and competitive manufacturing sector in Barranquilla and similar contexts.

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When digitalisation influences quality practices – do the competences of quality practitioners match?

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Abstract

Digitalisation influences most, if not all, areas of quality management (QM). The influence of digitalisation includes e.g. digitalised quality management systems, digitalised customer feedback, and changing roles of QM practitioners. However, still there are few papers focusing on how digitalisation changes QM practitioners' hands-on practices and activities. The purpose of this paper is to identify digital practices and tools supportive of quality improvements, to further the understanding of quality practitioners' present and future competence needs. The study has a qualitative inductive approach based on a layered data collection, including a pre-survey, interviews, diaries, and a workshop. The result shows that quality practitioners mainly working at an operational level focus on competences and practices related to interpersonal relations or hands-on methods, while practitioners working mainly on a strategic level work more with practices related to overall management of the firm or introduction of new concepts. Simplified, the operational practitioners work with 'traditional quality work' such as translation of customer needs and data analysis, while the strategic work to show how quality work can support organisations' digitisation overall, e.g. by new methods, processes, and value propositions. In contrast to other studies exploring digitalisation initiatives and processes on an organisational level, this paper contributes with practitioners' perception of how digitalisation affects their everyday practice alongside concrete examples of tools and competences used in their daily work. Further, the dual nature of digitalisation, serving as both a facilitator for simplifying practices and a challenge to quality practitioner's role and position per se is described.

Keywords: Digitalisation, Quality practitioners, Manufacturing, Competences

Relevant topic: TQM in the digital age

Introduction

Scholars broadly agree that digitalisation, with its possibilities and challenges, transforms society and organisations in multiple ways. More advanced technology in the wake of Industry 4.0 (Zangiacomia et al., 2020), new business models (Aas et al., 2020), changing customer requirements and expectations (Birch-Jensen et al., 2020), and new ways of working (Martin et al., 2023) are just a few examples. Following this societal transformation, digitalisation also influences most, if not all, areas of quality management (QM). The influence of digitalisation on QM includes e.g. digitalised quality management systems (Aleksandrova et al., 2019), digitalised customer feedback (Gremyr et al., 2022), and the impact of digitalisation on the roles of QM practitioners (Elg et al., 2021). Chiarini and Kumar (2021) propose that digitalisation can contribute to quality practitioners becoming more relevant and secure more strategic positions in companies. Carvalho et al. (2019) on the other hand, suggest that that digitalisation in itself and the new professions that digitalisation 'brings' challenges QM practitioners to redefine their work and its boundaries in order to stay relevant. Thus, it is suggested that quality practitioners need to take an active role in (re)forming their role and work. Despite the growing research interest in how QM practitioners' work is changing due to digitalisation, there are still few papers focusing on QM practitioners' hands-on practices and activities and how they change resulting from digitalisation. Thus, the purpose of this paper is to identify digital practices and tools supportive of quality improvements, as a means to further the understanding of quality practitioners' present and future competence needs. The purpose is decomposed into two research questions:

> RQ1: what areas of quality work are changing in manufacturing firms that could benefit from digitalisation?
>
> RQ2: what practices and tools are needed when quality work is becoming more digitalised?

To answer the two research questions, this paper builds on previous studies on QM practitioners' competence (Martin et al., 2021) and skill needs (Martin et al., 2023). Focusing competences, Martin et al. (2021) describe a framework of four competences suggested to be needed as a QM practitioner: human, methods and process, conceptual, and contextual competences. The human competence includes social skills, ability to build and maintain relations and communication skills, the methods and process competence includes methodological knowledge about QM principles and tools, the conceptual competence includes conceptualisation and innovation, and contextual competence includes to make use of previous experiences in other contexts and situations (Martin et al., 2021). In relation to such competencies, digitalisation gives rise to new potential roles for quality practitioners either to be more advanced in their present skills, or even being challenged to take on new roles or develop new skills. Turing now to skills, Martin et al. (2023) suggest seven skill areas that practitioners should possess to utilise the potentials arising from digitalisation namely having a holistic perspective, a pragmatic approach based on a good understanding of possibilities, change management skills, process management skills, general project management skills, improvement analysis skills, predictive and proactive approach in Quality Management, IT skills, and Big data proficiency. Based on previous research,

Table I presents a proposed framework combining competences and skills that practitioners should possess to utilise the potentials arising from digitalisation.

Table I. A proposed framework combining competences and skills that practitioners should possess to utilise the potentials arising from digitalisation.

Competence dimensions (Martin et al., 2021)	**Skills (Martin et al., 2023)**
Human competence	Change management
Method and process competence	Process management skills General project management skills Improvement analysis skills Predictive and proactive approach in Quality Management IT skills Big data proficiency
Contextual competence	Pragmatic approach based on a good understanding of possibilities
Conceptual competence	'Integrator' - Holistic perspective

Methods

The study has a qualitative inductive approach based on a layered data collection (Flick, 2014), including a pre-survey, interviews (Brinkman and Kvale, 2018), diaries, and a workshop. See Table II for further details. A stratified purposeful sampling approach (Miles and Huberman, 1994) was applied to sample respondents working either strategically or operationally in the manufacturing sector. Of the 13 respondents, six worked operationally and seven strategically, coming from a total of eleven different organisations.

Table II. *Summary of the data collection.*

Respondent	**Strategic/ Operative**	**Pre-survey**	**Interview**	**Diary**	**Workshop**
R1	Strategic	x	x	x	
R2	Strategic	x	x		x
R3	Operative	x	x	x	x
R4	Strategic		x		
R5	Operative	x	x		
R6	Operative	x	x	x	x
R7	Strategic	x	x	x	x
R8	Strategic		x	x	x
R9	Strategic	x	x	x	x
R10	Strategic	x	x		
R11	Operative	x	x		
R12	Operative	x	x		
R13	Operative		x		x

To get insight into the practitioners' current digital work, all respondents were asked to fill out a pre-survey before the interview. Ten respondents answered the pre-survey where the respondents were asked to grade, on a Likert scale, the extent of their use of different practices, tools and techniques in their daily work related to digitalisation previously identified by Elg et al. (2021). The scale was 1 to 5 where 5 equals 'use to a high extent' and 1 equals 'do not use at all'.

Thirteen interviews based on a semi-structured interview guide was conducted to explore respondents' day-to-day work, challenges, current and future need of digital tools, and digital competence need. Further, concrete examples of how competences, from the framework by Martin et al. (2021) were applied in their work were collected. The interviews were held digitally in and were automatically transcribed using MS Teams. Two pilot interviews were conducted to test and finetune the interview guide (Brinkmann and Kvale, 2018). Six respondents (three strategic and three operational) submitted diaries outlining current issues, work tasks, challenges, developmental needs, encountered during one workweek. Seven of the respondents attended a co-creative and validating workshop. During the workshop, the researchers presented the preliminary results which the participating respondents got to discuss e.g. by clustering the identified practices into categories (see Figure 1 and Figure 2 below).

The qualitative data was analysed in three steps. Firstly, the interviews and diary notes were analysed using the inductive method developed by Boyatzis (1998) where practices described was identified. Secondly, the result of the analysis was discussed during the workshop where the participating respondents clustered the practices into areas. Thirdly, the researchers conducted the final clustering to create the areas. To enhance research quality, multiple data collection methods were used that enabled triangulation of data, moreover, to add to trustworthiness of the analysis one of the authors was not involved in the data collection and thus acted as an external investigator (Eisenhardt, 1989).

Results

In this section, the main findings for each research question are presented. Firstly, the empirically derived areas of quality work changing due to digitalisation are presented. Secondly, some practices, tools, and techniques in digitalised quality work is outlined.

Areas of quality work changing due to digitalisation

Four key areas of quality work changing due to digitalisation were identified. Figure 1 and Figure 2 displays the respondents' clustering. The suggested key areas are: (1) process control, quality assurance, and root cause analysis, (2) competence development and utilisation of competences, (3) quality management systems, and (4) use of digital tools.

The area 'process control, quality assurance, and root cause analyses' was the most frequently mentioned by the respondents, likely due to them being traditional quality improvement practices in manufacturing. However, it was highlighted that the data handling and analyses are becoming more complex and require more advanced competences in data handling, statistics and programming. Further, digitalisation is described to facilitate automation of data collection, visualisation and analysis.

Concerning competence development and utilisation of competences, respondents mentioned needs of new competences in their teams such as IT-architects and enhanced specialised competences in e.g. programming, data quality, and data base handling. The possibility to utilise multiple competences during digital ‘go to Gemba’ visits were also mentioned, as well as the need for a general enhancement of digital competence and increased use of e-learnings for competence development.

The cluster quality management systems included digitalisation of standard operating procedures, digital quality management system with features such as a search function. The digitalisation has also enabled remote audits via video, argued as a way to save time and resources.

Concerning digital tools, the respondents reported both digital communication tools and digital work tools. Communication perceived to be facilitated and enhanced internally and externally via digital tools through digital quality educations, digital meetings, and coordination of team members from different locations. Other digital tools mentioned were interactive animations, VR/AR, QR-codes and transparent face shields functioning as a screen for work instructions.

Figure 1. *Clustering of practices and tools conducted by the two groups during the workshop. Green boxes are the respondents cluster headings, yellow boxes are the empirically identified practices and tools from interviews, and red boxes are additional practices or tools added by the respondents during the workshop.*

Practices, tools, and techniques in digitalised quality work

As described under methods, ten respondents graded the extent of their use of digital practices, tools and techniques on a scale from 1-5. Average and standard deviation of the extent of the uses are shown in Table III. As presented in Table III, the quantitative results show that the most commonly used, with a score of 4.6-4.0, are (1) Online communication e.g. Skype, Zoom and MS Teams, (2) Tools for statistical data analysis e.g. MS Excel, Minitab, and (3) Educate employees about practices, tools and techniques. The top results changes when separating the score based on respondents working operationally or strategically. The most commonly used of operative respondents, with a score of 4.8-4.6, are (1) Educate employees about practices, tools and techniques, (2) Online communication e.g. Skype, Zoom, MS Teams, and (3) Tools for statistical data analysis e.g. Excel, Minitab. While for strategic respondents, with a score of 4.6-3.4, (1) Online communication e.g. Skype, Zoom, MS Teams, (2) Tools for statistical data analysis e.g. Excel, Minitab, and (3) Automation of production lines are the most common.

Table III. *The extent of the ten respondents' use of digital practices, tools and techniques in their daily work. Scale: 1-5 where 1 equals 'do not use at all' and 5 equals 'use to a high extent'.*

Digital practices, tools and techniques	**Average**	**Standard deviation**
Online communication e.g. Skype, Zoom, MS Teams	4.6	0.7
Tools for statistical data analysis e.g. Excel, Minitab	4.3	1.3
Educate employees about practices, tools, and techniques	4.0	1.2
Develop operational routines and processes	3.5	1.6
Visualisation of processes and work tasks	3.3	1.3
Data visualisation tools e.g. MS power BI, Qlik Sense	3.3	1.5
Decision making supported by digital tools	3.2	1.3
Establish fora for cross-functional meetings	3.2	1.4
Visual management/planning/pulse boards	2.9	1.1
Real time root cause analysis	2.9	1.4
Online workspace	2.8	1.4
Collaboration with IT	2.6	1.3
Monitoring compliance with legal requirements	2.5	1.4
Program for real-time monitoring	2.3	1.4
Automated production lines	2.2	1.6
Automated service processes e.g. handling of customer inquiries	1.4	0.7
Development of new digital service offerings	1.3	0.7
Development of service-based apps	1.2	0.4

Turning now to the qualitative results from the interviews, the respondents reported multiple practices, tools and techniques used in their daily work that in some way relate to digitalisation. The results are presented for each of the four competence dimensions and for operationally and strategically focused respondents respectively.

Human competence: The operationally focused respondents report that internal communication with operators in production and other functions are central in their daily work. The majority of the respondents agree that building relationships and trust with other employees is vital to be able to cooperate in e.g. development of new practices, to implement new ways of working or making other employees help out in improvement projects. In addition to communication, some respondents describe a need for pedagogical skills to educate other employees in quality tools and data visualisation tools e.g. Power BI.

Similarly to the operationally focused respondents, the strategically focused respondents report a need of both pedagogical and communicative competence. Communication with customers, employees, and top management is highlighted as central. 'Selling' and packaging the need to focus and prioritise quality and systematics improvement work to top management is highlighted by some as vital for quality managers which the quite below illustrates:

> "We have implemented ISO 45000, and we have to ensure that the requirements are maintained without everyone fully understanding the value of it. ... when you have management review with top management and the board you can do it in many different ways. If you read the standard and go into all the requirements and laws, then it will be like that [however] you should try to package it like 'this is what we should do' and then the organisation will work better and commit to it" (R10).

<u>Method and process competence:</u> Starting with the operationally focused respondents, a majority describe hands on practices as data collection, data handling, qualitative and quantitative data analysis, and data visualisation to be central daily practices. They thus describe a need of skills in programming e.g. Python, database handling, data analysis e.g. MS Excel and MiniTab, and visualisation tools as Power BI. Both operational and strategic respondents highlight practices related to using systematic improvement models such as PDSA and improvement methodologies such as DMAIC (Six Sigma). One operational respondent state that to stay relevant and contribute with 'unique' knowledge, the quality professionals should focus on data analysis to a greater extent.

Continuing with the strategically focused respondents, they generally report practices such as developing and monitoring KPIs, compiling performance data from different systems, being responsible for visual management boards/meetings and other types of data visualisation, development and continuity of quality management systems and development of standardised routines in-house and between sites. One respondent describes an increased need to identify, configure, and implement relevant digital systems such as non-conformance, quality management and customer feedback systems and adapt the practical data collection methods to get appropriate data.

<u>Contextual competence:</u> The operationally focused respondents report that contextual competence is necessary to use experiences of digital tools or work tasks and translate them into other contexts or applications. The use of digital non-conformance tracking was highlighted by one respondent as a means to find information and translate it to handle problems in production.

> "... there were a lot of problems that we saw in [product A] that we are now seeing in [product B] for example. And then we been helped by how [product A] resolved certain things from the type of quality document that was used that resolved everything." (R11)

Another practice highlighted by three respondents is identification of who could benefit from collected data and distribute it to the right forum or function to be used for example in decision making, problem-solving, marketing, or research and development. Further, the strategically focused respondents highlighted contextual competence in translating knowledge from previous workplaces into their new workplace e.g. machines with digital features or QR-codes for safety instructions. One respondent highlight quality managers' possibility to contribute with broad knowledge about the organisation and operations is discussions about what to digitalise and how to adapt it to the context as illustrated by the following quote:

“There are lots of digital [visual management] boards, which are nice looking, but then you have to think, what is the underlying purpose? What is it that we want to achieve? And there I feel that some of us argue for digital solutions because they look good not because they serve a purpose. So, in this digital world we have to get better at understanding why we choose one or the other. Because if we choose haphazardly, then the risk is that we lose some important feature.” (R2)

Conceptual competence: The operationally focused respondents report practices, tools and techniques that require conceptual competence that are closely related to operations. One respondent described the need for conceptual thinking in brainstorming about product development. Another practice highlighted by multiple operational respondents was the need to think holistically about data handling and analysis as well as finding new ways of utilising process, performance, or customer data. One example concerns development of Power BI reports:

“... we have so many different customers for this type of data ... What is important to you and to see from the data? What is important for someone perhaps higher up in management? It has been difficult, but it also means that you have to create a lot of new thinking, find different ways to sort of solve their wishes.” (R7)

Further, a majority of the operational respondents describe that they regularly identify development needs in their daily work and independently develop their own solutions and acquire relevant skills or knowledge to be able to do so, for example skills in programming, statistical analysis, and visualisation tools.

Turning to the strategically focused respondents, highlighted needs related to digitalisation of quality work are recruitment and organisation of quality team, analysis of present and future competence needs, and to have long term, value-adding, and sustainability perspectives on implementation of new digital practices and tools. One respondent report that digitalisation has enabled the organisation of a global quality team, another that digitalisation is facilitated by working in a matrix organisation. Further, a few describe needs to recruit either employees with pure IT competence or a combination of quality and IT competence to the quality team.

Discussion

As previously described, the purpose of this paper is to identify digital practices and tools supportive of quality improvements, as a means to further the understanding of quality practitioners’ present and future competence needs. To guide this work, two research questions were formulated: RQ1 - What areas of quality work are changing in manufacturing firms that could benefit from digitalisation?, and RQ2 - What practices and tools are needed when quality work is becoming more digitalised?

Consistent with the literature (e.g. Chiarini and Kumar, 2021; Elg et al., 2021; Martin et al. 2023; Ponsignon et al., 2019) this research found that the quality management practitioners are affected by digitalisation in several ways in their daily work. Similarly to Martin et al. (2021), this study shows that the functional scope of quality practitioners, being either strategic or operational, affect their work content on a general level however, this study shows that this is also the case in relation to digitalisation specifically. Unsurprisingly, as the respondents were sampled from within the quality area, the practices and tools identified are predominately related to traditional quality work, such as process control, root cause analysis, and quality management systems. The exception is the area labelled *competence development and utilisation of competences,* where operational practitioners especially highlighted a need for individual competence development in areas related to digitalisation such as data handling, data analysis, and programming while strategical practitioners highlighted a need for new competences in the quality team such as business IT and collaboration with other professions such as IT departments in digitalisation related matters. In contrast to the study by Chiarini and Kumar (2021) where the respondents were undecided about whether quality staff needed new digital skills for quality management the respondents in this study agreed that there is a need ranging from tools for communication or application of machine learning in data analysis.

Both the quantitative and qualitative data in this study indicate that operational quality practitioners focus more on practices and tool recurring from human and method/process competence dimensions, whereas the strategic quality practitioners focus more on contextual and conceptual. Simplified, the operational practitioners work with 'traditional quality work' such as translation of customer needs and data analysis, while the strategic work to show how quality work can support organisations' digitalisation overall, e.g. by new methods, processes, and value propositions. Although, incremental improvements of existing practices through digitisation (Elg et al., 2021) seem to be most prevalent on operational level, the operational practitioners also show the need for conceptual competences when attempting to find new ways of working through their initiatives to e.g. independently find new ways of handling and visualising data. Such developments require new competencies in terms of IT such as programming, database handling and system configuration. This finding is interesting as the strategic practitioners' state to want to recruit individuals with knowledge in both IT and quality and our results indicate two ways that this need may be fulfilled; recruiting and/or allowing quality practitioners to 'learn on the job' or acquire such competence 'on their own'. In summary, the envisioned way to fulfil this need varies in between the groups: up-skilling of current quality practitioners or up-skilling teams through external recruitment. Such a potential divide among quality practitioners could be an avenue for future research, as there is a strength for a functional area to be present both operationally and managerially in an organisation. Having a representative within the management level can create strategic openings for the operational level, ensuring its relevance and visibility. This representation is beneficial, particularly in securing resources, such as those needed for competence development.

The result presented above indicates that there is a large difference between working with QM operationally and strategically. Other scholars (Elg et al. 2021; Carvalho et al., 2019) have proposed that QM practitioners should be more entrepreneurial and widen their work area to stay relevant. Based on the findings presented in this paper, there is a risk that redefinition of the quality work can lead to a split among QM practitioners and thus a tendency for strategic QM roles to become a general management role more distant from the more operational quality practitioners. Irrespective of in-between group differences, the data supports a need to redefine quality work to stay relevant in times of digitalisation (Carvalho et al., 2019). Suggestions for future research are to further explore how to ensure a continued relevance of QM on strategic as well as operational levels, as well as how to warrant access to, or development of the competence needed.

Conclusions

Digitisation poses challenges and opportunities in most areas, also in quality management. In contrast to other studies exploring digitalisation initiatives on an organisational level, this paper contributes with practitioners' perceptions of how digitalisation affects their everyday practice alongside concrete examples of practitioners' daily work with digital tools and needed competencies. Four key areas of quality work changing due to digitalisation were identified: (1) process control, quality assurance, and root cause analysis, (2) competence development and utilisation of competences, (3) quality management systems, and (4) use of digital tools. In terms of competence needs, areas in need of development include both soft skills, such as to educate other employees in quality tools or visualisation tools e.g. Power BI, and more hard skills, such as digital non-conformance tracking. Finally, the data points to a risk of a divide between operationally and strategically focused quality practitioners in terms of views on how to develop competences related to digitalisation, be it by up-skilling existing quality practitioners or by recruiting IT-staff to the quality function.

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Track 10: TQM and Sustainability

Study of the reasons for the application and factors contributing to continuous improvement in manufacturing companies

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Abstract:

The study examines the implementation of Continuous Improvement (CI) in Polish manufacturing companies, focusing on reasons for adoption, supporting factors, and key application areas. Using a quantitative methodology with the Computer-Aided Telephone Interview (CATI) technique, the research involved 70 participants from various Polish manufacturing companies. Key findings indicate that the primary motivations for adoption CI are to meet customer expectations and improve product quality. Essential factors supporting CI include the quality management system and employee commitment. Knowledge management emerged as the most important area within the CI framework. These insights can help organizations effectively implement and sustain CI efforts, leading to improved operational efficiency and competitive advantage.

Keywords: Continuous Improvement (CI), Quality Management

Relevant Topic: Quality culture, leadership, and human factor in quality management

Introduction

Continuous technological development and changing societal needs influence the ongoing needs for the development of manufacturing organizations. Because of the wide scope of CI, the concept has been interpreted in different ways in the scientific literature. Although these interpretations share similarities, each one emphasizes different aspects (Sanchez-Ruiz, Gomez-Lopez, and Blanco 2020). It is important to highlight that many authors consider CI as one of the fundamental tools for implementing production systems based on TQM, Lean Management, Lean Production, Six Sigma, the hybrid Lean Six Sigma, or World Class Manufacturing (Marin-Garcia, de Val Manuela, and Bonavía Martín 2008; Sunder M. and Prashar 2020). The cultural context undoubtedly also influences how the CI concept is understood and implemented. Research on applying different aspects of the CI concept has been conducted among companies operating in Italy (Corso et al. 2007), in the Netherlands (Middel, Op De Weegh, and Gieskes 2007), Spain (Jaca et al. 2012; Jurburg et al. 2017; Sanchez-Ruiz et al. 2020), Ireland (McDermott et al. 2022), UK (Fannon, Munive-Hernandez, and Campean 2022), in Australia (Terziovski and Power 2007), Brazil (Oprime, de Sousa Mendes, and Pimenta 2011), in Mexico and Ecuador (Alvarado-Ramírez et al. 2018). A comparative study of critical failure factors has been conducted in the US, UK, China and India (Sunder and Prashar, 2020). To the best of the researchers' knowledge, such analyses haven't been previously conducted so far among companies operating in Poland. Therefore, considering the need to diagnose the approach to CI, the following research questions were proposed:

- **RQ1.** What are the reasons for using CI in Polish manufacturing companies and what is its level of importance?
- **RQ2.** What factors support CI and what is the degree of their influence?
- **RQ3.** What are the key areas of the CI system and what is their importance in relation to the level of CI maturity in Polish manufacturing companies?

The aim of the papers is to identify the most important factors that promote the use of CI and facilitate the development of the effectiveness of this concept.

Methods

The research used a quantitative methodology, specifically the Computer-Aided Telephone Interview (CATI) technique. This method was selected for its effectiveness in conducting cross-regional research, providing access to a large and geographically diverse respondent pool while ensuring rapid implementation. The standardized interview questionnaire used in the study included three substantive questions, formatted as closed questions (with predetermined response options) or constructed on a scale basis. In addition, the questionnaire featured five metric questions designed to characterize both the respondents and the companies they represented. The Cronbach's alpha reliability coefficient, which assesses the internal consistency of the questionnaire, yielded a highly reliable result of 0.981 on a scale from 0 to 1. A higher coefficient value indicates a higher reliability of the questionnaire. The complete study design is shown in Figure 1.

A total of $N = 70$ individuals participated in the survey, representing Polish manufacturing companies involved in quality management, the implementation of CI methods, and organizational management participated in the survey. The survey was designed to achieve the objective stated in the introduction of the article. The selection criterion was the company's involvement in production activities, with special emphasis on the importance of the respondent's specified role. Among the respondents, those specializing in quality management formed the majority, representing 37.1% of the total. A quarter of the respondents were in senior management positions (25.7%), with managers, coordinators, and quality management specialists also making up 25.7%. In addition, there were representatives of the integrated management system (8.6%) and members of the management board of directors (2.9%).

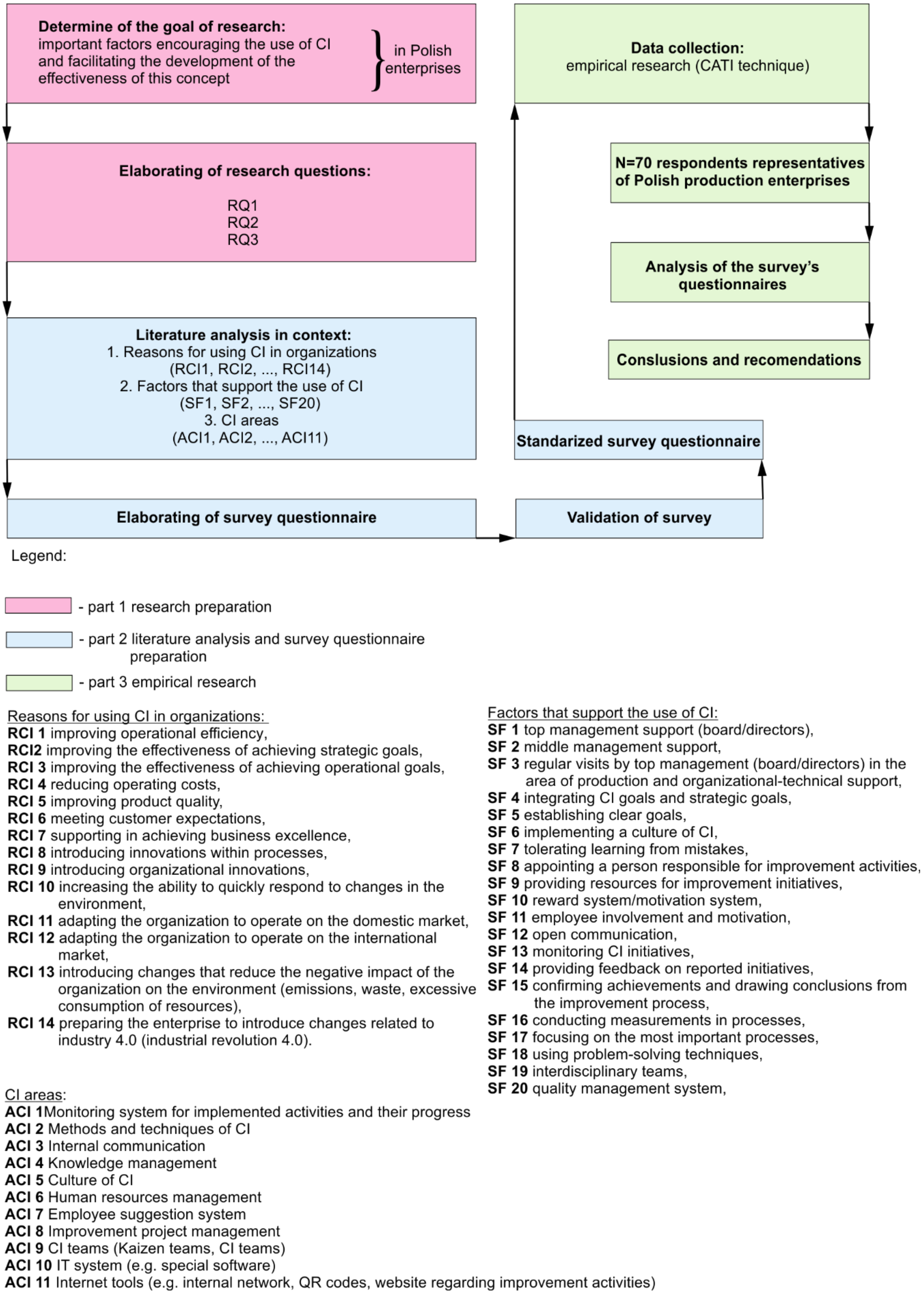

***Figure 1**. Scheme of conducted research.*

The majority of the companies surveyed, more than 84%, fall into the category of medium-sized companies, which are characterized by having between 50 and 249 employees. Small companies, with 10 to 49 employees, represent one tenth of the companies surveyed. Large companies, with more than 249 employees, represent a modest share, comprising less than 6% of the research sample. Among the respondents, the electromechanical industry - covering sectors such as metal, machinery, precision, transport, electrical engineering, and electronics - was predominant, accounting for 40% of the companies surveyed. Other significant industries included the wood and paper (30%), the food (20%), and the cosmetics (10%).

The authors conducted an extensive literature review to develop the survey questions used in their empirical investigation. The first part of the survey focused on the reasons for implementing CI in the organization. The literature review identified fourteen reasons for implementing CI (RCI) in organizations (Fig. 1). The importance of these reasons was rated on a 5-point scale, with an additional option to indicate "not applicable". The second part of the survey focused on the factors that support (SF) the use of CI. Based on the literature review, twenty such factors were identified (Fig. 1). The influence of these factors was rated on a 6-point scale, with 0 indicating no influence. The third part of the study concentrated on eleven identified areas of CI (ACI) (Fig. 1). The importance of each area was rated on a 5-point scale.

Results and Discussion

The main reasons why companies adopt CI (Fig. 2) are to meet customer expectations (72.9%) and to improve product quality (71.4%). The least frequently cited reason, with ratings of "1" and "2", was to prepare the company for Industry 4.0-related changes (industrial revolution 4.0) (12.9%). Almost all potential reasons for adopting CI were considered important by the majority of entrepreneurs surveyed. The least frequently mentioned reasons (each of which received 94.3% positive responses) were the desire to adapt the organization to international market operations and improving the effectiveness of achieving both operational and strategic goals. From the respondents' perspective, the least important reason for CI was the desire to prepare the company for changes related to Industry 4.0 ($m = 3.49$). Conversely, the most important reason was the desire to meet customer expectations ($m = 4.01$).

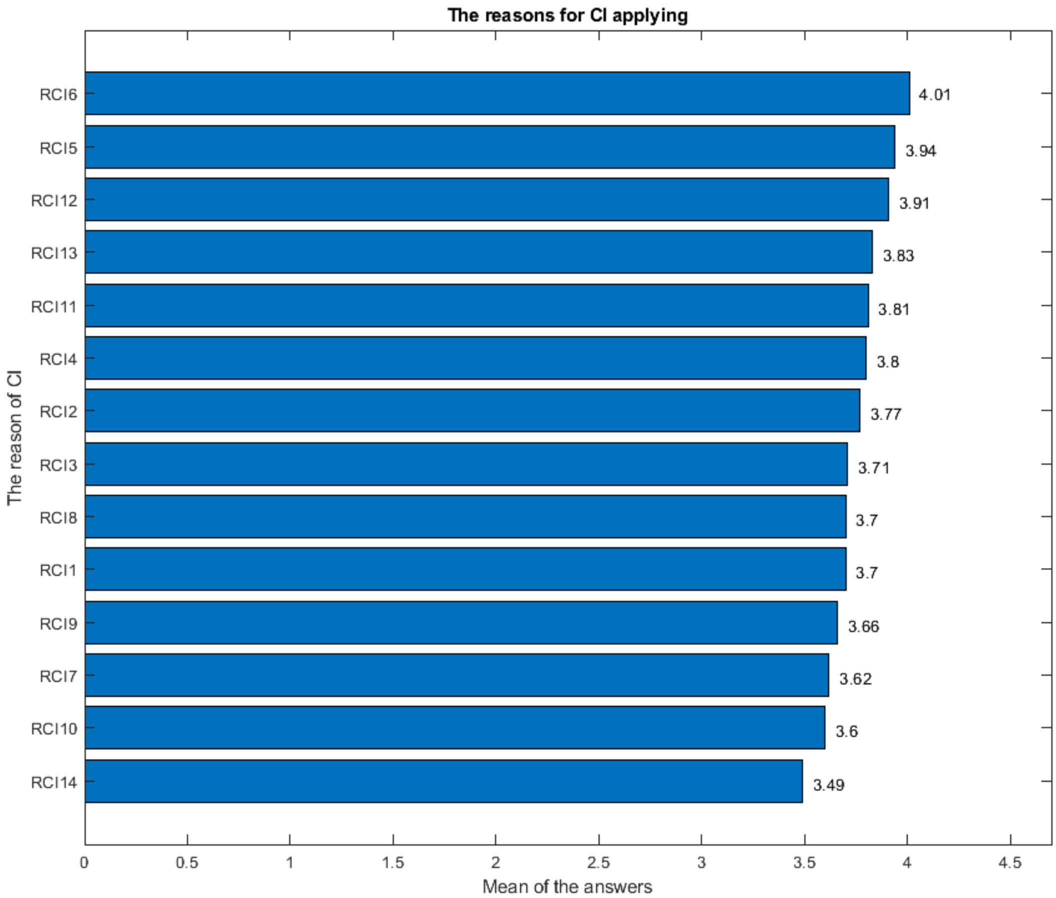

Figure 2. *The degree of importance of the reasons for CI applying in the enterprise; scale* $[1,5]$; $N = 70$.

As the role of CI within the organization expanded (across all aspects discussed), respondents' perceptions of the importance of individual reasons for CI also increased.

The second part of the study focused on factors that support the implementation of the CI concept (Fig. 3). The most frequently cited factors supporting CI were the quality management system (38.5%) and employee involvement and motivation, as well as recognition of successes and conclusions drawn from the improvement process (35.7%). The factors most often perceived as having little or no impact were the tolerance for learning from mistakes (38.5%) and the monitoring of CI initiatives (34.3%). The impact of nearly all of the factors discussed was rated as moderately significant. The most important factors were the implementation of the quality management system in the company ($m = 3.14$) and the use of problem solving ($m = 3.13$). Conversely, the least important factors were regular visits by senior management to production areas for organizational and technical support ($m = 2.84$) and the formation of interdisciplinary teams ($m = 2.83$).

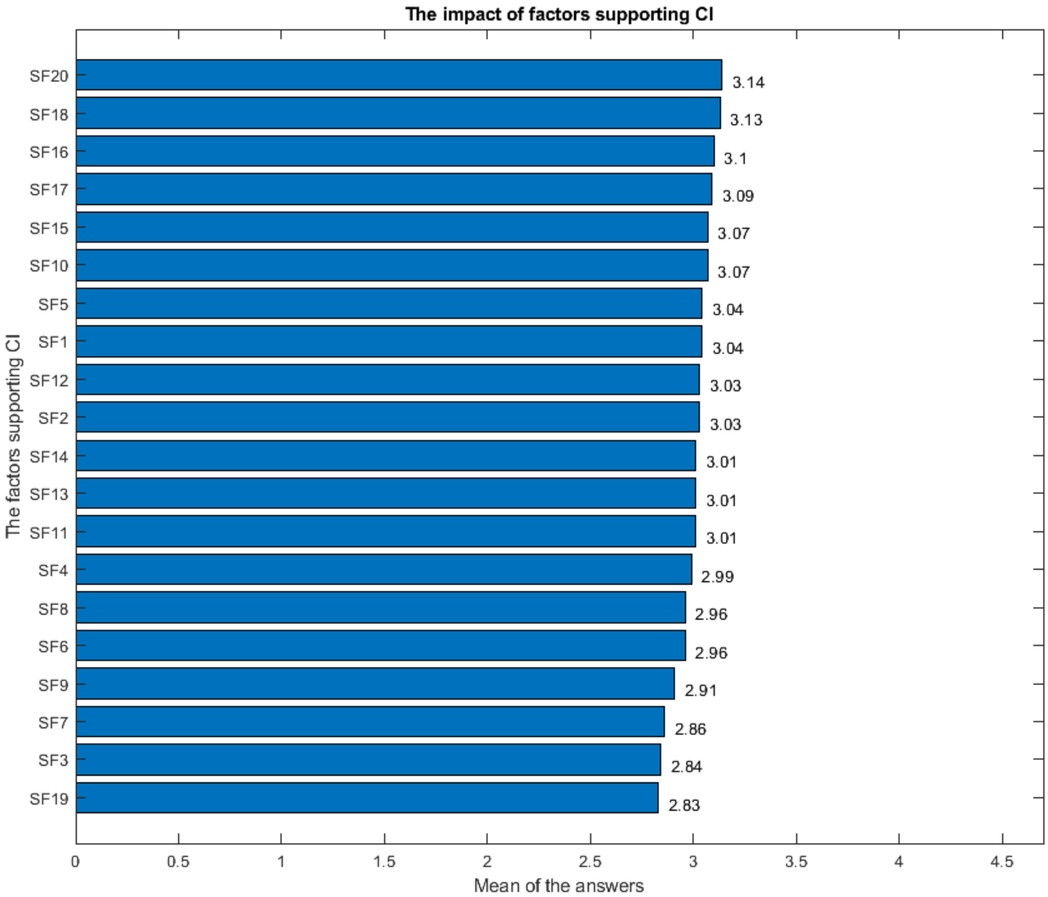

Figure 3. *Assessment of the impact of factors supporting CI on the company's operations; scale* $[1,5]$*;* $N = 70$.

The third part of the study focused on specific areas of CI and assessed their importance in the operational activities of the surveyed manufacturing companies surveyed (Fig. 4). Knowledge management was considered the most important area by the largest number of respondents (67.1%). Slightly less important were human resource management and improvement project management (61.4%). According to the respondents, the most critical areas in their CI systems are knowledge management ($m = 3.87$), the employee suggestion system ($m = 3.76$), and human resource management ($m = 3.75$). The next areas were considered slightly less important. The only element ated as moderately important was CI teams ($m = 3.38$). Notably, none of the areas were identified as either particularly important or particularly unimportant.

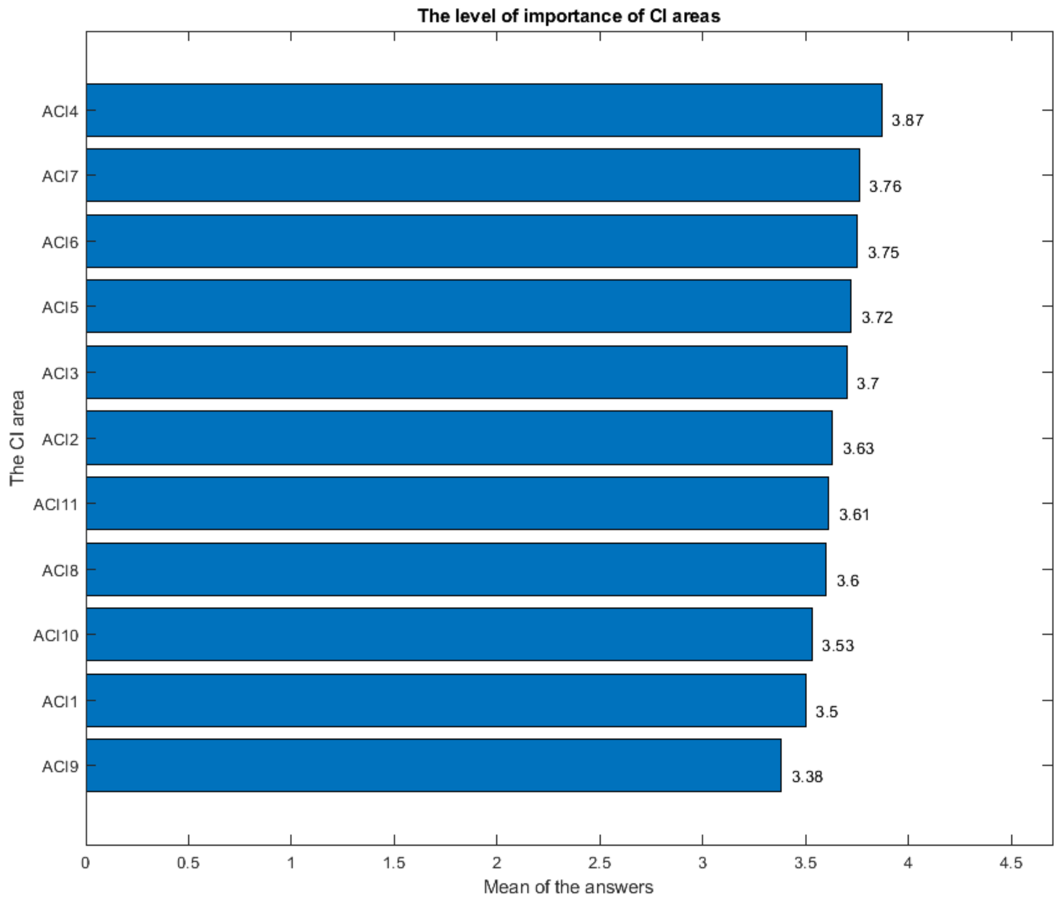

Figure 4. *The level of importance of each area of CI; scale* $[1,5]$*;* $N = 70$.

Conclusions

The study has underscored the importance of CI as a key element in the operational strategies of manufacturing companies. The findings highlight that the primary motivations for adopting CI include meeting customer expectations and improving product quality. In addition, the implementation of a quality management system and the use of problem solving techniques emerged as critical factors that facilitate CI within organizations.

The research also identified knowledge management and human resource management as critical areas within the CI framework, indicating their significant impact on the overall effectiveness of CI initiatives. Respondents emphasized the importance of integrating CI practices with strategic goals and maintaining open channels of communication to foster a culture conducive to CI.

The literature on CI supports the findings of this study. Bhuiyan and Baghel (2005) provide a comprehensive overview of CI, highlighting its evolution and importance in modern organizational practice. Similarly, Sanchez and Blanco (2014) discuss the various interpretations of CI and its fundamental role in the implementation of production systems like Total Quality Management (TQM) and Lean Management. The study's findings on the critical importance of quality management systems are consistent with Marin-Garcia et al.'s (2008) research, which emphasizes CI as a cornerstone for achieving operational excellence. Employee engagement and motivation were identified as important factors in supporting CI, echoing the findings of

Jurburg et al. (2017), who explored the motivational aspects that influence employee participation in CI activities. The importance of knowledge management and human resource management is also supported by Terziovski and Power (2007), who advocate for continuous learning and development as key to sustaining CI.

In conclusion, the adoption and integration of CI practices is essential for companies that want to improve their operational performance and product quality. The study provides valuable insights into the factors that support CI, offering a comprehensive understanding that can help organisations to effectively implement and sustain CI efforts. By recognising and addressing the key drivers and barriers to CI, companies can better navigate the complexities of CI, ultimately leading to sustainable operational excellence and competitive advantage in the marketplace.

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A Sustainable Quality Assurance System

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Abstract

Even though quality assurance of education and research is a global matter, the quality assurance processes must be adapted to each individual organisation. This paper describes a case study of how a university has redesigned its quality assurance processes and built a sustainable quality system including both management system and quality assurance of education and research.

In 2017 an institution in Sweden started to redesign and renew the overall quality system. The purpose was to simplify and streamline and ensure a comprehensive and transparent quality management system sustainable over time. The work was developed through quality management involving middle management, the Research and Education Board and Student Union who were all very committed. Many of the ideas for improvement were inspired from reviews and benchlearning both nationally and internationally.

Swedish Higher Education Authority performed an institutional review of the institution's quality assurance processes of education and research in 2020. The result was "Approved quality assurance processes with reservations", which requires follow up no later than two years after decision. In January 2023 this institution was the first university in Sweden with "Approved quality assurance processes" in both education and research.

This paper presents the main parts of the sustainable quality assurance system and its connection to the overall management system. The commitment from both top and middle management, the Research and Education Board and the Student Union is believed to be the key to success.

Keywords: Quality Assurance, Higher Education, Sustainable Quality System, Management

Relevant Topic: Quality culture, leadership, and human factor in quality management

Introduction

In 2016, Sweden implemented a new national system for quality assurance in higher education. It was designed, among other things, to create a cohesive system for all internal quality assurance processes in the Higher Education Institutions (HEI) (Johansen, 2016). Institutional reviews will evaluate the effectiveness of the HEIs' quality assurance processes. This includes monitoring, action, and feedback mechanisms, and how they contribute to the development and maintenance of course and program quality (ibid). One challenge faced by HEIs in Sweden was to develop and implement internal quality assurance and quality improvement systems that foster commitment throughout their organisations (Boström and Kettis, 2017). Additional challenges include avoiding excessive bureaucracy and ensuring that the system supports improvements in teaching and learning (Tavares et al. 2016).

The new quality assurance system in Swedish higher education presented both challenges and opportunities for HEIs. It allowed institutions to expand their quality assurance system beyond mere monitoring to include quality improvements (Linde and Sundkvist, 2012). In 2019, after the initial evaluation cycle involving four HEIs', it was revealed that only one of these institutions were fully approved. While the HEIs' had made progress in developing their quality assurance processes, the audits highlighted areas where improvement was needed. These included systematic application of routines and processes, as well as clarification of structures and responsibilities within the organisation.

Research by Prakash (2018) indicates that quality in higher HEIs is primarily influenced by external factors such as stakeholder needs, expectations, and evolving service delivery methods. Consequently, the aspects related to teaching excellence receive less attention and exploration. Quality assurance processes often focus solely on audits, accreditations, assessments, and management-driven improvements (Sahney, et al., 2008). National quality assurance systems have compelled HEIs to establish internal quality assurance mechanisms for evaluating and monitoring teaching and learning. These systems operate under strong managerial oversight (Mårtensson, et al., 2014). However, involving teachers and academics remains a challenge in many HEIs. Prchal and Messas (2016) highlights this issue, attributing it to the pressures of teaching loads, administrative responsibilities, student support, and research output demands. As a result, teachers rarely have the opportunity to reflect on teaching quality or discuss how to contribute to its improvements (Feigenbaum and Iqani, 2015). Interestingly, Amundsen and Haakstad (2017) demonstrate that the impetus for improving teaching quality often arises from within the discipline community itself, rather than being driven solely by external or internal quality requirements.

Moreover, HEIs' have sometimes introduced monitoring systems and collected data without fully leveraging that information for continuous improvement and systematic development. This gap may stem from a lack of knowledge in quality management. To create effective quality assurance systems, it is essential to adapt scientific theories from Quality Management to the context of HEIs'. Research (Sternad, et al., 2019) highlights that obstacles during implementation often arise from insufficient awareness or understanding of existing quality improvement systems and managerial attitudes. Similarly, Bergman and Klefsjö (2010) argue that implementing Total Quality Management (TQM) without considering an organisation's specific characteristics (such as size, sector, and national culture) can lead to problems due to a lack of theoretical foundation.

Hence, it is crucial to possess in-depth theoretical knowledge of quality management, along with an understanding of the organisation and its context, when developing a quality assurance system tailored to the HEI's structure (Lycke and Tano, 2017; Manatos, et al., 2018). The authors, with experience in both research and teaching in quality, emphasise that both internal and external assessments of education as well as institutional accreditation need this adaptation.

Given the complexity of a HEI's organisation and its multifaceted activities (Mintzberg, 1989), effective methods or concepts are needed to ensure high-quality education. Process Management (Melan, 1993; Ljungberg and Larsson, 2012) and the Learning Organisation approach (Garvin, 1998) offers valuable frameworks, as shown in Eriksson and Lycke (2024). All emphasise continuous improvement and follow the Plan-Do-Study-Act (PDSA) cycle (Bergman and Klefsjö, 2010; Deming, 1994). The authors have previously highlighted that these methods are particularly well-suited for HEIs' working on quality assurance and cultivating a quality culture (Lycke and Tano, 2017). One effective approach to fostering such a culture, characterised by ongoing improvement and employee commitment, is through Learning Meetings—a strategy explored in case studies by the authors (Lycke and Tano, 2017; Tano and Lycke, 2019). When developing a quality assurance system, it is crucial to involve teachers, not just management, in focusing on teaching and learning processes. To ensure clarity and reduce the risk of confusion, a common language and well-defined expressions related to “quality” should be used (Lycke and Tano, 2017). Additionally, qualitative methods should take precedence over quantitative ones (Prchal and Messas, 2016). It should encourage dialogue and learning meetings among various roles responsible for quality (e.g., program coordinators, examiners, course coordinators, and teachers). Recognising the diverse contributions of these roles fosters respect for different competencies and clarifies assignments (Lycke and Tano, 2017). Through dialogue with students, course evaluations, collaborative analyses within teaching teams, and through personal and others’ research, teachers systematically and continuously enhance and improve courses and educational programs. Continuous improvement and development of courses are thus inherent in a teacher’s DNA.

On the other hand, strategic planning in HEIs, is not consistently systematic and structured (George, et al., 2019). Consequently, there is a risk that the expected results may not be achieved (Mintzberg, 1993). Nevertheless, operational plans and follow-ups are frequently established and documented, even though they may not always rely on facts or systematic measurements for development and enhancement. However, this means that there are processes for establishing and following up various action plans even if it is not ensured that it leads to improved quality (Lycke and Tano, 2017). In a quality assurance system for HEIs it is important that there is no gap between strategic planning processes and the quality assurance processes for education (Lycke and Tano, 2017). The hypothesis in this study is that internal quality assurance systems can be developed to be more resource-efficient while still serving their purpose, allowing teachers to dedicate more time to teaching, student guidance and research. Shifting the focus to evaluation and minimising excessive documentation.

Methods

This paper is based on action research over several years (2017-2024), making it a longitudinal study. Action research allows the researchers to examine and observe a practice with a critical reflection to understand, analyse and act to further develop the practice (McNiff, 2013) and show how the practice has improved. Action research was selected due to the professional obligation to enhance the HEIs procedures. This study can be referred to as practitioner action research, since the researchers have participated through learning, actions and critical self-reflection.

Action research involves learning in and through action and reflection (ibid) and learning means personal, professional and/or organisational growth. In this study the researchers focus on a practical problem to improve practice, and at the same time aim to gain further professional knowledge and insights to understand and generate new knowledge to improve organisational processes.

The action research process involves typically five steps (Johnson, 2011): Identify the problem (1), Decide method of data collection (2), Collect, organise and analyse the data (3), Explain the findings and describe how to use them (4) and Act, implement the result and share the findings (5). It is often necessary to repeat several steps after reflecting and acquiring new knowledge (ibid), which also occurred in the present study, where at least two full cycles were conducted.

This study includes various data sources, such as policy and governing documentation and regulations, quality assurance systems and evaluation results from several HEIs', questionnaire, literature references and in-depth analyses and evaluations of seven HEIs in Sweden and Denmark.

Cycle One

The problem identified (1) was a new national quality assurance system (Johansen, 2016), which made it necessary and eligible to review, develop and improve the existing quality assurance system in a HEI, henceforth referred to as “the institution”. Method of data collection (2) was observations and analysing the new national quality assurance system, different HEIs' quality assurance systems and other governmental regulations (2017-2018). Analysing, reflecting and gaining profound knowledge (3) of different quality assurance systems became the starting point for developing and improving the institution's quality assurance system (2018-2019). During the time the new system was being developed and implemented (4 and 5), the institution was included and assessed in the national HEIs' quality assurance processes. Therefore, a self-assessment (5) was made in the fall of 2019 and site visits and interviews were conducted by the external assessment panel in the spring of 2020. The results of the institution's assessment were presented in the fall of 2020.

Cycle Two

Experiences, learning and reflections during the period (2018-2020) led to developing a quality assurance system that was different from the others, with a focus on being simpler and more resource efficient, particularly regarding external evaluation of education programs. To understand the incentives of other quality assurance systems, this component (external evaluation of education programs) was selected to investigate further (1) with a survey (2). The focus of the survey was to examine both how much effort (time) was spent on conducting external evaluations and whether it led to the development and improvement of the educational program.

To investigate this, a questionnaire was designed to collect quantitative and qualitative data (2). The questionnaire was sent (April 2020) to a network of quality coordinators at Swedish HEIs focusing the process of external evaluation of educational programs and how much effort, time, and/or resources used on this process per evaluation (3). This process was chosen partly because that component differed from the institution's system and partly because teachers must dedicate time to additional documentation, and teachers from other HEIs (often) serve as external assessors. The survey was created by the authors based on their experience and expertise as external auditors in higher education. It was designed according to a general process of external evaluation, consisting of six parts: 1. Preparation, 2. Self-assessment, 3. Preparation for external auditors, 4. External review, 5. Reporting, 6. Quality improvement (see figure 1).

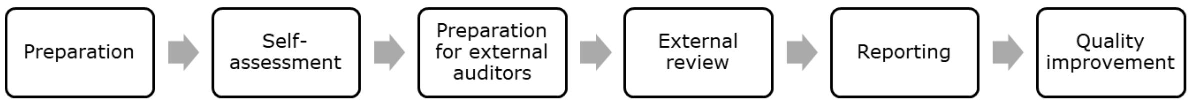

Figure 1*. A general process of external evaluation. (Source: authors)*

The survey was sent to the respondents through the software Evasys (www.alcom.se/evasys/) with two reminders. Analysis of the quantitative answers were made through the software SPSS (www.ibm.com/spss). The qualitative answers were analysed, systematised and structured by the methods affinity diagram and interrelationship diagram (Bergman and Klefsjö, 2010) (3).

Improvement and further development of the institution's quality assurance system (4) was conducted (2020-2022). The development was based on the survey results, analysis of the institution's review results and a deeper examination of various quality assurance systems and outcomes from other HEIs' institutional reviews. Also experiences from in-depth analyses and evaluations of HEIs in Sweden and Denmark (as external experts in assessment panels in institutional reviews, 2018-2023) was used.

The updated institution's quality assurance system was implemented (5), and the feedback report was submitted to Swedish Higher Education Authority (UKÄ) in October 2022. In January 2023, the new results came in, which was “Approved quality assurance processes”. An overall assessment of “approved quality assurance processes” means the HEI's quality assurance processes are well described, well-reasoned and well-functioning in practice (Swedish Higher Education Authority, 2023).

Results and Discussion

Cycle One

The new national quality assurance system, which was developed by UKÄ in collaboration with the Swedish HEIs, assigned an increased responsibility for quality assurance of education in each HEI. Therefore, all HEIs quality assurance processes were developed to meet the new demands (1). Different quality assurance systems and other governmental regulations, were to studied and analysed (2) in order to develop and improve the institutions quality assurance processes and systems. Reflections and discussions led to gaining profound knowledge and understanding of quality assurance processes.

The existing quality assurance system (at the institution where the study was conducted) was redesigned and renewed based on findings and experiences through observations (in Sweden and Denmark) and by analysing the sources and references stated above (2018-2019), (3). It emerged that most HEIs quality assurance systems were very similar, and it was obvious that the HEIs were benchmarking each other to develop new quality assurance systems. One difficulty identified was to ensure that the quality assurance system for education and research was related to the HEIs overall quality system (management and governance). Many HEIs' had meticulous and comprehensive quality assurance of education, but often there was insufficient connection to overall strategic planning processes. This gap was important to bridge (4).

To bridge the gap between strategic planning processes and the quality assurance processes for education, a structure was developed with systematic dialogues including quality reports at various levels throughout the institution, with a focus of still being simple and resource efficient.

Systematic dialogues including quality reports (5)

Quality development discussions start in teacher teams, where continuous improvement is discussed for courses and programs. Suggestions for further progress are documented in course analyses and program reports. Once a year program reports from each program is written by program councils (consisting of teachers within each program), see figure 2.

The yearly program reports are based on a simple template (established by the HEI's Research and Education Board) to ensure and document that all quality requirements within education are systematically reviewed. A common template also simplifies and facilitates the documentation for the teachers (in program councils) who also assess how the quality requirements are met within “their” educational program. In the program report, improvements and development implemented during the last year, are reported. The program council also proposes new actions for improvement based on the review and analysis of the quality requirements and notes these in the program report, which completes a typical PDSA-cycle.

The reports are evaluated by a departmental educational committee (consisting of teachers elected from the faculty). Then the committee has dialogues with each program council and the suggested improvements are discussed and decided.

Once a year, the most important improvements and suggestions for continued development are compiled in a department quality report. This is done by the departmental educational committee, which is responsible for the educational quality at each department. The committee thereafter initiates a dialogue with the department's management about staffing and other development proposals that require resources like teacher time or investment.

The institution's Research and Education Board, which is a board consisting of teachers elected from the various departmental educational committees, produces an institution-wide quality report based on the department's quality reports. In that report, proposals for overall quality improvements in education are compiled. The quality report subsequently is the basis for dialogues with each department's management and with the HEI's top management i.e., a part of the overall management system. In the education quality dialogue with top management, strategic decisions for education are decided and planned. The core value here is that top management listens to and trusts the competence of employees throughout the organisation. External auditors are therefore unnecessary because employees are the ones who best understand the organisation and know what is in need of improvement.

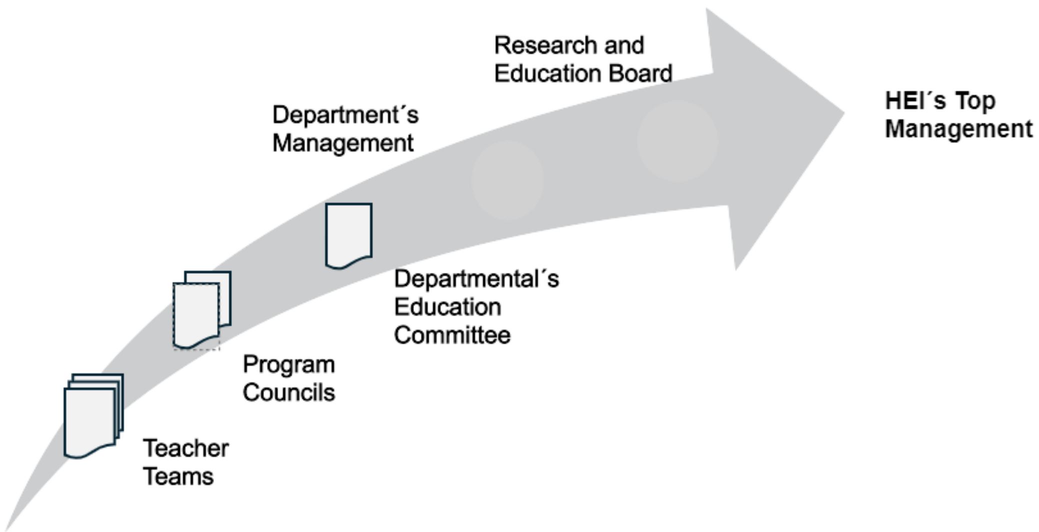

Figure 2. *Systematic quality dialogues to bridge the gap between strategic planning processes and the quality assurance processes for education. (Source: authors)*

Cycle Two

During the national review, describing quality assurance procedures for a comprehensive self-assessment, various reflections naturally occurred. Later, in 2020, the external assessment panel conducted site visits and interviews with different employees, including both physical and online visits, which also prompted further reflections (1).

Further benchmarking and analysis of several quality assurance systems and evaluation results from various HEIs' (2019-2020) indicated that most quality assurance systems were unnecessarily complicated and resource intensive. It seemed that benchmarking and evaluations led to a "national "standardisation of quality assurance systems (3). It became clear that the institution's quality system thereby differed from other HEIs'. Typically, the HEIs' quality assurance systems are based on a cycle of activities that involve measuring, adjusting, and reassessing processes. In several of these systems, external peer review of educational programmes appears to be an important component, where the HEI (i.e., the teachers) produces a comprehensive amount of material. The external reviewers (i.e., a teacher from another HEI) then need to understand and evaluate the material, after having to request supplementary documentation, and thereafter carefully describe weaknesses, clarify strengths, and suggest improvements and development. This seems to be too time consuming for teachers who should focus on teaching and research without being overwhelmed with new tasks (1).

This reflection therefore resulted in conducting a survey (2) with the aim of understanding the time and effort invested in external evaluations and assessing the impact on the improvement of the educational program. A questionnaire was developed and distributed to a network of quality coordinators at Swedish HEIs in April 2020 (3).

The total number at the network send list were 88 quality coordinators representing 44 different HEIs in Sweden (there are approximately 50 HEIs in Sweden according to uka.se). Answers from 30 different HEIs were received. The survey revealed significant variation for time allocated to external reviews. Figure 3 shows that for example part 1, preparation (see figure 1) the time vary from 3h to 100h. For part 2, self-assessment the time vary between 8h to 120h. The variability may stem from the fact that many respondents do not measure the time directly but instead make informed estimates. Also, they might not have the same process as described in figure 1, which caused difficulties in timing the various parts.

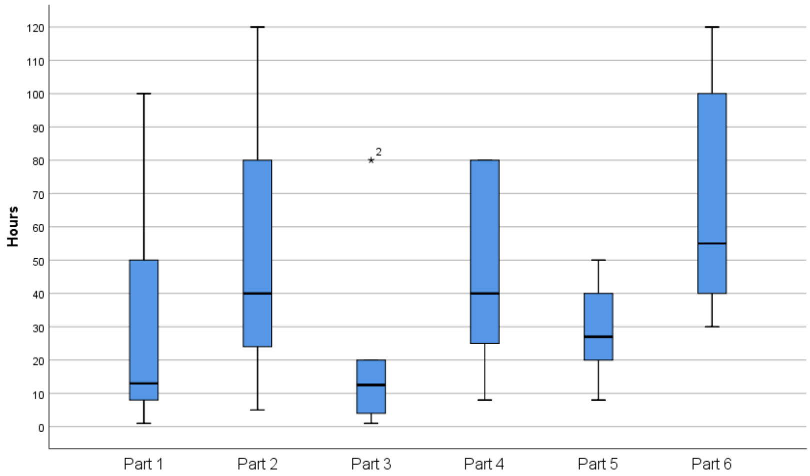

Figure 3*. Box-plots showing the variation of time spent on various parts (figure 1)of an external evaluation.*

The study also revealed significant variation in the number of implemented improvements, ranging from zero to eight (see Table 1). In average the external review led to two-three improvements taking, in average 65 hours per improvement. If the survey had included responses from other roles within the institutions, the results might have been different.

Table 1. *Distribution between number of improvements conducted after an external review.*

Number of improvements	0	1	4	8
Number of HEIs	6	1	8	1

In October 2020, the institution received the result "Approved quality assurance processes with reservations" from the national institutional review of the quality assurance processes. That result meant that the institution had a two-year period to enhance and refine its quality assurance system, incorporating the improvement recommendations suggested by the assessment panel. The most important identified assessment criteria that had not been assessed as fulfilled, concerned external evaluations of education.

Therefore, the institution started to plan for external educational evaluations as a new component in the quality assurance system (4). The process of developing the external evaluation was based on recommendations from assessment panel, results from the survey, and experiences from in-depth analyses and evaluations of HEIs in Sweden and Denmark (as external experts in assessment panels in institutional reviews, 2018-2023). There was also a focus on trusting the internal processes and the continuous improvement work conducted by teachers and students. Finally, there was also a clear focus on minimising resource usage and not putting extra burden on the teachers and still receive valuable feedback on education quality. The work on developing external evaluations was driven by the quality manager in dialogue with top and middle management, the Research and Education Board and the Student Union. The starting point was to use already existing documentation extensively. The most important information about the program's content and quality can be understood by using course syllabuses, course evaluations, course analyses, programme syllabus, program description, and annual program reports. A pilot evaluation was initiated and carried out in 2022 with satisfactory results.

External evaluations have been an important component of the institution's quality assurance system since 2023. Each program undergoes an external review every six years. The teachers' responsibility is to appoint and contact two external evaluators and to take an active part in a feedback dialogue which is considered to be the most important part of the full process. At the feedback dialogue, the internal teachers get a chance to discuss development and improvement with two deeply knowledgeable external teachers. These dialogues are very fruitful.

Otherwise, all documentation is prepared by the quality department, which also has contact with the external evaluators if they need additional material. The evaluators receive clear information about the evaluation criteria, and they get a template to facilitate the assessment. The feedback is partly received through the dialogue described above, but they also from a short and written report based on a simple template the evaluators have access to. In terms of time estimation, the evaluators have stated that they have spent between 20-40 hours on evaluation and feedback, which is significantly less than what other reviews take, according to the authors' experience.

From 2022 to June 2024, more than 20 programs have been evaluated according to the new process. The vast majority with satisfactory results. The external evaluators have mostly had enough material and documentation to be able to assess. The internal teachers have been very satisfied with the feedback received. The quality department systematically collects feedback from both the internal and external teachers and updates and improves the process annually.

Conclusions

Increased external demands for measurable quality in the public sector, thus also within the HEIs, have led to increased requirements to measure, follow up, and document all processes with respect to quality. The intention is good, but lack of competence in quality development has led to a development of complex, rigid, and extensive quality systems that require a lot of resources. In HEIs, these complex and extensive systems affect the teachers, who therefore have less time to teach and research. This case study shows the possibility to simplify and build an efficient quality assurance system based on teaching and learning processes used by teachers.

The purpose of quality assurance systems is to improve education for students while maintaining or improving the working environment for teachers, i.e., fit for purpose. To be able to develop resource-efficient and appropriate quality assurance systems, those responsible must have competence in quality, understand and appreciate internal dialogues, and have confidence in teachers' competence. By building a chain of trust within the institution, this is possible.

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The role of sustainability as a Hypernorm for Service Ecosystem Transformation of Circular Economy

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Abstract:

Sustainable business practices based on Agenda 2030 Sustainable Developmental goals (SDGs) as a hypernorm, is in this paper used to conceptualize the transformation of business ecosystems from a firm centric to a societal perspective. The transformation of business practice is crucial for achieving a circular society. Our article uses theoretical and conceptual framing embedded in service ecosystem research by focusing on sustainability to identify and discuss key concepts for developing a conceptual model to explain how to transform from circular economy thinking to a circular society. There is a widely accepted view that transformation into a circular society is needed. Circular economy is about resource efficiency to decrease an environmental impact with more efficient use of a resource leads to higher consumption of that resource. However, it is lacking in understanding and assessing the societal thinking and practice of engaging with the actors and stakeholders. Hypernorm is used as the guiding "light" for collaborating actors to achieve a circular society. The hyperlight guides engaged actors, their efforts, and collaboration, when transforming different service ecosystems, including value creation in different nested sub-systems. The explanatory power of the suggested framework is shown in three role model firms in different business ecosystems: IKEA, Löfbergs, and Toast Ale. They all use circular thinking and innovation when identifying challenges and transforming their business ecosystems, thus contribution to implementing the SDGs.

Keywords: Hypernorm; Sustainable Developmental goals(SDGs)-Agenda2030; Service Eco-system; sustainability; transformation; service.

Introduction

Overall, business and society face many global challenges, including economic, social, and environmental challenges (Sebhatu et al. 2021; von Weizsäcker and Wijkman 2018; Elkington 2019). These challenges need to be understood and tackled in a new manner by considering both the details of the systems, including sub-systems and the landscape of the service ecosystem as a whole. There is a need for sustainable business and societal practices fostered by a transformation agenda to meet interrelated global challenges, such as climate change, the imbalance between humanity and nature, the distribution of value, the acceleration of globalization, and digitalization (Sebhatu et al. 2021; Rockström and Klum 2016; Raworth 2018; Vargo and Lusch 2017).

We may argue that a transformation agenda that is widely known and accepted, namely, the UN's Agenda 2030 and its Sustainable Developmental Goals (SDGs), is in place to meet these global challenges today. These goals are operationalized and grounded in a plan of action for "people, planet, prosperity, peace, and partnership,"(UN, 2015).)[1] in which regions, nations, cities, companies, and civil society are encouraged to transform into sustainability. SDGs can be seen as a hypernorm in transforming the values of businesses and other organizations and act as a driving force for multiple actors to join forces toward a circular society. A hypernorm (Laczniak and Kennedy 2011) refers to institutionalizing and facilitating processes in the ecosystem, thus forming the basis for stakeholders to join forces when collaboration in an ecosystem.

Viewed through the lens of Service Dominant logic - S-D logic, an ecosystem is understood as a configuration of actors, resources, and institutional arrangements (Vargo and Lusch 2016), and the system is emerging and self-adjusting (Vargo et al. 2022). Despite the importance of self-adjustment to service ecosystems (Frow et al. 2019), relatively little is known about how it unfolds within and across these sub-systems, and how self-adjusting processes influence the shaping (including transformation) of the ecosystem as a whole. There is a need for a shared purpose across stakeholders and a transformation focus grounded in shared values and shared meaning (Edvardsson and Enquist 2009).

Extant literature offers multiple, sometimes conflicting accounts of the general emergence of service ecosystems (Vargo et al. 2022). Therefore, this paper aims to contribute to conceptualize the dynamic transformation of the ecosystem by adopting a hypernorm used as the "light." The hyperlight unites the actors/ stakeholders, their efforts, and their collaboration and thus influences the different sub-systems as well as the action in the different nested sub-systems, creating forces that may impact the ecosystem as a whole–the planet. Therefore, in this context, SDGs and sustainability are the light that drives the complex transformation process.

Sustainability and its social dimensions have also been identified numerous times as important research themes in transformative service research (TSR) (Blocker et al. 2021, cited Anderson et al. 2021; Anderson and Ostrom 2015; Anderson et al. 2013). A central concept in service research is value co-creation in the context of service ecosystems (Vargo and Lusch 2018). To meet the global challenges of transformation, this value creation must be balanced with sustainability thinking and social justice in multi-stakeholder dialogue too (Sebhatu and Enquist 2022). Mazzucato (2018) has criticized the distribution of value in the systems and sub-systems, asking: Who is making and who is taking in the global economy? She wants to reinvent value as a key concept and return to the question: What creates value? (Mazzucato 2018). She argues for a green transformation, which is not only about developing green infrastructure but also about having a clear vision of what living a green life means. This also implies the transformation of all sectors (Mazzucato 2018, 278) as a hypernorm and makes sustainability circular or regenerative (von Weizsäcker and Wijkman 2018; Elkington 2020; Raworth 2018). However, existing frameworks in management and service research have primarily

[1] Henceforth, we use the official United Nations (2015) "Transforming Our World" agenda (A/RES/70/1) to describe the SDGs unless it is referenced.

focused on value creation and economic challenges rather than adopting a holistic approach. Thus, they have fallen short of explaining and tackling social and environmental challenges by looking at multi-stakeholder dialogue for a holistic transformation of systems and sub-systems.

The focus of this conceptualization is therefore different in that it builds on the foundation of sustainable business practices in a circular society, more specifically a transformation process from a product- and firm-centric perspective to adopt a holistic ecosystem view to embrace new societal practices (Laczniak and Murphy 2012). These practices are characterized by inclusive stakeholder orientation, when moving from a firm-centric perspective to a societal perspective grounded in ethical, macro-oriented, and ecosystem views.

This conceptual paper contributes to the ongoing discussions on sustainability and service research and the underdeveloped perspective of the transformation of ecosystems. This is done by focusing explicitly on linking a conceptual model of sustainability to a circular economy using the sustainable transformation of business-societal practices to make society more circular. Our conceptual development follows Jaakkola (2020) and identifies previously unexplored connections between constructs. Specifically, we identify and reconcile the connections between sustainability and service research, more specifically adopting a service ecosystem view. Furthermore, the conceptual model introduces new constructs (Jaakkola 2020) by building on the construct of hypernorms. The new constructs in our study link the adoption of sustainability beyond a circular economy toward a circular society. The circular economy is mainly concerned with resource efficiency to reduce environmental impact. The circular society view emphasizes understanding and assessing the thinking and practice in which resources are circulated in sustainable loops and stakeholders/actors are also circulated and transformed.

The purpose of this conceptual paper is to explain how sustainable business practices enable the transformation of a circular economy into a circular society. This transformation does not occur in a vacuum. It is systemic and emergent in nature and is driven by multiple interactions in the systems and sub-systems of collaborating actors (Vargo and Lusch 2018; Vargo et al. 2022) or stakeholders. The explanatory power is shown in an empirical investigation using a qualitative approach of three values-based enterprises: IKEA, Löfbergs, and Eataly. These three enterprises use circular thinking and innovation as proactive tools to identify challenges and develop a transformation agenda for implementing the SDGs.

Method

The purpose of this conceptual paper is to explain how sustainable value co-creation, manifested in business practices, enables the transformation of a circular economy into a circular society. The explanatory power of the framework is shown by referring to three businesses that have developed a transformation agenda towards a circular society: IKEA, Löfbergs, and Eataly. In this study, we adopted a qualitative research methodology and case study approach. This study focuses on three values-based businesses, namely IKEA, Löfbergs, and Eataly, and includes their business ecosystem context. The three companies use circular thinking and innovation in different ways as a proactive tool for identifying challenges and developing a transformation agenda in implementing the SDGs. Consistent with a grounded theory approach, our cases were developed over a long period, for instance, IKEA (Edvardsson & Enquist, 2002; Edvardsson et al., 2005). The data used in this study were collected between 2015 and 2020 (each case over a different timeframe) and include interviews, interview transcripts, observations, transformation lab (T-lab) discussions (Sebhatu et al., 2021), and documents (e.g., steering documents, field narratives of positive and negative incidents, key performance figures, and annual reports), in combination with field data (Alvesson & Sköldberg, 2010). The collected materials were transcribed, thematized, and analyzed through within- and cross-case analysis (Eisenhardt, 1989) based on grounded theory procedures (Glaser, 1992).

Results and Discussion

The evaluation of the multidisciplinary theory and conceptual framework building for the template fits with the aim of this study to look for a new model of the circular economy into a circular society based on the business model using sustainable value co-creation. This aim is achieved by using SDGs as hypernorms to guide sustainable business practices, thus creating sustainable societal practices. Our suggested model highlights key elements of transforming from a firm-centric perspective to a societal perspective. This means that the service ecosystem is characterized by ethical, macro-oriented, and holistic views when shaping values-based business and societal practices (Laczniak & Murphy, 2012). The paper illustrates this by referring to three businesses that work with circular thinking and innovation in developing their business models and ecosystems toward a circular society. These three cases illustrate how businesses can adopt sustainable practices, guided by SDGs as hypernorms, to transform their business ecosystems toward a circular society. They show the importance of collaboration, innovation, and a systemic approach in achieving sustainability goals. This conceptual article contributes to the ongoing discussions on sustainability and service research and follows Jaakkola (2020) and identifies previously unexplored connections between constructs. Specifically, we identify and reconcile the connections between sustainability and a service ecosystem view. Furthermore, the conceptual model introduces new constructs (Jaakkola 2020).

Conclusions

This conceptual paper has developed a framework for understanding the transformation from a circular economy to a circular society, guided by SDGs as hypernorms. The framework emphasizes the importance of sustainable business practices, value co-creation, and collaboration among stakeholders in achieving this transformation. The case studies of IKEA, Löfbergs, and Eataly provide practical examples of how businesses can implement these principles and contribute to a circular society.

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Track 11: TQM and Employees

Thriving in complexity: A systematic literature review of the presence and application of psychological safety when leading for quality

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Abstract

The current era is defined by unprecedented complexity and uncertainty, presenting new demands on organizations and individuals to thrive in an interconnected environment with constant change. In the field of quality management, there is ongoing discussion about the emergence of a new paradigm. This shift challenges traditional hierarchical management models and traditional ways of leading for quality, accelerating the decentralization of authority and coordination in self-managing teams. Collaboration emerges as a critical success factor, highlighting the phenomenon of psychological safety, recognized as pivotal for high-performing teams to navigate complexity and meet new demands. The aim of this study is to contribute knowledge about the presence and application of psychological safety within quality management practices. A systematic literature review was conducted to examine the current research landscape and identify gaps. A total of 81 articles were included, with both descriptive and open coding accomplished. The results from reviewing peer-reviewed articles revealed a growing body of literature on psychological safety within quality management, evidenced by the increased number of articles over the past 2.5 years. Notably, 84% of the publications are focused on the healthcare sector, indicating a significant research gap in other sectors. The thematic analysis revealed emerging themes related to leadership, frequently linked to psychological safety and leading for quality. The results reflect a shift in the leadership dynamics towards leading for quality with less hierarchy focusing on the potential of shared leadership. Psychological safety appears to be an antecedent that fosters the development of shared leadership when leading for quality in today's complex world.

Keywords: Psychological safety, Quality management, Complexity, Leadership

Relevant Topic: Quality culture, leadership, and human factor in quality management

Introduction

Quality management is embarking on a new paradigm characterized by complexity and constant change, which in many cases demands transformation (Fundin et al., 2020; van Kemenade and Hardjono, 2018). In parallel, the phenomenon of psychological safety has been highlighted as a prominent enabler for navigating and thriving in such an interconnected and complex world (Edmondson, 2018). The curiosity of this paper lies in determining whether quality management utilizes the potential of psychological safety in this evolving paradigm. The first step is to get an understanding of the presence and application of psychological safety within quality management practices today and to obtain an overview of the research landscape.

The unprecedented complexity and uncertainty of today's world present new demands on both organizations and individuals to thrive in this interconnected environment with constant change (Edmondson, 2018; Lilja et al., 2022; van Kemenade and Hardjono, 2018). The challenges will become even more profound, given the exponential pace of change. Thriving in this environment requires capacity for transformation, as the methods and approaches that once led to success are no longer as effective (Norrman Brandt, 2019). The old logic no longer applies. Many organizations are still designed for more stable conditions and are not prepared for or capable of transformational change. This is supported by research indicating a mere 12% success rate in transformational efforts (Mankins and Litre, 2024).

According to Edmondson (2018), today's organizations must build resilience within the organization to navigate unpredictable changes and enable adaptive capacity. At the same time, they must ensure that their employees are prepared, willing, and well equipped to embrace constant change. This is confirmed by Uhl-Bein and Arena (2018) who express that one of the biggest challenges facing leaders today is the need to position and enable organizations and people for adaptability in the face of increasingly dynamic and demanding environments. In an interview, Peter Senge highlights the large shift of giving up control and the need to become comfortable in change, by not knowing and not controlling what will emerge (Reese, 2020).

Steiber and Alänge (2013) highlight the risk that total quality management (TQM), considered in this paper as part of quality management, might hinder companies' ability to innovate and quickly adapt to change, especially in rapidly changing environments. Van Kemenade's and Hardjono's (2018) research show that TQM must enter a new paradigm. They describe a paradigm that they call the "emergence paradigm", which addresses quality management in complex contexts where wicked problems are dominant and demand an increased level of collaboration to be managed. They further believe that this paradigm has not received enough attention, even though it seems to be the best equipped for finding new ways of working to meet the demands in a complex environment. Fundin et. al (2020) express potential by addressing that quality management over the years has shown an impressive ability to update and evolve in response to the context and shifting needs of organizations.

According to this paradigm, there is no right way to lead a business. Van Kemenade and Hardjono (2018) use a metaphor to illustrate this transformation towards a new paradigm by describing leadership in terms of moving from being a conductor of an orchestra to being a jazz musician in a jam session where you improvise, remain attuned to the contributions of others, and adapt to the ever-changing dynamics. This metaphor is also similar to that of Laloux (2014) and his theories of self-organization. This transformation challenges traditional hierarchical management models, as well as traditional ways of leading for quality, by accelerating the decentralization of authority and coordination in self-managing teams to foster greater autonomy and innovation (Lee and Edmondson, 2017).

In traditional hierarchical management models decision pathways become too slow, and mandates and decisions need to be moved into teams to pace with the rapid speed of change (Lee and Edmondson, 2017). This places new demands on both teams and leaders. Runsten and Werr (2016) express that when we can no longer coordinate from above, coordination must occur from the bottom up. They further argue that a consequence of this is more coordination in groups and teams along with a greater need for self-organization and collaboration skills. Self-managing teams are formed more as self-determining units instead of building on hierarchical structures. Fundin (2020) indicates the importance of enabling and supporting self-organization in response to increasingly complex and challenging situations.

Consequently, collaboration emerges as a critical success factor and highlights the phenomenon of psychological safety, recognized as pivotal for high-performing teams where relational dynamics and individual development take precedence (Harvey et al., 2023) Psychological safety is not only an important factor and vital for collaboration, innovation and, learning, studies also show that psychological safety is an enabler for successfully navigating and performing in a complex, unpredictable and interdependent world (Edmondson, 2018). The connection between team psychological safety and quality was already expressed in the early work of Edmondson (1999) in the 1990s.

Psychological safety is defined as a shared belief held by members of a team that the team is safe for interpersonal risk taking (Edmondson, 1999). This means that team members dare to take interpersonal risks despite feeling uncomfortable. It is about reducing interpersonal risk so that we dare to take risks and think differently, try new ways, talk about mistakes, speak up, ask questions, and challenge the status quo. These behaviours are necessary for addressing complex problems, being innovative and acting in an agile way to adapting to change (Edmondson, 2013; Harvey et al., 2023).

Edmondson (2018) emphasizes that psychological safety is not about always agreeing and affirming one another in order to be kind, which can sometimes produce misconceptions. Psychological safety is the opposite; it is about sincerity and openness to productive conflicts to learn from different perspectives. Psychological safety sets the standard for a more honest, challenging, collaborative and, thus, more efficient environment. It is also important for the discourse that psychological safety is not the only thing needed to create high-performing teams, but psychological safety removes the brakes that hold people back from reaching their and the organization's full potential (Edmondson, 2018). The ability of a team to create a psychologically safe atmosphere that cultivates the willingness to take interpersonal risks and share information and knowledge becomes vital.

Social human beings tend to hold back, driven by the perception of risk and the fear of being rejected and appear as less competent, a completely rational reaction from a social perspective (Argyris and Schön, 1995). However, when individuals hold back, we receive inferior input and miss crucial information. Bugdol (2020) highlights the absence of a deeper discussion about the effect of fear within today's quality management, referring to Deming's (1986) principle for effective quality management, the importance to "drive out fear".

As a background, Amy Edmondson is the researcher currently most closely associated with psychological safety due to her groundbreaking work. In the 1990s, she conducted studies that opened the door to exploring psychological safety. Within the health care sector, she hypothesized that successful teams would make fewer mistakes. However, the results showed the opposite trend. This led to the exploration of whether these teams actually made more mistakes or whether they were more willing to acknowledge and discuss their errors, thereby reporting more mistakes (Edmondson, 2018).

Psychological safety is not a new concept, but it is now used more frequently in the business world because it appears to be increasingly important and relevant today and it has also become well established in the organizational literature (Bahadurzada et al., 2024). Another major reason for the increased interest in the phenomenon is related to the impact of Google's five-year study in 2014, Project Aristotle. Google wanted to understand what differentiates successful high-performing teams from less effective ones to be able to build the best teams (Duhigg, 2016). What was interesting in the study and what surprised the research team was the importance of psychological safety. It turned out to be the most important of the five success factors for high-performing teams and the factor that creates the conditions for being successful in the other four areas (Duhigg, 2016). This turns out to apply to teams regardless of their role and level in the organization (Edmondson, 2018).

The transition towards decentralization of authority, more self-managing teams and the potential of psychological safety also challenges conventional leadership dynamics and forces the expansion of traditional leadership models, including concepts such as self-leadership and shared leadership (Bligh et al., 2006). In this leadership dynamic, Runsten and Werr (2016) emphasize that employees must be as large a part of the leadership process as possible. They further argue that interpersonal skills, the ability to build relations, are critical skills for collaboration and for building psychological safety. According to this the need for self-awareness is highlighted when the cognitive and emotional dimensions of teamwork are fundamental for high-performing teams in a changing economy (Eurich, 2018).

This redefines the role and expectations of leaders, positioning them more as facilitators of self-managing team development and amplifying emergence of creativity, innovation, learning and growth (Uhl-Bien and Arena, 2018). According to this approach, leaders are often much less hands-on and much more behind the scenes and willing to step back than traditional leadership. More distributed and involving, recognizing that they do not always have the answers and are not the primary decision-makers. According to Uhl-Bien and Arena (2018) these behaviours are associated with leadership for organizational adaptability. The strong relation between psychological safety and leadership behaviours is also confirmed in research (Edmondson, 1999; Nembhard and Edmondson, 2006). Van Kemenade and Hardjono (2018) describe the evolving emergence paradigm within quality management by highlighting that future leadership when leading for quality will not dictate direction but rather will listen to where the organization aims to go.

Purpose

The purpose of this study is to contribute knowledge about the presence and application of the phenomenon of psychological safety within quality management. It aims to provide an overview and understanding of the current research landscape that focuses on the utilization and discourse surrounding the concept of psychological safety within quality management practices. It also examines the gaps in the literature and seeks to understand how further research might address these gaps.

Research Questions

RQ1: What is the current research discourse surrounding the presence and application of the phenomenon of psychological safety within quality management practices?

RQ2: What gaps exist in the literature regarding the intersection of psychological safety and quality management practices?

Methods

A systematic literature review was conducted, and the study was guided by two research questions. The review followed the guidelines outlined by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, with some minor adaptations related to the characteristics of the research questions and research design (Gough et al., 2017). It included three basic steps: planning the study, conducting the study, and reporting the results of the study (Tranfield et al., 2003).

Search Strategy

A systematic literature search was conducted in May 2024 using a combination of specific key words: "psychological safety" AND "quality management" OR "TQM" OR "quality improvement" OR "lean" OR "six sigma" OR "business excellence." The search terms were chosen to encompass a broad range of quality management practices and ensure the inclusion of diverse perspectives from different areas and sectors. Academic databases were searched for peer-reviewed articles and reviews, ensuring access to full-text articles in English across all geographic areas and years. These were the inclusion criteria, and duplicates were excluded. The first screening was performed to ensure full-text access. The remaining articles were screened by reading the abstracts for relevance and inclusion in the full-text review. Exclusions were made after the full-text review if the articles were not considered relevant and did not address the presence and application of psychological safety within quality management practices. The literature search yields 81 articles.

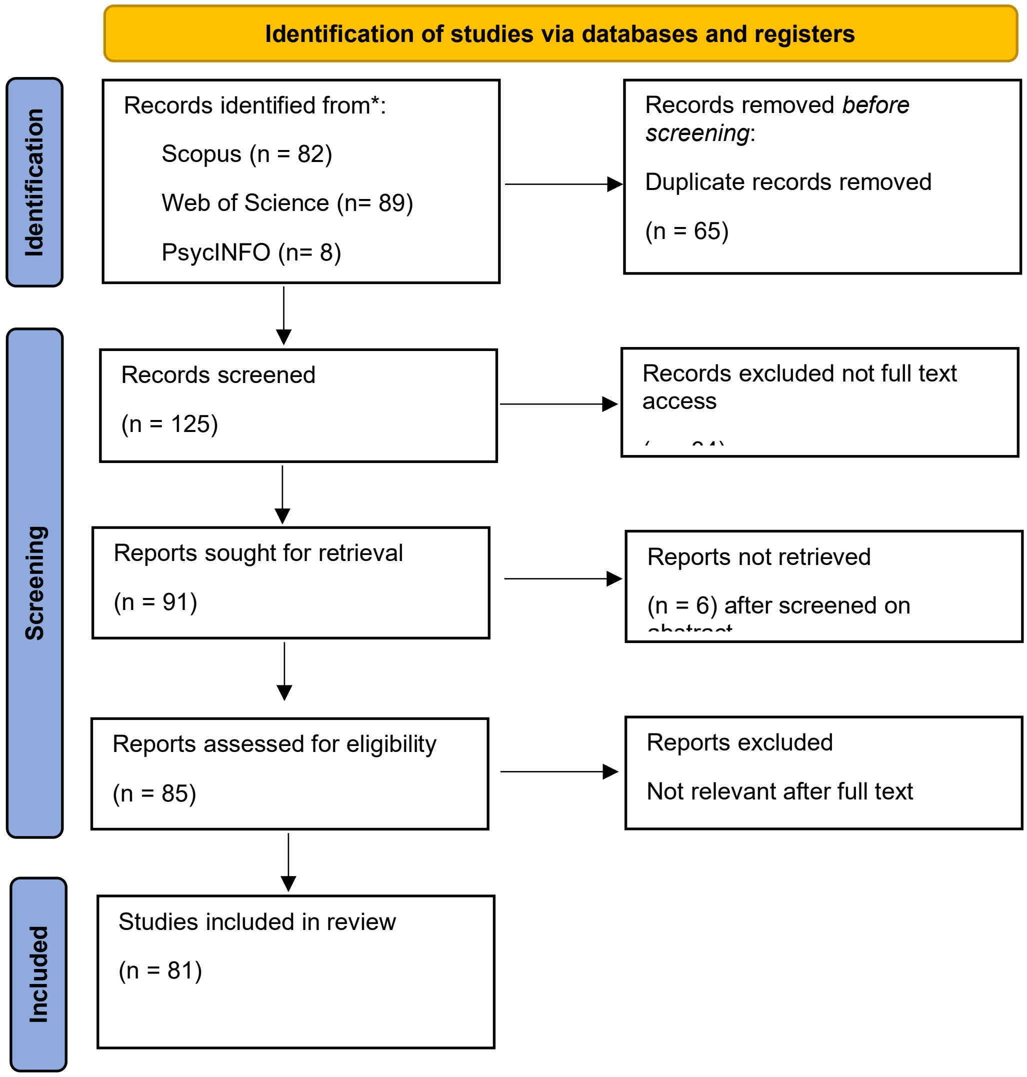

Figure 1. *Adjusted version of the original PRISMA flow sheet diagram (Page et al., 2021).*

Data Extraction and Coding

The data extraction process involved descriptive and open coding to systematically categorize and analyse the collected data. The process involved three steps: identifying, piloting, and testing the codes (Gough et al., 2017). This method provides a structured way to analyse the data and extract key information from each article, ensuring that the main aspects of each study are captured and can be compared across the dataset (Booth et al., 2016).

The descriptive coding process was designed to categorize and organize the extracted information from the selected articles (Gough et al., 2017). Coding was applied to categorize the extracted data based on the year of publication to identify the development of the presence and application of psychological safety within quality management practice over time. The data were also coded by sector to understand the context where the research was conducted, for example health care, manufacturing, education or services. Other coding elements were journal and research method. The purpose and title of the study was to determine whether psychological safety was the primary focus and objective of the study. Conclusions were extracted together with directions for future research to identify suggested areas for further investigation related to psychological safety and quality.

The open coding was conducted with an inductive approach. Open coding involves identifying and categorizing concepts and themes directly from the data without preconceived categories (Gough et al., 2017). This method allows a more flexible and comprehensive understanding of the data. The initial phase of the open coding was to access the full-text and use the search function in the PDF document to search for psychological safety within the full-text article to obtain an understanding of the context related to RQ1. Meaningful citations were marked and passed into an Excel spreadsheet, including details such as page number and article ID code, for reference. To provide a quick overview, a short summary was made, in a referred column in the Excel sheet, to describe the context in which psychological safety was mentioned in the article.

Piloting and test coding were performed with the research team of three people to ensure the relevance and reliability of the selected coding method. The first step was to ensure descriptive coding, and eight articles were selected randomly. Every researcher independently applied the coding method to all eight articles, and then the researchers convened as a group for discussion and evaluation. The pilot on the open coding was performed on two articles using the same procedure as the deductive pilot.

This piloting procedure was also part of the quality assessment of the process, and continuous dialog between the researchers was planned during all phases of the review. While acknowledging the potential for researcher bias, being systematic helps reduce the likelihood of bias and is a way of ensuring that a comprehensive body of knowledge is identified on the chosen subject (Tranfield et al., 2003). The involvement of a team of three researchers further mitigates the risk of individual bias. At the same time, the researchers allow subjective elements of meaning-making, recognizing that data interpretation is a social construction, and embrace the hermeneutic circle, where understanding is constantly refined through the interaction of parts and whole (Bryman, 2018).

After the pilot coding, the included articles were divided into three groups, one for each researcher. After completing the individual data extraction, the research team convened as a group to discuss the findings collectively to obtain an overview and discuss any discrepancies or uncertainties that emerged during the individual reviews.

Method of Analysis

A thematic analysis was conducted, based on the data from the open coding, to identify recurring themes and patterns within the citations and relevant excerpts related to psychological safety that were extracted from the full-text paper. The process involved gathering and analysing data using the digital tool Mural, which facilitated visualizing and organizing of the citations. The involvement of three researchers aimed to enhance the credibility of the findings, and the Mural workplace supported collaboration.

The initial phase of the analysis the researchers independently read through the collected citations and tried to identify key concepts and themes. This initial phase was aimed at capturing the essence of each citation without preconceived categories. The next step was collaborative sorting, where the researchers came together to discuss their initial reflections and grouped the citations into broader categories and themes. This step involved significant discussions on the categorization, ensuring that the themes reflected the data and included multiple perspectives. This iterative process involved refining and merging themes until a coherent set of themes emerged that accurately represented the data (Grant and Booth, 2009).

Results and Discussion

This systematic literature review aimed to identify and analyse the body of research focused on the intersection of psychological safety and quality management in relation to the two research questions.

- RQ1: What is the current research discourse surrounding the presence and application of the phenomenon of psychological safety within quality management practices?
- RQ2: What gaps exist in the literature regarding the intersection of psychological safety and quality management practices?

One important result is that the literature search revealed a trend with a growing interest in this area over the years, as evidenced by the number of articles retrieved from various databases. In the early years, starting from 2006, few articles explicitly addressed psychological safety together with the search words related to quality management. During this period, the concept of psychological safety was still emerging following Edmondson's first findings from her research on psychological safety, published during the late 1990s (Edmondson, 2018). There was a notable increase in the number of publications around 2016. The large increase is likely related to the impact of the Google study conducted in 2014 (Duhigg, 2016). In recent years, there has been a continuing upward trend in publications, with 30 articles, more than one-third of the articles included in the review, published in the last 2.5 years (2022, 2023 and Jan-May 2024).

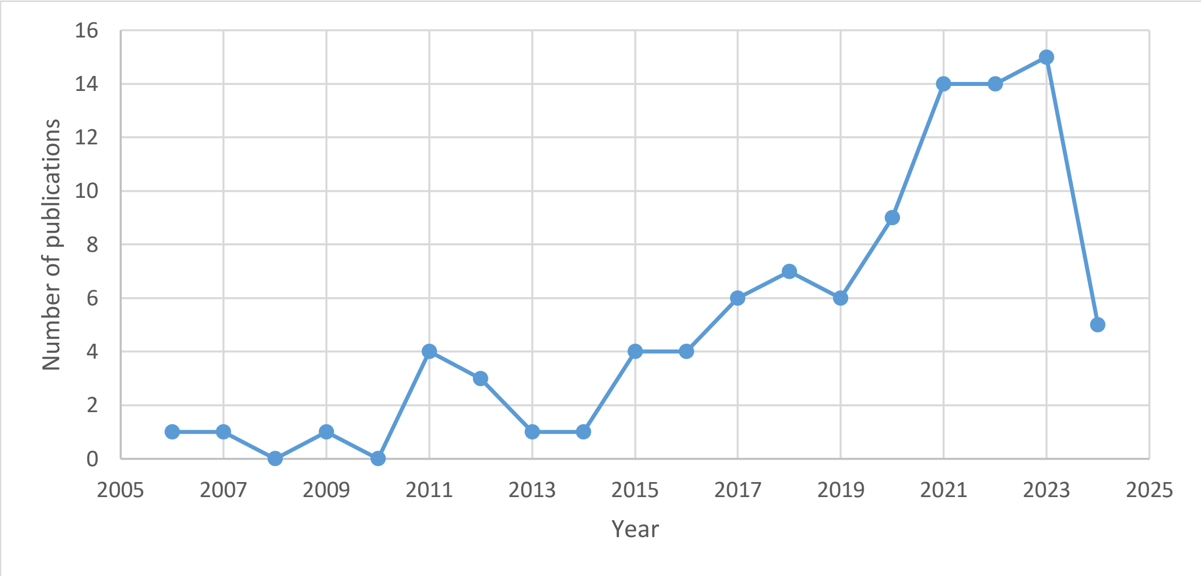

Figure 2*. Publications by year, covering the articles from the initial search.*

The result of the descriptive categorical coding by sector shows that health care is the dominant sector with 84% of the publications. This indicates a significant research gap in the literature on the presence and application of psychological safety within quality management practices in other sectors. Given that the collective existing research, predominantly in health care, so strongly indicates that psychological safety is a critical enabler and prerequisite for quality and improvement, that gap is surprising. This may be because Edmondson's initial research during the 1990s on the important connection between psychological safety and quality improvement was conducted in health care (Edmondson, 2018).

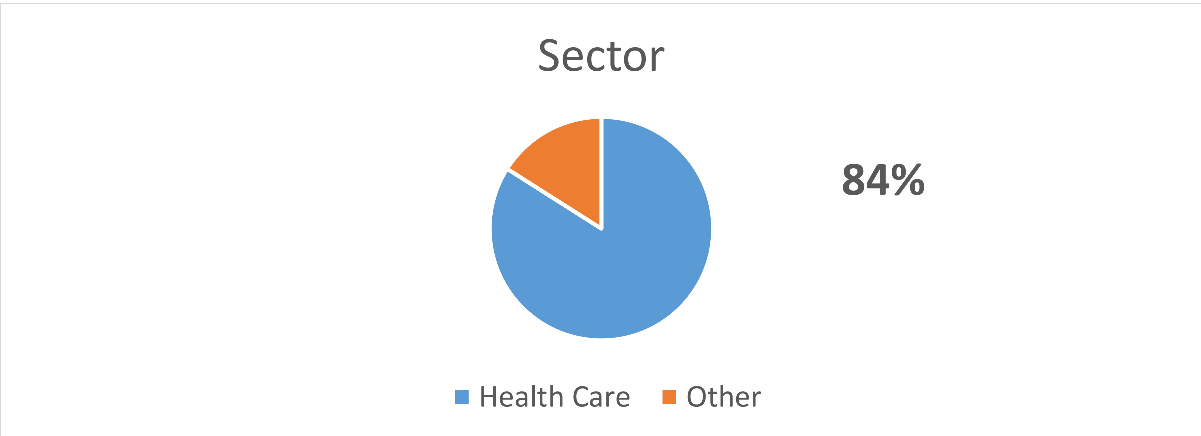

Figure 3*. Reviewed articles by sector*

According to the descriptive coding by title, 15 articles had psychological safety included in the title. In general, the purpose of the reviewed articles mainly focused on development, organization, and quality improvements. In the studies performed, the importance and relevance of psychological safety appears as part of the results rather than an intension to include it in the study from the start. This finding may indicate a gap in the literature on research intentionally examining quality management practices from a psychological safety perspective.

The thematic analysis of the open coding of extracted citations, showing the presence and application of psychological safety within quality management, has for this paper been limited to patterns concerning leading for quality. The analysis revolved around how leadership is frequently linked to the concept of psychological safety in the extracted citations. One result being that in the frequently recurring discussions on the necessity of a culture and environment characterized by psychological safety, leadership tends to be mentioned as a key factor for creating that culture. This type of statement is for instance made by Aranzamendez et. al (2015): "The findings show the complex dyadic interplay between leaders and team members. Current literature supports the significant role of leaders as one of the major contextual influences in promoting a psychologically safe environment" (p. 171). Alami and Krancher (2022) also support such notion, stating that "When people are culturally inclined not to speak up, then it becomes the role of the leadership to promote psychological safety to counter the effect of this cultural attitude" (p.164). Another related statement is "(…) strong leadership which establishes a constructive culture in order to promote process factors of trust, psychological safety, and culture of safety" (Campbell et al., 2023, p. 10).

In other words, leadership often appears as the solution to the question of "how" to enable, encourage, or facilitate for psychological safety in practice. While the articles frequently describe and suggest approaches for effectivity, performance, organizing and improvements, leadership gains increased presence in several citations when the focus shifts to how these objectives should be accomplished. Furthermore, the discourse tends to focus on the importance of specific leadership behaviour to encourage steps towards a culture of psychological safety, as exemplified by the following citation: "Leaders were involved in interventions through their behavior facilitating psychological safety or through showing their support and commitment to the intervention of psychological safety, speaking up and voice behavior within interdisciplinary teams" (O'Donovan and McAuliffe, 2020, p. 9). Examples of prominent behaviors or abilities mentioned in the articles are empathic and affirmative communication (Vikan et al., 2024), adaptability and anticipation of the needs of others (Santana et al., 2011), and being open, accommodating, and accessible to employees (i.e., strong, inclusive leadership) (Lin et al., 2022).

The value of the leader's presence also recurs, as shown in this citation: "Interaction between leaders and staff can foster psychologic safety. Leadership rounds - creates opportunities for communication and learning. Which can lead to engagement among staff" (Knobloch et al., 2018, p. 308). O'Donovan et al. (2019) also support such notion, stating that "Leadership walk/rounds, engaged leaders show leadership commitment to safety, foster trust and psychological safety" (p.877). An interpretation of this is the importance for leaders to foster relational connections with the organization and its employees. The need for training and leadership development programs is also visible in the following citations: "Leadership development programs must be designed to cultivate the ability of a leader to identify when to implement a specific leadership domain, being sensitive to the individual needs and context, in order to develop and sustain a psychologically safe environment" (Aranzamendez et al., 2015, p. 176).

The analysis of the reviewed articles also reveals a predominant view of leadership as hierarchical. However, the shift towards alternative leadership dynamics with an expanded view of leadership is also becoming increasingly visible. Recent articles have shown a greater focus on shared leadership in discussions on creating culture and meeting challenges and new complex demands. This is supported by Bligh et al. (2006) in the discussion of self-management teams. In the result psychological safety is highlighted as a vital component of the implementation of shared leadership, to see each other as leaders that facilitate psychological safety. This is exemplified by the following citations: "Our research results point to team psychological safety as an antecedent that fosters the development of shared leadership and, more importantly, these effects are stronger when the tasks are more complex and more interdependent" (Wu et al., 2024). This finding somewhat aligns with the future leadership that Van Kemenade and Hardjono (2018) describe as necessary for quality management in complex contexts. Moreover, discussions in the articles often highlight hierarchical structures as a challenge for fostering psychological safety and speaking up culture; however, citations indicate that shared leadership may oppose that challenge "Leadership, if viewed as a collective responsibility, could help breakdown power structures" (McElroy et al., 2024, p. 567).

Conclusions

This study provides a unique overview of the current research discourse surrounding the presence and application of psychological safety within quality management practices. The findings show a significant increase in interest in psychological safety and highlight a major escalation of published articles during the last 2.5 years. The study also reveals that the majority of research and hence articles, 84%, are focused on the health care sector. This result indicates a research gap in the literature on the presence and application of the phenomenon of psychological safety within quality management practices in other sectors.

Focusing more specifically on leading for quality, leadership emerged as an important theme in relation to psychological safety and creating a culture of quality improvement. The results highlight more specifically that 1) leadership often appears as the solution to the question of how to enable, encourage, or facilitate for psychological safety in practice, 2) the importance of specific leadership behaviour in doing so, 3) the value and quality of the leader's presence, and 4) the need for new ways of training and leadership development programs related to leading for quality.

The results furthermore reflect a shift in the leadership dynamics towards leading for quality with less hierarchy, and the potential of shared leadership is highlighted as an enabler of team effectiveness and quality development in areas of complexity. Psychological safety appears to be an antecedent that fosters the development of such shared leadership when leading for quality in today's complex world.

Future research

While much of the existing research predominantly focuses on the health care sector, an implication for future research is to expand this exploration to other sectors. Since psychological safety appears as vital for quality improvement, investigating psychological safety in diverse sectors could uncover broader applications and insights and enhancing an overall understanding of its role as an enabler when leading for quality. Related to the shift in leadership dynamics and the potential for shared leadership when creating a culture characterized by psychological safety, an interesting approach in future research is to identify how leading for quality can evolve with less hierarchical leadership structures. And to understand whether phenomena like self-leadership and relation leadership, accompanied with shared leadership can be enablers when leading for quality with a more interconnected and less hierarchical view of leadership.

Acknowledgements

The writing of this paper has partly been made possible by funding from the Kamprad Family Foundation through the project "Develop and improve together".

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Investigating the Relationship Between Employees' Demographics and First-Time-Right Measurement of Quality Performance: An Empirical Study in the Banking Sector

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Abstract

This study investigates the relationship between employee demographics (age, gender, educational background, and years of experience) and quality performance indicators in the banking sector of the UAE. Using data from 327 frontline employees of a major Islamic bank, the research employs a quantitative methodology to assess the impact of these demographic factors on quality performance. The results demonstrate significant positive correlations between age, gender, educational background, years of experience, and quality performance. The findings suggest that educational background has the highest impact on quality performance, followed by years of experience, age, and gender. Practical recommendations include the importance of tailored training programs and retention strategies to enhance human capital and organizational performance. This research contributes to the literature on human capital and demographic diversity, providing valuable insights for HR and quality management practices in the banking industry.

Introduction:

Due to the rapid advancement in technology and globalization, the market place has become highly competitive (Khajeheian et al., 2018). The same can be applied to the banking sector in terms of high competitiveness (Goldberg, 2009). Thereby, to become successful and sustainable in this sector various factors are determined in the literature out of which employees' demographic characteristics (Hassan & Olufemi, 2014; Saheed & Ireti, 2020) and the quality of internal processes (Zhang & Li, 2009; Owusu, 2017) are important elements that influence the competitiveness of organizations.

The role of people in any quality management framework has been deemed crucial for a successful implementation of quality management practices. According to the International Standards for Organizations (ISO), the role in the principle of people involvement is described as per ISO 9004:2009 refers to employees at all levels are the heart of companies and their complete involvement empowers their abilities to be used for the company's benefit. Therefore, it is important to understand the relationship between demographic characteristics of employees and their quality performance.

Furthermore, organizations tend to adapt to the external environmental changes through organizational restructure, employee layoffs and outsourcing, process engineering, and facilities relocation (Wu & Chen, 2016), which has an impact on employees' demographics specifically in multinational organizations (Triandis et al., 1993). The literature had identified a significant relationship between organizational communication and employee demography which subsequently impacts the organizational performance (Chua et al., 2018; Pratama, 2019; Kasiaheng, et al., 2021). or the individuals' performance (Nasaj, 2020; Nasaj et al., 2022). Consequently, it is imperative to assess the relation between employees' demographic characteristics and quality performance in order to effectively achieve both employees' performance and objectives of the organization. This study aims to investigate and identify the type of relationship between performance quality and demography of employees (Age, Gender, Educational background, and years of experience) and the quality performance to better support HR managers in developing and implementing effective evaluation and planning systems within the organizations.

Literature Review:

Quality Management Performance:

The term 'Quality' has been described in various ways in the literature. Juran (1947), for instance, has defined quality in terms of "fitness for use' which puts the user's best judgment in perspective, on the other hand, Crosby (1979) uses "conformance to requirements" while defining quality. Though both of the definitions provide similar meaning, the one described by Crosby implies better towards internal process in an organization referring the 'requirements' to customer needs and internal processes of organizations as well. For successful implementation of quality management practices, the role of people has been identified significantly in all quality management concepts, frameworks, and theories. Juran & Gryna (1980) has emphasized on the awareness people should hold in terms of their roles and responsibilities when implementing quality practices which also includes "know how" and employees' work experience. As per the quality guru Ishikawa (1985), training and educating employees is highly crucial and is backed up again multiple times in the literature (Crosby, 1979; Juran, 1974; Deming, 1982). Thus, the relationship between quality performance and employee demography calls for exploration which will be effective in identifying employees who may need training and engagement during the implementation of quality management practices so that they can align their work and jobs with the quality systems as well.

The banking sector has also discovered the added value through the implementation of quality management practices (Pakurár, et al., 2019; Nasaj & Al Marri, 2020; Othman et al., 2020; Elhawi, et al., 2021). The role of people in implementing quality management has been considered vital by most of these studies. For instance, in the study conducted by Luburić (2015) the involvement of people in effective implementation of these practices was discussed. However, people specific factors that affect the performance of the quality management systems wasn't identified.

One of the quality performance measures is first-time right measures, that refers to get the task done correctly from the first time with no errors (Seymour, 2020). This concept is widely used as a measure for employees' quality performance (Gewohn et al., 2018; Thomas, 2022). This study will adopt measuring the first-time right quality indicator for employees who work on submitting applications for availing services or loans as a measure of their quality performance.

Employee Demography and performance:

The variation in organization's demography or personal differences and the impact it has on organizational performance has been addressed in many studies. In any organization, human resources are vital resources and the attributes attached to employees highly impact the outcome of their performance (Saheed & Ireti, 2020; Nasaj & Badi, 2021; Nasaj, 2021; Badi & Nasaj 2023).

Researchers have defined relational demography as the variation in the demographic characteristics of employees (Depeng et al., 2021). Age, experiences, education, and gender are some of the demographic characteristics which tends to have an impact on employees' work attitude and processes which in turn impacts their performance (Kirkman et al., 2004; Depeng et al., 2021; Blaique et al., 2022). However, the relationship between relational demography and quality performance of employees specifically in the banking sector has been least explored.

The literature has examined the association between employee age and their performance, however, till present there has not been conclusive results in terms of the effect of age on performance (Christian Grund & Niels Westergaard-Nielsen 2008). According to the human capital theory, the expertise and acquired experience of an employee increases over his or her career cycle and it ultimately enriches a person's human capital value (Subramaniam & Youndt, 2005). The enhancement of an employee's skillset, knowledge, and expertise due to experience spent on the job accumulates with age and affects performance (Pahos & Galanaki, 2018). Therefore, the first hypothesis formulated is as follows:

H1: The Age of employees is significantly related to employees' quality performance indicator.

Previous research has indicated contradicting results in terms of male or female dominated workplaces and performance (Selvaraj, 2015). For instance, some searches revealed a positive impact of mixed gender group on performance compared to same gender groups (Wood 1987; McMillan-Capehart, 2003; Frink et al, 2003). Other studies showed a negative effect of male dominated sample on performance and no effect at all when the sample was female dominated (Pelled, 1997). Another study by Gupta (2013) indicated that a mild level of gender diversity increases performance while a higher level tends to negatively affect performance. Therefore, the second hypothesis is:

H2: Employees' Gender has an effect on employees' quality performance indicator.

Human capital is considered a vital aspect for the success of an organization (Mahmood & Azhar, 2015). Human capital pertains to education, experience and knowledge that the individual has acquired (Subramaniam & Youndt, 2005; Niklas et al., 2015). The educational background and years of experience of the employees are some of the demographic factors that has been investigated by previous literature. The more the educational level of employees is higher the more productive they will be (Ming-Jiuan Wu & Shin-Tien Chen, 2016). Hence, we have determined the third hypothesis to assess the relationship between employees' educational background and quality performance indicator.

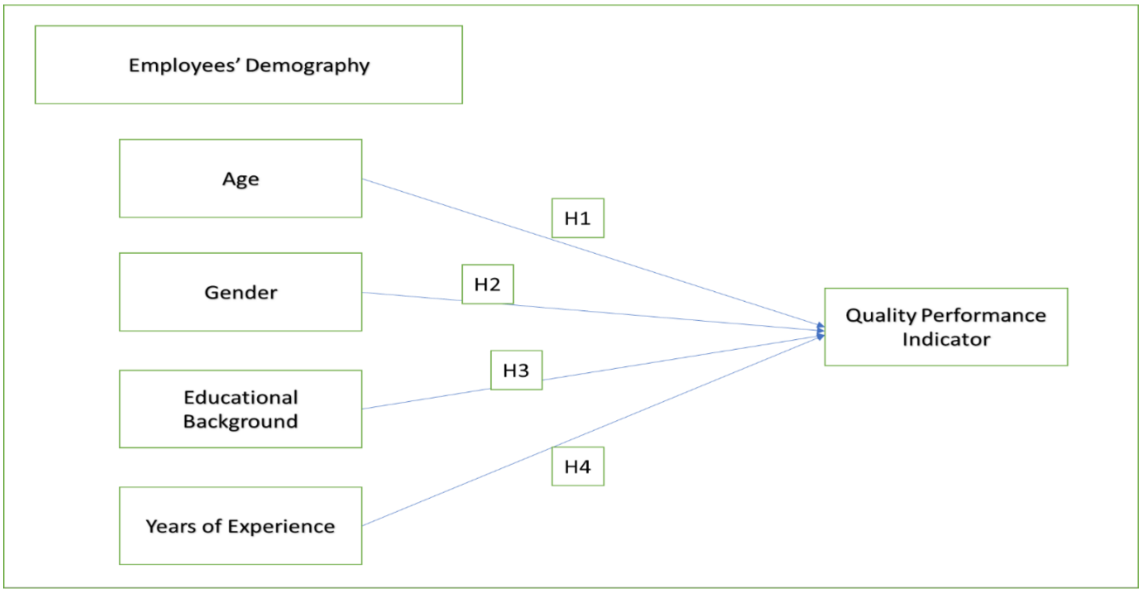
H3: Employees' educational background is significantly related to employees' quality performance indicator.

Human capital is a major factor for enhancing firms' assets and employees in order to increase competitive advantage of the firm (Alnachef & Alhajjar, 2017). As indicated earlier, human capital includes years of experience in addition to acquired skills and knowledge. To enhance knowledge skills and social assets of an individual, human capital relies on education, training and other professional initiatives. It will ultimately lead to employee satisfaction and performance that will result in enhanced organizational performance (Alnachef & Alhajjar, 2017). Research indicates that employees who have the opportunity to learn within their organization tend to have stronger work engagement which ultimately enhances performance (Blaique et al., 2022). Therefore, the fourth hypothesis states the following:

H4: Years of experience that the employees have is significantly related to employees' quality performance indicator.

Based on the above discussion, the research conceptual frame work is represented in figure1.

Figure 1: *Conceptual Framework*



Methodology:

Sampling and Research Techniques

The aim of this research is to investigate the relation between employees' demography and their quality performance indicator in the banking sector in UAE, one of the biggest Islamic bank that operates in UAE has agreed to help us in conducting our research as a consultative report for them, the bank management expressed their desire to keep the bank name anonymous and the collected information will be used to report statistical relationships with no reference to employee's name. Data were collected from employees working as front-line employees mainly working in the branches. 327 employees were included in this study, 136 were female and 191 were male. Since the main aim of this research is to study the statistical relationship among the research variables, a quantitative research methodology deemed appropriate to follow (Hair et al., 2010). In order to test the hypotheses and to identify the type of relationships among the variables, a range of statistical tests were applied using SPSS v.23 software.

Measurement

Dependent variable: Quality Performance Indicator (QPI)

We calculated QPI based on the below equation used by the bank management to track and control quality performance indicator for of the frontline employees, this indicator is calculated as the following:

$$\text{QPI} = \frac{\text{Total number of submitted application} - \text{number of returned applications}}{\text{Total number of submitted applications}}$$

Total number of submitted application refers to the total number of applications that the employee has have logged in the system.

Number of returned applications refers to the number of times the application has been returned back to the employee for missing documents, wrong data entry, or failure to adhere to the product policy. Therefore, in this study we will use the above-mentioned formula to calculate QPI.

Independent Variables:

In order to collect the primary data of our chosen sample of branch frontline, a survey was developed to collect which included gender, age, educational background and years of experience in the same field.

For gender variable the classification considered was male and female. As for the age of the employees, the data collected ranged from (18 years old till 52 years old) and then further categorized in seven categories with four years gap in each age range.

Employees' educational background was measured by three levels (High school, Bachelor degree and Master's degree or higher). As per the years of experience the research adopted a scale of four levels (New joiners: less than a year, 1 to 3 years, 3-5 years and 5 or above years).

Data Analysis and Results

The research participants profile is summarized in table1.

Table 1: Participants' profile summary

Variable	Item	Frequency	Percentage
Gender	Female	136	**41.6**
	Male	191	**58.4**
Age	18 - 22	45	**13.8**
	23 -27	116	**35.5**
	28 - 32	81	**24.8**
	33- 37	49	**15.0**
	38- 42	19	**5.8**
	43- 47	10	**3.1**
	48 - 52	7	**2.1**
Experience	> 1	80	**24.5**
	1 – 3	146	**44.6**
	4 – 5	71	**21.7**
	5 <	30	**9.2**
Education	High School	53	**16.2**
	Bachelor	255	**78.0**
	Master	**19**	**5.8**

Table 2 describes the Correlation matrix among the variables and the variables' descriptive statistics.

Table 2: Correlation matrix and descriptive statistics

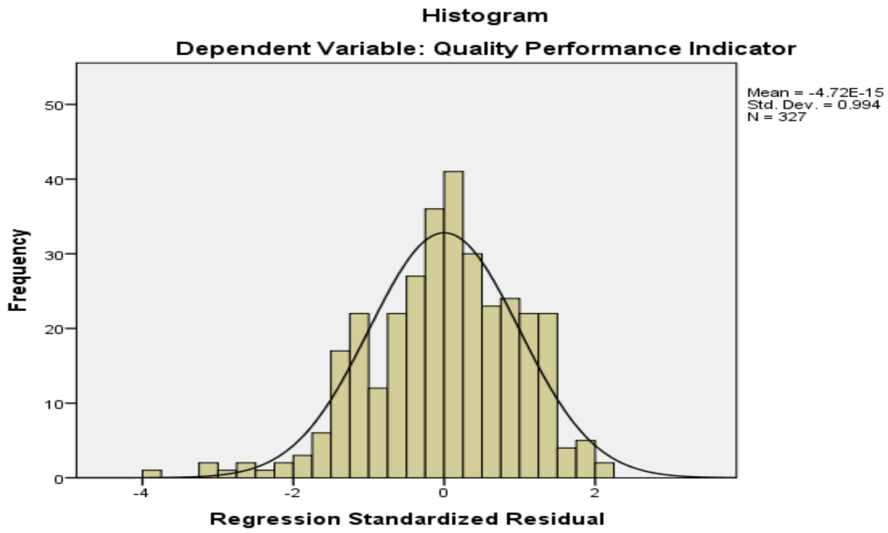
	Mean	Std. Deviation	1	2	3	4	5
1-Gender	1.584	.4936	-				
2-Age	2.813	1.3697	.053	-			
3-Experience	2.156	8983	.154**	.470**	-		
4-Education	1.896	4583	120*	.106	.047	-	
5-Quality Performance	77.2331%	17.37970%	.203**	.519**	484**	.228**	-

Note: N= 406. *p<.05, **p<.01.

As shown in table 2, the employees' demography: Age (519**), gender (203**), education (484**) and years of experiences (228**) are significantly correlated with employees' quality performance indicator. To further explore the relationships among the variables, a multiple regression analysis was conducted.

Quality performance indicator normality assumption was tested before running the regression analysis Normality test results are presented in figures 2 and 3.

***Figure 2**: Quality Preference Indicator Normality test*



As demonstrated in figure 2, the normality assumption was met.

***Figure 3**: Quality Preference Indicator P-P Plot*

The normal plot of the residuals illustrated in figure 3 shows the points close to a diagonal line; thus, the residual normality is satisfied as well, with no obvious outliner to be identified. therefore, we can run the regression analysis for the research model.

The overall repression model is significant as demonstrated by table 3:

Table 3: *Overall Regression Model*

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	38196.557	4	9549.139	51.015	.000[b]
	Residual	60273.081	322	187.183		
	Total	98469.638	326			

a. Dependent Variable: Quality Performance Indicator

b. Predictors: (Constant), Years of experience, educational background, Gender, Age

Table 4 demonstrates that the hypothesized relationships are significant

***Table 4**: Regression Analysis Results*

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	33.979	4.113		8.262	.000		
	Age	4.566	.630	.360	7.248	.000	.771	1.297
	Gender	4.240	1.565	.120	2.710	.000	.963	1.039
	Educational	6.144	1.674	.162	3.670	.000	.975	1.025
	Experience	5.586	.966	.289	5.781	.000	.762	1.312

a. Dependent Variable: Quality Performance Indicator

Based on the results, it is safe to say that there are no apparent multicollinearity problems in the model, since none of the predictor variables has a variance inflation factor (VIF) greater than ten.

In addition, the employees' demographics variables (Age, Gender, Education and Experience) have a positive significant relationship with the employees' quality performance indicator at 99% confidence level. Therefore, H1, H2, H3 and H4 are accepted.

As demonstrated in table 4, the highest variable contributing to employees' quality performance is educational background with a positive value of (6.144) then years of experience with a positive value of (5.586) then Age with a positive value of (4.566) and finally gender with a positive value of (4.240).

To further understand the relationships between employees' gender and quality performance, t-test was applied to highlight the differences in male and female quality performance. The t-test analysis results are represented in table 5 and table 6.

***Table 5**: T-test Quality Performance Indicator and Gender*

Group Statistics

	Gender	N	Mean	Std. Deviation	Std. Error Mean
Quality Performance Indicator	Female	136	73.0537%	20.39339%	1.74872%
	Male	191	80.2090%	14.18994%	1.02675%

***Table 6:** Independent Samples Test Quality Performance Indicator and Gender-*

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Quality Performance Indicator	32.257	.000	-3.742	325	.000	-7.15536%	1.91222%	-10.91725%	-3.39347%
			-3.529	225.114	.001	-7.15536%	2.02786%	-11.15138%	-3.15934%

Based on the results demonstrated by the t-test analysis the rejection of H2 null hypothesis is supported since the equal variances assumed was statistically significant and hence, we looked at the equal variances not assumed was (0.001) as illustrated in table 6, therefore we can reject the null hypothesis of H2. In addition, table 5 illustrate that the female overall average quality performance is (73.0537%), whereas male quality performance is (80.2090%).

Discussion

This research offers several contributions. First it attempts to highlight the importance of age and gender on quality performance. It also adds to the human capital theory on the importance of leveraging knowledge and skills of employees as well as retaining employees with relevant and necessary experience. The findings of this research indicate that employees' age has a positive relationship with quality performance. This result challenges pervious findings that indicate that performance declines with an aging workforce (Bratsberg et al., 2003). Nonetheless, this result is supported by pervious findings that indicate that performance does not decrease with an aging workforce (Ng & Feldman, 2008).

The second hypothesis tested whether employees' gender has an effect on employees' quality performance. The findings of this study indicate that there is a statistical relation between employees' gender and their quality performance. After comparing the mean of male performance against the female performance as indicated in Table 5, results show that the female average quality performance is (73.0537%) and the male average quality performance (80.2090%). When we compare this with the whole sample mean (77.2331%) we can infer that the male quality performance is comparatively higher than that of the females. There are several explanations for the findings on the effects of gender differences on quality performance. One possible explanation is that females in our sample may actually be performing less than their male colleagues. Another explanation is that gender-based stereotypes might strongly influence the performance of employees. Research indicates that the gender effect on performance may be evident through institutional channels, like gender differences pertaining to culture, and discrimination (Aidis et al., 2007; Terjesen et al., 2009; Hoang et al., 2019). Countries in the Middle East region still to some degree face challenges of gender stereotype at the workplace (Jalbout, 2015).

Our finding is consistent with previous research that explained, for instance that men perform better than women in negotiation and bargaining (Kray & Thompson, 2004; Eckel et al., 2008; Vandegrift & Yavas, 2009). Other studies also indicated that gender differences are prevalent in business motivation and skills where females are less likely to be motivated compared to men by growth and profits (Anna et al., 1999; Morris et al., 2006).

The final two hypotheses investigated whether employees' educational background and years of experience have a relation with employees' quality performance. These findings are consistent with previous research. Years of experience and educational background as constituents of human capital and have a significant impact on performance as indicated by previous studies (Rahman and Azhar, 2011; Wu & Chen, 2016; Alnachef & Alhajjar, 2017). It is expected that employees human capital becomes richer as they acquire more knowledge and gain more work experience. This in turn is expected to have a positive impact on their work performance (Subramaniam & Youndt, 2005). Our findings are inline with previous research that found a positive relation between education and performance in banking sector, such as King et al. (2016) and Elsharkawy et al. (2018) that they found a positive relation between Banks CEOs education and their performance. As per years of experience relationship with performance our results are supported by previous literature that found a similar positive relationship in the banking sector (Gunu et al., 2013; Zheng et al., 2016)

Practical and Managerial Recommendations:

The findings of this study have major practical implications relating to the role of employees' demography on quality performance. Our findings indicate a relationship between age and quality performance which is similar to previous results as indicated earlier. This is an indication that employees are valuable assets to the organization. As employees advance in age, their performance might also enhance. In their study, Kooij et al. (2013) explained that the relationship between maintenance HR practices and employee well-being gets stronger with age. Aging employees are expected to focus less on promotion and career development, and more on allocate their resources towards maintenance and regulation of loss (Baltes et al., 1999). Career goals, and alternatively the utility of HR practices, will change with age. Therefore, HRM professionals and senior managers are advised to pay less attention to development HR practices, and expand HR practices that will advance well-being of aging workers. In addition HR mangers should be aware that although young employees might have enthusiasm to do work they need to make sure that they get the appropriate training to be able to perform with high quality.

Based on the findings, male employees show high quality performance than their female counterparts. Therefore, it is highly advisable that senior managers offer adequate on the job training for female employees to help them advance and enhance their performance. Since it has been established by literature, as indicated previously, that women's motivational sources differ from men, HR managers might invest in motivational schemes tailored specifically to the needs and wants of female employees.

The findings of the study also indicate a significant relationship between years of experience and educational background and quality performance. Various research has indicated the positive impact of human capital on employees' satisfaction and performance as well as organizational outcomes such as competitive advantage, productive and performance (Kim et al., 2015; McIver et al., 2013). Therefore, the findings of this study shed additional light on the importance of human capital as a driver of firms' overall performance. Senior managers and HR personnel are advised to provide retention programs to existing employees who have invested in knowledge and professional experience in order to tap in human capital which is vital for performance and competitive advantage of their organizations. HR managers could also offer programs of continuous learning and training and development for existing employees that would enhance their human capital and ultimately performance. And finally, since education demonstrated a positive relation with employees' quality performance, HR department should consider giving a set of motivators for employees to further pursue their educational development by offering lowering their working hours, interest-free educational loans for staff to help them paying their educational fees or any other practices that stimulate the employees to further develop his education level.

Limitations and Future Research Implications

The research has several limitations. The sample utilized in this study was collected from one single bank, hence the generalizability of this research might be challenged. In addition, the data was collected over a period of three-month quality performance report. Future research built on longitudinal data and a sample from several organizations is recommended to validate the research findings. Future research can also incorporate additional demography data that might impact quality performance such as marital status, nationality and geographical location of employees. Based on the results of the impact of gender differences on quality performance, it would be interesting to explore this relationship in different geographic locations and across various sectors.

Conclusion:

The study aimed at determining whether or not a statistical relationship between employees' demographic characteristics and their quality performance indicator exists in the banking industry. In this study we determined that there is a relation between the two variables. This study contributes to the theory of human capital on further stressing the importance of years of experience and educational background of employees on quality performance management. These results have significant practical and managerial implications, specifically for quality and human resource managers. HR mangers are advised to plan and monitor systems that can impact the selection and recruitment of high performing individuals for positions in an organization. Since quality performance has a positive relation with organizations innovative performance and or organizational competitiveness (Nasaj & Al Marri, 2020; Badi & Nasaj 2023), quality mangers are advised to pay attention to the employees' demography as a factor of success of new systems relating to quality concepts.

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Employee silence during external audits

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Keywords: external audits, employee silence, effectiveness of audits

Relevant Topic: Quality culture, leadership, and human factor in quality management

Introduction

In the literature on the subject, an audit is most often defined following the definition provided in the ISO 19011 standard and is understood as a systematic, independent, and documented process for obtaining objective evidence and evaluating it objectively to determine the extent to which the audit criteria are fulfilled (ISO 19011, 2018). There are two main types of audits. Internal audits in an organization are carried out by employees of that organization. External audits are carried out by people from outside the organization – professional auditors or customer representatives.

It should be emphasized that external audits are based primarily on information from the organization's members. Therefore, employees' conscious concealment of vital information affects audits effectiveness, usefulness, and credibility. Although the phenomenon of employee silence is analyzed in the literature (as necessary from the point of view of the level of efficiency, innovation and change implementation processes), these considerations have not covered issues related to employee silence during audits. For this reason, the study's primary goal is to diagnose the state of knowledge in this area and design research that will help understand the mechanisms of the impact of employees' silence on the effectiveness of external audits. The article is based on a literature review.

Literature review

Audits

The literature on various types of audits is pervasive. The most significant part is publications on financial audits e.g. (Nogueira & Jorge, 2017) and audits related to management systems (such as the ISO 9001 quality management system, ISO 14001 environmental management system, etc.). It is assumed that the audit quality assessment criteria are identical for all types of audits, regardless of their kind, area and scope (Lisiecka & Lisiecka-Biełanowicz, 2016).

The subject of publications on auditing focuses on two main (connected) topics. The first one is to propose optimal ways to conduct audits. The second topic is the assessment of the effectiveness of audits in relation to such phenomena as their credibility or usefulness.

The studies belonging to the first group (optimal ways to conduct audits) propose various types of models, methods, rules for conducting audits (Abuazza et al., 2020; Algabry et al., 2020; Gritsuk et al., 2020; Lenning & Gremyr, 2017; Pivka, 2004; Karapetrovic & Willborn, 2001).

The second leading research topic is the assessment of audit effectiveness. Opinions on the effectiveness of the audits are divided. Various problems in this regard are often indicated. Many researchers emphasize the usefulness of audits in the processes of organizational evaluation and improvement (Lenning & Gremyr, 2017; Jounila et al., 2020; Alic & Rusjan, 2011). On the other hand, some researchers point out numerous problems with audits' effectiveness and reliability (Manning, 2018). In the case of external audits, it is noted, for example, that there is a phenomenon known as "ceremonial conformity" (or "ceremonial certification"). This concept is understood as conducting audits (mainly third-party) so that they do not lead to a reliable image of the organization (Nurcahyo, 2019; Biazzo, 2005). An extreme manifestation of this phenomenon is "fake certification" (Heras-Saizarbitoria & Boiral, 2019). However, it should be emphasized that the conducted assessments mainly concern the usefulness of audits only for the audited organizations (Manning, 2018). The usefulness of audits for other interested parties is analyzed to a minimal extent. One such study was conducted in Australia. As a result, it was established that stakeholder perceptions of performance audit credibility are not high (Funnell et al., 2016).

Employee silence

C. C. Pinder i K. P. Harlos (2001) define employee silence “as the withholding of any form of genuine expression about the individual's behavioral, cognitive and/or affective evaluations of his or her organizational circumstances to persons who are perceived to be capable of effecting change or redress”. Employee silence concerns essential work issues, such as conflicts with coworkers, disagreements with organizational decisions, personal knowledge of potential weaknesses in work processes, concerns about illegal behaviors, and individual grievances. It is assumed that there are four types of employee silence, which is a consequence of the existence of four main reasons for which employees restrain themselves from speaking up: (1) the negative view of possibilities of change (acquiescent silence), (2) fear of negative consequences for oneself of speaking up (quiescence silence), (3) the need to maintain harmonious relations with others (prosocial silence), (4) the need to protect and enhance one's interests (opportunistic silence) (Adamska, 2017).

Results and Discussion

Although the phenomenon of employee silence is analyzed in literature (as necessary from the point of view of the level of efficiency, innovation and change implementation processes), there is a lack of research on the role and significance of employee silence in auditing processes conducted in an organization. It can therefore be concluded that a research gap has been identified.

The central premise for getting interested in this topic is the need for more knowledge about employee silence mechanisms in the organization during external audits. Thus, the extent to which the silence of employees in the organization affects the effectiveness of audits remains unrecognized. For the effectiveness of external audits, it is important to "speak," that is, the transfer of knowledge, information, and ideas by employees, which is essential for the organization's functioning. The silence of individual employees in the organization (or during an audit) may or may not have negative consequences. On the other hand, when silence concerns a more significant number of employees of a given organization, i.e., when employees refrain from speaking, and then when they have the knowledge, information, or ideas necessary for the functioning of the organization (see: Tangirala & Ramanujam, 2008), the negative consequences of silence have measurable consequences. From a management sciences perspective, knowing the mechanisms of employee silence is crucial. It should be emphasized that the extent to which the silence of employees in the organization is related to the silence of employees during audits and the lack of knowledge as to how silence affects the effectiveness of audits remains unrecognized.

The other new perspective that is used in the proposed research is the consideration of different forms of employee salience in audit processes as well as key stakeholders as the parts that benefit from the audit outputs. Most recent studies focus on examining the effectiveness of audits only from the perspective of the organizations in which the audits are conducted.

Analysis of the research problem has allowed the identification of the following research questions:

1. What factors affect the usefulness and credibility of audits for key stakeholders?

2. How does the employee's silence during audit differ from that within the internal organization processes (in relations between employees or between employees and their superiors)?

3. How does the employees silence during audits affect the effectiveness of an audit?

4. Is employees silence during audits deliberately supported by organizations (managers)?

5. How can the negative impact of employee silence on the audit results be reduced?

Conclusions

The study identified a research gap and formulated research questions that should be answered to eliminate the gap. The proposed scientific research will be essential to support the theory of employee silence and the management theory related to the effectiveness of audits.

The research will help to organize the knowledge on audits. It will contribute, above all, to:

1. A better understanding of auditee and auditor behavior.

2. Learning about various stakeholders' expectations regarding external audits.

3. A better understanding of the factors determining the effectiveness of the audits.

4. Identify opportunities for audit improvement.

The results of the project may interest practitioners. On their basis, it will be possible to optimize external audits. A large number of such audits, as well as the relatively high costs associated with them, are the reasons for considering this subject important.

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Knowledge Transfers on Blue Collars: Case of Good Manufacturing Practices for personal hygiene in Mexico

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Abstract

There are different ways to train personnel in a manufacturing plant, ranging from in-person to virtual training. However, there is currently no standard model or methodology to measure the effectiveness of this training on the position, work cell, and indicators. This work proposes a method to measure the impact of training strategies through an indicator called a "Real Training Indicator." This method is based on requirement 7.2 of the ISO 9001:2015 Standard, which refers to the "Competence of Personnel." The Kirkpatrick, Wade, and Phillips models are used to measure the impact of training in a transnational organization in Mexico. This method estimates the level of transfer and effectiveness of the training to cover the requirement of Good Manufacturing Practices

Keywords: Good Manufacturing Practices, Knowledge Transfer, Personal Hygiene, Real Training Indicator, Food Industry, Blue Collars, Mexico. 5

Introduction

Brief History of Standardization

The standardization of processes and activities has indeed been an idea that has evolved over the years and has had a significant impact in various fields. The International Federation of National Standardizing Associations (ISA) or ISA, which was founded in 1926, was an important step in this standardization process. However, it is important to note that the organization that has really played a central role in standardization at the international level is the International Organization for Standardization (ISO).

The ISO, as mentioned in the quote, was founded in 1946 and has played a key role in the development and promulgation of technical and quality standards around the world. Its creation was influenced by the need to control and improve production processes during and after World War II. ISO standards are applied in a wide variety of industries and sectors, and contribute to interoperability, quality, safety and efficiency in many areas.

Over the years, ISO has developed thousands of technical standards covering everything from quality management to food safety, environmental management and many other areas. These standards help organizations and countries standardize processes, products, and services, which in turn facilitates international trade and technical cooperation.

In summary, the standardization of processes and activities has evolved, and the ISO is one of the most prominent organizations in this field, having been established after World War II to address quality control and production needs in that period.

Good Manufacturing Practices, GMP

Currently, in our country, health authorities consider it a priority to establish food safety policies, through the application of systems that minimize the risks of contamination, to reduce the number of food-borne diseases (ETA's). One of these forms is the application of quality assurance systems, within which the implementation of Good Manufacturing Practices (GMP) and Health Standard Operating Procedures (POES) are considered, in the production of food.

The hygienic-sanitary or sanitary quality of food refers to the composition, purity, and reliability of a product, which complies with governmental and international health standards that guarantee satisfaction of the consumer's expectations and needs, the above refers to to food safety; that is, the absence of physical, chemical and microbiological contaminants, toxins and any other substance in the food that may be harmful to health, in such a way as to ensure that the food will not cause harm to the consumer when it is prepared and/ or consumed under the use that should be given to it.

Foodborne Diseases

According to the World Health Organization, Foodborne Diseases are a “Set of symptoms caused by the ingestion of water and/or food that contain biological agents (viruses, bacteria, fungi, parasites) or non-biological agents (physical) in quantities such that they affect the health of the consumer.”

Among these we can differentiate food infections, which are produced by the ingestion of foods contaminated with infectious agents such as bacteria that can multiply in the intestine and produce toxins, the other hand, food poisoning is produced by the ingestion of toxins (metabolic products). Of microorganisms).

The GMPs cover elements and activities of hygiene, sanitation, adequate cleaning and disinfection methods, and the correct handling of food, as well as the raw materials and additives with which they are made (Health Office, 2009). These are mandatory nationally and abroad, their application allows important advantages for plants dedicated to food production, such as:

• Standardize quality.

• Reduce risks to consumer health.
• Compete with other markets.
• Maintain the image of the products and increase profits.
• Guarantee a physical structure by health requirements.
• Avoid sanctions from health authorities.

The importance of the sanitary quality of food lies in the contribution to the prevention and reduction of risks to public health, due to poisoning and infections transmitted by the consumption of contaminated food.

Concept and functions of training evaluation in organizations

We can define training evaluation as "the analysis of the total value of a training system, program or course in both social and financial terms. The evaluation attempts to assess the total cost-benefit of the training and not only the parrot of its immediate objectives" (Kenney-Donelly, 1972 p.69). The evaluation focuses on determining the degree to which the training has responded to the needs of the organization and its translation in terms of economic and qualitative impact, so it performs three basic functions:

Pedagogical Function, which verifies the process of achieving the objectives to improve the training itself.

Social Function, which certifies the acquisition of learning by the participants.

Economic Function, which identifies the benefits and profitability that training generates in the organization.

These three functions are aimed at achieving the ultimate purpose of the evaluation: the provision of information that guides decision-making, leads to the introduction of improvements in training, and must always be aimed at improving the training process, and not at control. of the people involved in it.

Training Evaluation Modalities

The evaluation, to be truly effective, must be integrated into the planning process, and must occur throughout it through its different modalities, which have a mutual interdependence:

Diagnostic Evaluation, focused on the analysis of the pedagogical coherence of the designed training and its adaptation to the training needs detected in the organization and in the participants.

Formative Evaluation analyzes the progress of the teaching-learning process and the progress in achieving the stated objectives.

Summative Evaluation, focused on the results obtained by the participants in terms of competencies achieved at the end of the training.

Transfer Assessment determines the degree to which participants transfer or apply the learning and competencies achieved with the training to their jobs.

Impact Assessment determines the repercussions that training has on the organization in terms of qualitative and quantitative or monetary benefits, thus aiming to discover the economic profitability of training for the organization.

Holistic Training Evaluation Model

The model consists of answering the five basic questions that affect the evaluation in an integrated way, crossing the answers and developing a set of evaluation strategies that cover the entire training process:

For whom do I evaluate? The answer determines the purpose of the process and its orientation.

What did you evaluate? Elements and aspects to evaluate, at six basic levels:

Level 1: Participant satisfaction with the training.
Level 2: Achievement of learning objectives by participants.
Level 3: Pedagogical coherence of the training process.
Level 4: Transfer of learning to the workplace.
Level 5: Impact of training on the organization's objectives.
Level 6: Profitability of training for the organization.

Who evaluates? The agents who make judgments about the training should be those affected by it.
When I evaluate? There are four basic moments:
Before starting training.
During training.
At the end of the training.
Sometime after finishing the training.

How do I evaluate? The instruments are varied, for example: surveys, questionnaires, interviews, etc.

The Holistic Evaluation Model arises from the crossing of the answers to these five basic questions and their integration into a global whole, thus allowing the design of an effective evaluation plan, which translates into effective and efficient evaluation processes based on available resources, measuring their impact on the organization.

Training Impact Assessment

Training impact is understood as the repercussions that carrying out training actions has for the organization, in terms of response to training needs; It consists of the changes that the completion of learning thanks to training and its transfer to the job generates in the department or area of the trained person and in the entire organization. The effects are of two types:

Impact Assessment Models

The evaluation of the impact and profitability of training is located at the last levels of existing evaluation models. Thus, the Holistic Evaluation Model presented occupies the fifth and sixth levels. There are other models that focus specifically on evaluating the impact and profitability of training, such as the Kirkpatrick, Phillips and Wade Models.

Kirkpatrick model

Kirkpatrick established the foundations of continuing education evaluation in the 1960s. The four levels of the model are:

Reaction of participants to the training.
New skills acquired thanks to training.
Conduct of participants in the workplace.
Results in the organization (the impact).
The author suggests guidelines that can facilitate the process:

Rigorously select the moment of evaluation.
Use a control group (essential).
Consider the cost-benefit ratio of the evaluation.
Accept the evidence in the face of the impossibility of proof (when it is not viable).

Kirkpatrick takes a qualitative approach to training impact. It is a mistake to make profitability the ultimate goal of any evaluation process, since it would lead to a reductionist vision of the impact of training.
Qualitative, or not translatable into economic terms.
Quantitative, or translatable to monetary values. The economic impact allows us to obtain a profitability index, expressed in monetary terms, generated by the investment made in training.

The evaluation of impact and profitability responds to one of the three functions of evaluation: the economic function, which is why impact evaluation is also called “Evaluation of Organizational Results”.

Phillips model

It is based on Kirkpatrick's guidelines, but adopts a more quantitative approach, and focuses on developing a methodology that allows evaluating the economic impact of training, taking the return on investment (ROI) as a calculation tool. The phases of your model:

Data Collect.
Isolation of training effects.
Classification of economic and non-economic benefits.
Conversion to monetary values.
Calculation of Return on Investment (ROI).

The vision is reductionist since it focuses on economic results and forgets the results of training.

Wade model

Wade conceives evaluation as measuring the value that training brings to the organization. Structured in four stages:

Response: reaction to training and learning by participants.
Action: transfer of learning to the workplace.
Results: effects of training on the business (quantitative or hard or qualitative or soft indicators).
Impact of training on the organization, through cost-benefit analysis.

The model is like Kirkpatrick's, but with important differences in the levels referring to the impact (evaluation of the impact and profitability of the training). It identifies two progressive levels in this type of evaluation: evaluation of the results of training in the workplace (hard or soft indicators) and evaluation of the impact that the training generates in the organization, for which it proposes a cost-benefit analysis. As a measuring instrument.

Methods

Real Training Indicator

The sampling plan

A sample size of 289 employees with operating positions in a factory dedicated to the production of powdered beverages located in the State of Mexico was defined. The study group was given the Good Manufacturing Practices Course in 16 groups of 18 people before conducting the study. An internal audit scheme was followed in the 11 lines of the facility, constituted by a group of 6 auditors belonging to the Quality Control department.

The audit

The audit consisted of identifying, through observation, those behaviors that are part of the Good Manufacturing Practices and how the operating personnel performs or fails to perform them (for example, using long fingernails, not using a mask, using rings, etc.) during 3 weeks, establishing a relationship between the qualification in the classroom and the non-compliances, considering this a transfer basis between training, understanding, purpose, and application of the knowledge acquired and regulated through a regulation.

Once the evaluation has been carried out, it should be reviewed with the areas of Manufacturing, Quality, Food Safety, and Human Resources to define opportunities, as well as to establish plans for correction, prevention, and improvement of the teaching-learning process.

Evaluation and calculation

Description of the Psycho-Social Mathematical Model:
The model is formulated as follows:

RTI= Classroom qualification – HRI

Where,

RTI= Real training indicator (psycho-social part) that measures how the trained person transfers the knowledge acquired in the classroom to their workplace.

HRI= [(# events of non-compliance with BPM's) / defined days of working hours] referring to the performance you present in your job, aware of your new skill or new knowledge (psychological part).

Results and Discussion

Please insert your Results and Discussion text here. The Discussion text can be in a separate section if preferred. Text alignment is formatted as justified. Tables, like Table 1, should be centred, have a self-explanatory caption placed above the table and should be referenced in the main text like in this sentence.

The audit is carried out in 3 plants in three cycles, randomly and on different days, as seen in table 1, an extract of the information collected in the evaluation cycles carried out is shown.

Table 4. *GMP evaluations.*

Employee	Test evaluation	RTI
Employee 1	10	8
Employee 2	7	3
Employee 3	7	7
Employee 4	7	7
Employee 5	7	5
Employee 6	10	8
Employee 7	10	8
Employee 9	8	6
Employee 10	7	5

Audits were carried out from May to August, observing the behaviors of the collaborators, identifying faults in personal hygiene practices, impacting them on the result of their exam and establishing the difference between the qualification obtained in the training and the execution in the workplace (see Chart 1).

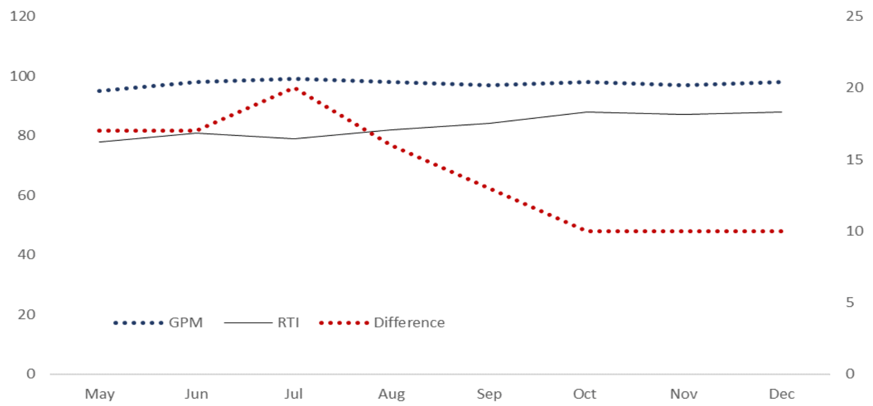

Chart 3. *Trend of evaluations for training in personal hygiene practices, those obtained in the job review, as well as the difference between the two.*

The strength of the relationship between the training rating and the behavior observed in the workplace was analyzed to compare the transfer of the event (Graph 2).

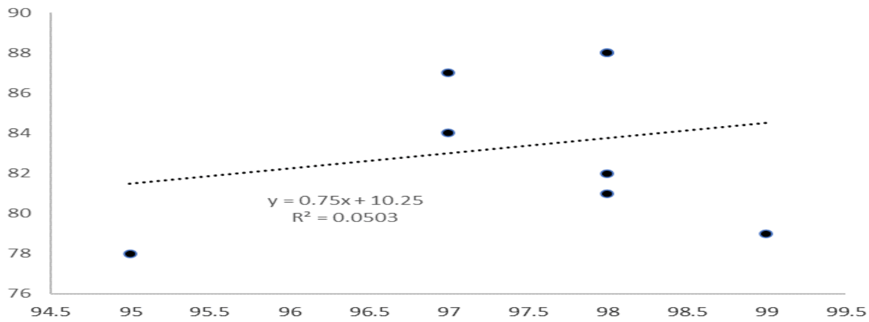

Chart 2. *Strength of relationship between the evaluation of training and the behavior observed in the groups studied.*

Conclusions

The food industry presents great challenges within the supply chain, and within this context we find safety and as part of its requirements, we have good manufacturing practices, stopping specifically at personnel hygiene practices, to understand how the transfer occurs from the moment the blue-collar leaves training until the execution in the workplace. The audits were a fundamental key to identifying the behaviors that employees perform in their position during the day, contrasting with the evaluation of their written test.

The results of the Human Rate Factor (HRF) show that of the people sampled, 27% committed at least one violation of the GMPs, while only 6% committed two violations and no collaborator committed more than 3 violations, of which The most common was "long nails" with 38.5%, "bad phase mask" with 20.5% and "makeup" with 12.5%, mainly.

The most frequently presented grades were "7" with 42.4% and "10" with 32.3%, however, the RIT evaluator observed that the highest grade continued to be "7" with 31% and "10" passed. from 32.3% to 17%, almost half of the people who had obtained this qualification in the training.

During the follow-up from April to December, the monthly average of these evaluations during training was 9.75, while the RTI was 8.33 with a difference of 1.41 points. It was also observed that behavior improved by feeling observed since from August to December the difference was reduced to only 1.18, which provided leadership and communication opportunities within the GMP program.

A study was carried out to understand the relationship between the result obtained in the exam and the behaviors observed in the workplace and the result of the linear regression was that the r-sqr was 0.05, while for the correlation study we calculated the Pearson, who tells us that training for personal hygiene practices does not have a strong impact on the behaviors of employees in their jobs.

These results lead us to several conclusions:

a) The people who execute the training have communication opportunities as well as training skills.

b) Development plans are not focused on identifying opportunities in soft skills.

c) The detection of needs focuses only on the audit requirement, and not on the needs of the system.

d) There is no well-communicated meaning and purpose of GMP compliance.

e) The audit scheme must be modified to integrate more questions of reflection and conversation than the search for good/ no good.

It is recommended to continue with this study to understand how e-learning platforms are currently working and, under the concept of Operational Excellence, link the master training plans with the reduction, containment, and elimination of losses, with the objective that the training program tangibly supports Quality and Productivity programs.

Research limitations

The present work was carried out on 11 lines within the same complex, so these results represent only this level of research, and the field of study would have to be expanded to have information that includes a representative sample.

Future research

As part of further research, a scheme is being developed to design and evaluate the effectiveness of training within a Kaizen Event. This was mentioned by Van Aken, Van Aken, Farris, and Cross, Glove (2010).

The findings of the research focused on critical thinking when Good quality practices are carried out in the company, allowing the employees fundamental personal growth in their development, future research focuses on observing this critical thinking behavior in Kaizen events to validate if the conclusions in the seminal paper by Van Aken et al., (2010) can be observed for the behavior and thinking of employees when a Kaizen event is carried out. In addition, trying to find critical thinking as part of the theoretical framework of Kaizen and mindfulness developed by Suárez-Barraza and Huerta-Carvajal (2023).

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Track 12: Quality Management and Improvement

Measuring the impact of KAIZEN techniques on operational performance. A quantitative study in Mexican multinational companies

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Keywords: Kaizen, Kaizen Practices, Operational Performance, Multinational Companies, México

Abstract

Despite the unfortunate death of the great promoter of kaizen in the world, Masaaki Imai, the Kaizen philosophy is still more alive than ever, and multinational companies in the world and in Mexico continue to use it as a badge and value continuous improvement in search of operational excellence. However, at the academic level, there is still a long way to go to deepen the impact of kaizen and its techniques on operational performance. The objective of this study is to ascertain the impact of kaizen techniques on the operational performance of companies. For this purpose, a quantitative methodology of Exploratory Factor Analysis (EFA) was used. This method was used to discover the correlated variables (factors) and find the groups of variables with unique (latent) factors that can help to better and more concisely define the model. To understand the structural model, an orthogonal extraction method was used and items with factor loadings greater than 0.5 were retained. Finally, the data were confirmed using the Kaiser-Meyer-Olkin test. The results show that of the three hypotheses proposed, two are satisfactory, showing the impact of basic kaizen techniques on the operating performance of the sample of multinational companies taken, a total of 192 (manufacturing plants) mainly from the North and Centre of the Mexican Republic.

Introduction

Masaaki Imai (1930–2023), was a Japanese organizational theorist and management consultant known for his work on quality management, specifically on kaizen. Known as the father of Continuous Improvement (CI), Masaaki Imai was a pioneer and leader in spreading the kaizen philosophy all over the world. Despite his demise, the kaizen philosophy remains more alive than ever, both as a business management philosophy and as a philosophy of life, and it is still present in organizations around the world in order to improve their competitiveness (Berhe et al., 2023). For its part, the concern of multinational companies continues to focus on operational performance; the reason being that competition in the 21st century is getting stronger every day and represents a threat to each of these companies in an increasingly turbulent environment.

However, academic literature does not yet know the impact of kaizen techniques on company performance; therefore, more and more importance is being given to research in this field. In this sense, the purpose of this article is to test a set of hypotheses that allow us to link quantitative relationships between kaizen practices and the operational performance of companies. The article is divided into four parts: a literature review to construct the hypotheses and the model, methodology, findings, and finally, discussion and conclusions.

Literature Review

Kaizen Philosophy and Kaizen Managerial Practice and Techniques

In recent years, different empirical studies continue to point out the importance of kaizen in organizations and academia in the 21st century (Kharub et al., 2023; Ishijima et al., 2021; Franken et al., 2021). In 2022, at least fifteen academic papers were presented at the 6th World Conference on Production & Operations Management held in Nara (Japan). Meanwhile, Masaaki Imai published his new book in 2021, "Strategic KAIZEN™," in which he develops the idea of kaizen leading to a new global operational management. In this book, Masaaki Imai advocates replacing the traditional emphasis on volume and speed with a more effective approach: evaluation, synchronization and flow levelling, focusing kaizen on reducing process waste by focusing work on the value stream of each process (Imai, 2021). Similarly, a kaizen Special Issue was published in 2018, which featured 11 articles, in Emerald Publishing's TQM Journal. Each author contributed certain theoretical elements that helped to further clarify the definition and characteristics of kaizen (Suárez-Barraza et al., 2018). These examples indicate that it is still a current topic in academia.

Defining kaizen in the 21st century remains a complicated and complex issue, both in the academic world and in practice. We know that the origin of kaizen in the business arena was specifically in manufacturing processes (Imai, 1986; Fujimoto, 1999). Some authors attributed its beginning to the work of William Deming and Joseph Juran (Mizuno, 1988), while others related it to process improvement at the Toyota Motor Corporation during the 1950s and 1960s (Nemoto, 1987; Bessant and Caffyn, 1997; Ohno 1988). Brunet and New (2003) conducted a study in Japan and indicated that kaizen is "a continuous space of activities in which different actors participate in specific roles to identify and ensure improvements that contribute to corporate goals." Meanwhile, Macpherson et al. (2015) reaffirmed in another study in Japan that kaizen still exists in Japanese organizations and defined it as "the way Japanese employees view the world. It is a metaphor for understanding life, at work, in their company, in their development, in their development, creativity, and independence."

According to Masaaki Imai (1986), kaizen means: "continuing improvement in personal, home, social, and working life. When applied to the workplace […] [it refers to] continuing improvement involving everyone, managers, and workers alike". In this sense, the Japanese Human Relations Association (1992, p.4) stated that, for the Japanese, the word kaizen is regarded as a symbol of everyday problems and struggles and the way people (employees) cope with them. kaizen can be characterized by the Japanese work culture, immersed in the philosophies of Buddhism, Confucianism, Taoism and Shintoism (Macpherson et al., 2015). For Newitt (1996), its definition is the derivation of two Japanese ideograms (Kanji): KAI (改) - change and ZEN (善) - virtuous, benevolent, for the better; and together they indicate: "change for the better".

Hence, kaizen has also been considered an ethical force (internal, within oneself) of each worker, who is able to solve problems on a daily basis, fully and voluntarily (Styhre, 2001). In this sense, Bessant (2003) indicated that employee participation generates a means for employees to contribute to the company's development. In simple terms, "working with your hands but using your brain to think". This idea compares and is similar to the early studies of the Human Relations School, in which Mayo, Maslow, McGregor and Herzberg advocated such an approach to management (Malloch, 1997).

On the other hand, some authors have pointed out that kaizen is composed of a series of guiding principles that direct its implementation. Cheser (1998) indicates that kaizen differs from Continuous Improvement (in the Western view of it) in the guiding principles and practices that define it. And although Masaaki Imai (1986; 1997) does not refer directly to a set of guiding principles, he indicates that kaizen can be defined in at least three types or forms: 1) management kaizen (strategic perspective), 2) group kaizen (improvement team perspective), and 3) individual kaizen (individual improvement proposals). In the same way, Imai (1986) points out that kaizen can be a large "umbrella" that encompasses different management practices: total quality control, quality circles, suggestion systems (Kaizen Teian), Kanban, JIT, Zero Defects, productivity improvement, new product development, Total Productive Maintenance (TPM), etc.

In addition, Berger (1997) proposes three guiding principles for kaizen: 1) *process-oriented kaizen*, referring to the improvement of processes in order to improve their results; 2) *standard maintenance and improvement-oriented kaizen*; that is, sustaining daily work performance involves maintaining work standards, which can be improved through continuous effort by the organization; and, finally, 3) *individual-oriented kaizen*, based on Imai's typology of group and individual kaizen, which focuses on the generation of improvement ideas by employees. Likewise, Ohno (2013) points out that the practice of kaizen is framed in typologies: 1) *manual kaizen*, focused on the improvements of workers directly in their work; 2) *team* or *machine kaizen***:**, once you learn how to improve and change the daily activities of each person, then you are ready to propose improvements or changes in your equipment or machine to which it relates. And finally, 3) once you work on improving your daily work and support machine improvements, you will be ready to propose improvements to the operating process.

From other perspectives, other authors have also considered both the guiding principles and the management practices and tools of kaizen. Aoki (2008), in a study conducted on the application of kaizen in Chinese companies, points to standardization as an initial management practice, supported by operational discipline and communication or transversal management, which helps to eliminate MUDA. In this context, the work carried out by Brunet and New (2003) in Japanese companies encountered practices such as Zero Defect, small group activities, the suggestion system (Kaizen Teian), and of course, policy deployment (Hoshin Kanri). Along the same lines Suárez-Barraza and Ramis-Pujol (2010) frame kaizen practices for On-the-Job Training, process redesign methodology to eliminate MUDA, and Kaizen teams. More recently, Berhe (2022) reports the application of kaizen practices in Ethiopian chemical manufacturing companies; in his findings he reaffirms practices such as Kaizen teams, QC Story problem-solving methodology, elimination of MUDA through 5 GEN, Total Productive Maintenance (TPM) and deployment of kaizen policies (Hoshin Kanri). Table 1 summarizes the research papers that bring together the management practices used in kaizen.

Table 1. Kaizen Management Practices

Kaizen management practices	Authors
Kaizen Event	Cheng (2018); Habidin et al. (2018); Kumar et al. (2018); Al-Hyari et al. (2019); Franken et al. (2021)
Kaizen teams (Quality Control Circles - QCCs, or small group activities)	Brunet & New (2003); Suárez-Barraza & Ramis-Pujol (2010); Al-Hyari et al. (2019); Aoki (2008); Alvarado-Ramírez et al. (2018); Berhe (2022); Franken et al. (2021)
Cross-functional management (targets)	Aoki (2008)
Standardization - application of Standard Operation procedure (SOP) and other standardization tools	Aoki (2008); Alvarado-Ramírez et al. (2018); Ma et al. (2018); Cheng (2018); Berhe (2022)
Muda/Waste elimination (process innovation redesign)	Aoki (2008); Kumar et al. (2018); Suárez-Barraza & Ramis-Pujol (2010); Ma et al. (2018); Berhe (2022)
5S	Aoki (2008); Alvarado-Ramírez et al. (2018); Ma et al. (2018); Berhe (2022)
Total Productive Maintenance (TPM)	Brunet & New (2003); Glover et al. (2013); Habidin et al. (2018); Berhe (2022)
Total Quality Control (TQC)	Berhe (2022)
Zero defects	Brunet & New (2003); Berhe (2022)
Policy Deployment (Hoshin kanri)	Brunet & New (2003); Berhe (2022)
Gemba and 5 GENS (the place where the action occurs at work)	Cheng (2018); Berhe (2022)
Suggestion system (Kaizen Teian)	Brunet & New (2003); Berhe (2022)
On-the-Job-Training	Suárez-Barraza & Ramis-Pujol (2010); Cheng (2018); Minh & Quyen (2022)
ISO 9001 combined with Kaizen	Alvarado-Ramírez et al. (2018); Fonseca & Domingues (2018)
Visual Management (Mieruka)	Ma et al. (2018); Berhe (2022)
PDCA cycle application	Al-Hyari et al. (2019); Hasan et al. (2021); Berhe (2022)

Education and Training	Cheng (2018); Marin-Garcia et al. (2018); Minh & Quyen (2022)
Problem solving methodology (A3 or Improvement Kata - problem-solving methodology-format)	Suárez-Barraza et al. (2009); Minh & Quyen (2022)
Senpai- Kouhai (Master-Apprentice) relationship	Macpherson et al. (2015); Macpherson et al. (2018)

Source: by authors

Similarly, Suárez-Barraza and Miguel Dávila (2011), in a pioneering work, perform a more detailed classification of kaizen techniques or practices, with each management technique or practice linked to guiding principles that can be understood as theoretical guides which provide an understanding or orientation. This allows a bridge between knowledge and practical action of kaizen, with each management practice linked to a guiding principle, and in turn the tools linked to management techniques or practices as shown in the table 2.

Table 2. KAIZEN guiding principles, techniques and tools

Guiding principle	**Management techniques or practice**	**Tools**
Guiding Principle 1: Basic Elements (Elementary Practices) Referring to the simple idea of what needs to be put in place first to cement KAIZEN	1.1 The 5Ss	- Red and yellow cards - Implementation plan sheet - Checklist or data collection sheet before and after implementation - Follow-up plan sheet - Preventive cleaning standards sheet - Preventive cleaning standards sheet
	1.2 Standardization	- Operating standard sheet or SOP (Standard Operation Procedure) - Data collection checklist
Guiding Principle 2: Maintenance and improvement of standards A fundamental requirement for continuous improvement is the establishment of standards.	2.1 Application of the PDCA cycle (Plan, Do, Check, Act)	- -Business plan and quality plan sheet (PDCA at the organizational level) -Policy Deployment Sheet (Hoshin Kanri) - Sheet of objectives at the three organizational, process and individual levels. - Purpose, objectives and indicators sheet for work processes (PDCA at process level) - Format of improvement ideas (PDCA at the individual level), also known as mini-improvement pills
Guiding Principle 3:	3.1 Process redesign	- System diagrams - Block diagrams - Flow diagrams and participants - Process selection matrix

Process approach KAIZEN focuses all its improvement efforts on the organization's processes.		- Process measurement indicators matrix - Mechanisms and automation software packages - Automation mechanisms and packages
Guiding Principle 4: Focus on people KAIZEN focuses all its improvement efforts with a high level of employee participation.	4.1 Network of improvement teams	- Team formation agreement - Team report (rules, roles, name, logo) - Control sheet for the improvement team network - Tracking sheet for improvement projects - Improvement project development manual - Affinity diagram or TKJ
	4.2 Education and training	- Short-, medium- and long-term training and education program - Course records - Career plans for each employee
	4.3 Senpai-sensei- kohai (master-apprentice) relationship	- Meeting and Study Program - Training and Education Program - Leadership Skills Matrix
Guiding Principle 5: Continuous improvement of daily work KAIZEN focuses on constant day-to-day improvement through workplace problem solving (gemba) and the elimination of muda (Japanese word for waste; any activity that consumes resources and does not meet customer requirements).	5.1 Gemba (Japanese word for workplace) management	- Check list or data collection sheet to detect muda in the workplace - Analysis and summary sheet of the anomalies found - Map of the physical distribution (layout) before and after the improvement - Diagnostic interview protocol (the 5 why's) - Time observation form
	5.2 KAIZEN Rapid Improvement Workshops	- Checklist or data collection sheet to detect muda at the workplace - Standard Operating Procedure (SOP) sheet - Analysis and summary sheet of the anomalies encountered - Physical distribution (layout) map before and after the upgrade - Diagnostic interview protocol (the 5 whys) - Time observation form - Summary table of changes
	5.3 the history of quality (QC Story)	- Checklist or data collection sheet of problem frequency - Table of effects of problems - Pareto diagram - Ishikawa diagram - Histogram - Gantt chart (improvement action plan)

Source: Suárez-Barraza and Miguel-Dávila (2011: 24).

As a result of the literature review, it was possible to formulate a hypothesis arising from kaizen management practices:

H1: Fundamental kaizen practices or techniques have a positive effect on the techniques applied in kaizen teams.

Operational Performance

“Kaizen companies” have to be better every day to remain competitive in a globalized and changing world. This situation leads industries to seek improvements in operational performance that meet the objectives set year after year. At the business level, performance is measured as the results obtained by the company after executing its operational processes in a given time. One of the performance indicators that is considered relevant is operational performance, since the expected results in the economic, social and environmental part of the company's products and services depend on it (Krajewski et al., 2007). Kong and Rajendra (2019) mention that operational performance measurements are important because the operational benefits in the form of cost reduction can subsequently be used in competitive pricing. Thus, operational performance can be defined as the performance resulting from the firm's daily operations in the productive and administrative area (De Leeuw & van den Berg, 2011; Inman et al., 2011).

According to Mizuno (1988) operational performance has been related to a firm's vital competitive priorities such as: quality (Quality-Q), cost (Cost-C), delivery (Delivery-D) and volume (Volume-V). Nawanir et al. (2013) indicate that operational performance is composed of a set of multiple dimensions such as customer satisfaction, based on product quality, and on-time delivery. Ghosh (2012) and Shah and Ward (2003), indicate that this operational performance encompasses the following dimensions: products produced with a standard quality for the first time (RTY [Rolled throughput yield]), delivery time, manufacturing-cycle time, cost reduction, waste (MUDA in Japanese) and accidents. For Abdallah et al. (2016) and Dos Santos and Tontini (2018) operational performance consists of introducing new products to the market taking into account quality, cost, delivery, flexibility and speed.

For all of the above, and for the purposes of this research, operational performance is defined as: “the set of operational indicators that encompass the dimensions of customer satisfaction with respect to quality and delivery times; specifically: products produced with a standard first-time quality (RTY [Rolled throughput yield]), waste and rework, manufacturing-cycle time, manufacturing unit costs and customer delivery time.

As a result of the literature review of operative performance and kaizen, it was possible to determine two complementary hypotheses to the previous one:

H2: Fundamental kaizen practices have a positive effect on operational performance

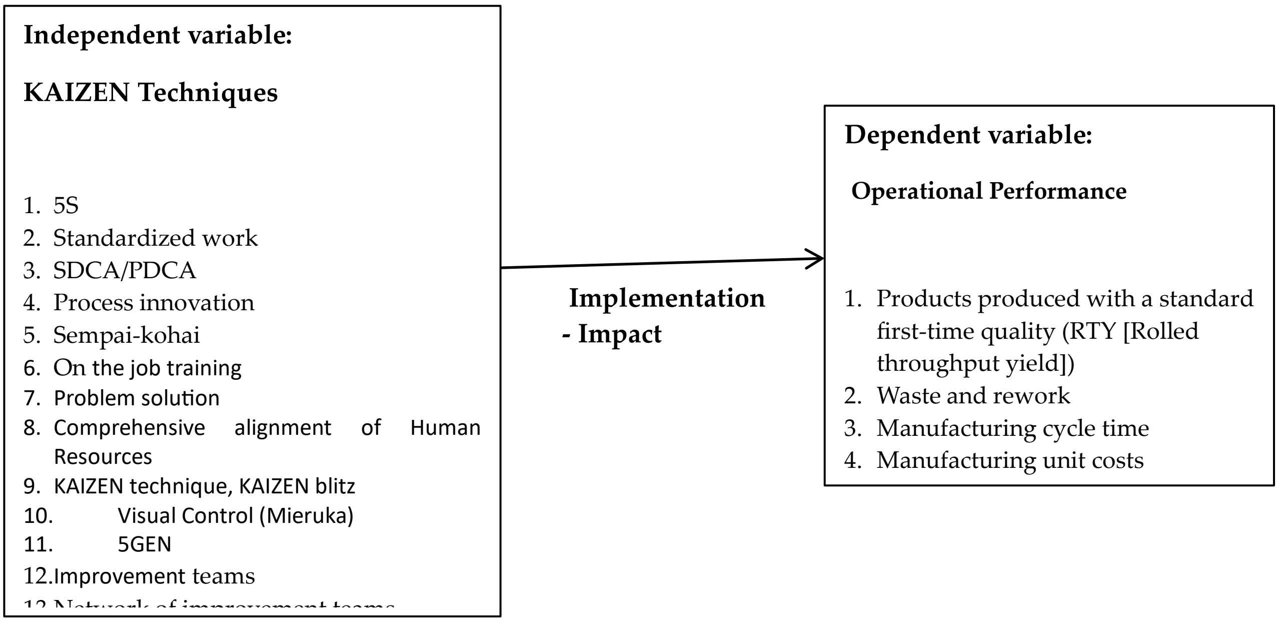
H3: The techniques used by kaizen teams have a positive effect on operational performance.

Methodology

Conceptual development

Based on the theoretical kaizen framework proposed by Suárez-Barraza and Miguel-Dávila (2011), an initial model was developed (Figure 1) which served as the basis for developing an exploratory factor analysis (EFA) to find a model to identify the kaizen techniques associated with operational performance improvement. The EFA was used to discover the correlated variables (factors) and find the groups of variables with unique (latent) factors which would help to better and more concisely define the model. To discover the structural model, an orthogonal extraction method was used and those items with factor loadings higher than 0.5 were retained. To validate the results obtained, the adequacy of the sample was confirmed by means of the KMO test (Kaiser-Meyer-Olkin) and Bartlett's test of sphericity.

Figure 1. Kaizen theoretical model



With these initial results (latent variables), the hypotheses were tested by verifying the factorial structure and the total model obtained from the exploratory factor analysis (EFA), the use of confirmatory factor analysis (CFA) and the cause-effect relationships between the different variables by means of structural equation analysis (SEM). The results of these statistical analyses were used to draw conclusions about the proposed hypotheses.

The reliability of the constructs was measured by means of the α Cronbach test. The validity of the model was assessed by measuring the variables that should not be related, were effectively unrelated (discriminant validity), and those that should be related were effectively related to each other (convergent validity). This was done by calculating the maximum shared variance (MSV), the average variance extracted, and the composite reliability. Finally, the goodness of fit of the model was calculated by means of the root mean square error of approximation (RMSEA), the standardized root mean squared residual (SRMR), the comparative fit index (CFI), a PClose calculation, and by verifying that they met the threshold specified for each of them.

Data collection and sample

The population under study is composed of manufacturing plants of multinational companies located in Mexico. The sample consists of 192 plants, surveyed by means of convenience sampling. This type of sampling was selected due to the difficulty of having access to participants who meet the selection criteria, and who were also willing to participate in the research, while trying to achieve the largest possible sample under these types of conditions.

Participants

Candidates were selected through the LinkedIn recruiter platform. The selection criteria were: managers and engineers in the areas of continuous improvement, with knowledge and experience in kaizen; professionals from manufacturing plants located in the states of: Chihuahua, Sonora, Tamaulipas, Nuevo León, Aguascalientes, Guanajuato, Puebla, Coahuila, Queretaro, Baja California, San Luis Potosi and Zacatecas. Selected participants were sent an electronic link to the survey once they agreed to connect with the researchers through the LinkedIn platform.

Measuring instrument

The questions asked are shown in Table 5. The degree of adoption of kaizen techniques was measured using a perceptual Likert scale with the following options: 1) 0% of the plant, 2) between 1% and 25% of the plant, 3) between 26% and 50% of the plant, 4) between 51% and 75% of the plant and 5) more than 75% of the plant.

A Cronbach's α test was performed on the data obtained through this instrument to evaluate the reliability and internal consistency of the questions used in the survey. For the independent variable composed of the kaizen techniques a value of 0.939 was obtained, while for the dependent variable of operational performance a value of 0.894 was obtained; both are higher than the threshold of 0.7 recommended by Nunnally and Bernstain, (1994). The adequacy of the sample was confirmed with a KMO value of 0.877 and a significant Bartlett's test of sphericity (Hair et al., 2010), in order to then perform the factor analyses.

Analysis of data

SPSS v.22 software was used for exploratory factor analysis. For the confirmatory factor analysis and SEM, AMOS v.26 software was used.

Results

Descriptive Statistics

Tables 3, 4 and 5 show different data related to the sample: by plant size, time of adoption of kaizen techniques and descriptive statistics of the variables under study.

Table 3. Sample distribution by plant size

Size	Number of plants	Percentage
Less than 250 employees	16	8.3%
Between 251 and 500 employees	37	19.3%
Between 500 y 1,000 employees	50	26%
More than 1,000 employees	89	46.3%
Total	192	100 %

Table 4. Distribution of the sample by time of adoption of Kaizen techniques.

Size	Number of plants	Percentage
Less than 1 year	21	10.9%
Between 1 and 3 years	47	24.5%
Between 3 and 7 years	46	24%
Between 7 and 10 years	26	13.5%
More than de 10 years	52	27%
Total	192	100 %

Table 5. Descriptive statistics of the independent variable (Kaizen techniques) and dependent variable (operational performance).

		Component		
Ítems	Label	N	Media	Standard deviation
Performance over the last 3 years RTY [Rolled throughput yield]	D1	192	4.39	1.46
Performance over the last 3 years waste and rework	D2	192	3.52	1.39
Performance over the last 3 years cycle time	D3	192	3.44	1.56
Performance over the last 3 years manufacturing costs	D4	192	3.16	1.53
Performance over the last 3 years delivery time	D5	192	3.11	1.60
The 5s technique has been implemented	K1	192	4.20	1.051
The standardized work technique has been implemented	K2	192	3.94	1.20
SDCA and PDCA cycle has been implemented	K3	192	3.78	1.21

Senpai-kohai technique has been implemented	K4	192	2.13	1.32
Process innovation methodologies have been implemented	K5	192	3.29	1.18
The training system (On job training) has been implemented	K6	192	3.71	1.31
The problem-solving technique (improvement kata, A3) has been implemented	K7	192	3.27	1.34
The HR department has a comprehensive alignment or development plan and its implementation	K8	192	3.02	1.34
The kaizen or kaizen blitz technique has been implemented	K9	192	3.46	1.36
In the plant the visual control methodology (Mieruka) has been implemented	K10	192	3.46	1.28
The 5GEN technique has been implemented	K11	192	2.91	1.40
Improvement teams (kaizen teams, quality circles, project kaizen teams) have been implemented	K12	192	3.39	1.32
A network of plant improvement teams has been implemented	K13	192	3.10	1.35
A kaizen support staff team has been implemented	K14	192	3.11	1.39

As shown in Table 5, traditional kaizen techniques (5s, standardization of work or the PDCA cycle) are more widely implemented; on the contrary, other lesser-known and less developed techniques have lower degrees of implementation, such as Senpai-Kohai, 5GEN, comprehensive alignment of the Human Resources department, implementation of a network of improvement teams or the implementation of a staff team to support kaizen.

Exploratory factor analysis model

To evaluate the initial theoretical model, an exploratory factor analysis (EFA) was performed. Three factors were extracted using the principal components technique followed by the calculation of factor loadings by means of a Promax rotation. To confirm convergent validity, factors with loadings above 0.5 were retained and items with low values were discarded.

By means of the correlation matrix reproduced it could be observed that 17 (21%) of the residuals is less than 50%, indicating that the factorization solution is determined more by the variance and covariance of the variables included than by the error (Hair et al., 2010) and the cumulative percentage of the total variance explained of these three factors resulted in 72.194%.

Convergent validity is established by factor, and as can be seen in Table 6, the three factors comply with an average of loadings above 0.700 and each of the items that make up the factor have loadings above 0.500. This indicates that the variance of each of the factors is explained more by their indicators than by noise or error (Reio and Shuck, 2015).

Table 6. Rotated component matrix, result of the initial theoretical model

		Component		
Ítem	Label	1	2	3
Performance over the last 3 years RTY [Rolled throughput yield]	C1	0.644		
Performance over the last 3 years waste and rework	C2	0.797		
Performance over the last 3 years cycle time	C3	0.911		
Performance over the last 3 years manufacturing costs	C4	0.900		
Performance over the last 3 years delivery time	C5	0.897		
The 5s technique has been implemented	K1		0.891	
The standardized work technique has been implemented	K2		0.892	
SDCA and PDCA cycle has been implemented	K3		0.642	
The training system (On job training) has been implemented	K6		0.634	
The kaizen or kaizen blitz technique has been implemented	K9			0.700
Improvement teams (kaizen teams, quality circles, project kaizen teams) have been implemented	K12			0.864
A network of plant improvement teams has been implemented	K13			0.999
A kaizen support staff team has been implemented	K14			0.931
Average		**0.829**	**0.764**	**0.872**
Cronbach's alpha		**0.891**	**0.823**	**0.909**

As shown in Table 6, the initial model of Figure 1 of kaizen techniques was divided according to the EFA analysis into two different constructs. On the one hand, the basic foundational kaizen techniques, which were grouped by the correlation between these items, including in this construct, the 5s technique, standardized work, SDCA and PDCA cycle and on-the-job training. On the other hand, under the Kaizen Team construct, the Kaizen blitz techniques, Kaizen teams, network of improvement teams and kaizen support staff were grouped together.

Regarding the discriminant validity, we can see in Table 7 the correlation matrix, where the correlation values that are not on the diagonal are less than 0.700; this means that there is sufficient discriminant validity among the three factors.

Table 7. Discriminant validity of the EFA analysis.

Component	1	2	3
1	1.000		
2	0.425	1.000	
3	0.477	0.613	1.000

Confirmatory factor analysis model

The model obtained through the EFA technique was subsequently analyzed using a confirmatory factor analysis (CFA) in order to validate the model found. As a consequence of this analysis, the factor "performance over the last three years of manufacturing costs" was eliminated from the operating performance construct to obtain a valid model. Different fit indicators have been used to confirm the goodness of fit of the model as shown in Table 8. As can be seen in the table, the model presents an adequate fit by complying with the different indicators established by Hu and Bentler (1999).

Table 8. Goodness-of-fit indicators for the model

Indicator	Estimate	Thereshold	Interpretation
CMIN (X^2)	104.25	-	-
DF	51.00	-	-
CMIN/DF	2.044	Between 1 and 3	Excelent
CFI	0.961	> 0.95	Excelent
SRMR	0.048	<0.08	Excelent
RMSEA	0.074	>0.06	Acceptable
PClose	0.029	<0.05	Acceptable

To confirm the convergent validity of the model obtained by CFA, the indicators shown in Tables 9 and 10 were verified. The average variance extracted (AVE) for each of the factors is greater than 0.500, while the composite reliability (CR) value is greater than 0.700 for each of the factors. Thus, there is evidence that each of the factors complies with convergent validity (Henseler et al., 2015).

Table 9. Confirmatory factor analysis model and reliability results

Construct	Standardized factor load	t-value
Basic Kaizen Foundational Techniques **(C.R. =0.829; AVE =0.550)**		
The 5s technique has been implemented	0.65	**
The standardized work technique has been implemented	0.81	8.995
SDCA and PDCA cycle has been implemented	0.78	8.779
The training system (On job training) has been implemented	0.71	8.176
Kaizen team **(C.R. =0.911; AVE=0.720)**		
The kaizen or kaizen blitz technique has been implemented	0.77	**
Improvement teams (kaizen teams, quality circles, project kaizen teams) have been implemented	0.85	12.807
A network of plant improvement teams has been implemented	0.88	13.212
A kaizen support staff team has been implemented	0.88	13.319
Operational performance **(C.R. = 0.861, AVE = 0.613)**		
Performance over the last 3 years RTY [Rolled throughput yield]	0.60	**
Performance over the last 3 years waste and rework	0.87	8.918
Performance over the last 3 years cycle time	0.87	8.908
Performance over the last 3 years delivery time	0.75	8.184
C.R. = Composite Reliability AVE= Average Variance Extracted		

The justification of the discriminant validity of the model obtained by CFA is demonstrated by the data in Table 10; the square root of AVE shown on the diagonal (0.742 for Basic Kaizen Foundational Techniques, 0.849 for the kaizen team construct and 0.783 for operational performance) has a higher value than the correlations; this means that the variance of each factor is explained more by its own indicators than by the indicators of another factor. Thus, the discriminant validity of each factor is demonstrated.

Table 10. Convergent validity of the model obtained by CFA.

	CR	AVE	MSV	Max R(H)	Basic Kaizen Foundational Techniques	Kaizen team	Operational performance
Basic Kaizen Foundational Techniques	0.829	0.550	0.543	0.841	0.742		
kaizen team	0.911	0.720	0.543	0.917	0.737***	0.849	
Operational performance	0.861	0.613	0.308	0.891	0.555***	0.480***	0.783

*** $p < 0.001$

Relationships between model constructs

To empirically test the effects of the Basic Kaizen Foundational Techniques and Team Kaizen constructs on each other and on operational performance, a structural equation model was developed. As shown in Table 11, Basic Kaizen Foundational Techniques have a positive effect on Team Kaizen (H1) and on operational performance (H2), while Team Kaizen has no direct effect on operational performance (H3). The results indicate that it is essential for companies adopting kaizen techniques to achieve stability in their processes through basic Kaizen Foundational Techniques in order to obtain the benefits that result from the adoption of kaizen techniques working in kaizen teams.

Table 11. Structural Model Results

Hypotheses	Standardized estimators	p-value	Verified hypothesis
H1: Basic Kaizen Foundational Techniques → Kaizen team	0.737	p<0.001	Yes
H2: Basic Kaizen Foundational Techniques → Operational performance	0.440	p<0.001	Yes
H3: Kaizen team → Operational performance	0.156	0.187	No
Multiple squared correlation (R^2):			
Kaizen team	0.543		
Operational performance	0.319		
Model Adequacy Statistics (X^2=104.259, df =51, CFI = 0.961, SRMR =0.048, RMSEA = 0.074, PClose = 0.029)			

Discussion

This study explores quantitatively the impact of kaizen management techniques or practices on the operational performance of companies. After an exhaustive review of the literature, fourteen kaizen management techniques or practices were identified: 1) 5S, 2) standardized work, 3) SDCA/PDCA, 4) process innovation, 5) senpai-kohai, 6) on-the-job training, 7) problem solving, 8) comprehensive alignment of human resources, 9) kaizen blitz or kaizen event, 10) visual control (Mieruka), 11) 5GEN, 12) improvement teams, 13) improvement team network and 14) kaizen support staff (Brunet and New, 2003; Suárez-Barraza and Ramis-Pujol, 2010; Al-Hyari et al. 2019; Aoki, 2008; Alvarado-Ramirez et al. 2018; Berhe, 2022; Franken et al. 2021), which formed the independent variables. The following operational performance variables were also obtained: 1) Products produced with a standard first-time quality (RTY [Rolled throughput yield]), 2) Scrap and rework, 3) Manufacturing cycle time, 4) Manufacturing unit costs, 5) Customer delivery time (Nawanir et al., 2013; Mizuno, 1988; Ghosh, 2012; Shah and Ward, 2003). All these variables constituted the theoretical framework that allowed us to test it quantitatively. The test results of the structural model indicate that there is a significant impact from kaizen management techniques and practices with respect to operational performance; that is, there is a statistically significant relationship between the independent variables and the dependent variables of the model.

The findings show that elementary kaizen techniques or practices have a significant impact on the operational performance of the companies studied. There are certain elementary roles of kaizen techniques or practices that Masaaki Imai (1986; 1997) and Taiichi Ohno (1988) have been pointing out in their seminars for years. This study also posed three hypotheses in order to test the relationships that emerged from the literature. Two of these hypotheses were statistically supported, which made it possible to see the relationship of kaizen practices in both improvement teams and operational performance.

This research is one of the first in the field that seeks to find this quantitative relationship in multinational companies, and that also allows positively testing this relationship by observing the findings of other research such as those of Imai (1997), Brunet and New (2003), Aoki (2008) or more recently, Berhe et al., (2023). For many years, in the practical "jargon" of the kaizen field, it has been believed that kaizen is just an event or simply a philosophy that does not have an impact on the operational performance of companies. This study begins to reaffirm that this relationship is positive.

For each of the hypotheses, the study findings are now discussed in detail. Hypothesis 1, in which elementary kaizen practices or techniques have a statistically positive impact on kaizen improvement teams, provides a 0.737 standardized estimator. This statistical confirmation allows understanding that kaizen teams working on problem-solving methodologies (Suárez-Barraza and Lingham, 2008), such as the Improvement Kata (Rother, 2010; Suárez-Barraza, 2010), or the 8D (Berhe et al., 2023) have a direct relationship to and impact on the company's performance variables. The reason for this confirmation is related to the fact that kaizen teams work to eliminate operational problems that have a direct impact on the performance of the processes of manufacturing companies.

In the second hypothesis, the elementary kaizen techniques (5S and standardized work) have a direct impact on the company's operational performance. The statistical findings not only corroborate the elementary kaizen techniques of problem solving through kaizen teams, but also generated evidence of managerial practice of both the 5S and standardized work. Both the 5S and standardized work generate organization, order, cleanliness and homogeneous work in the workplace, corroborating the traditional literature on the subject with the original masters (Kume, 1985; Imai, 1986; Ohno, 1988). Similarly, the literature of empirical studies validates this relationship (Ho, 1999; Suárez-Barraza and Ramis-Pujol, 2012; Berhe et al., 2023). Furthermore, the relationship to the problem-solving methodology is found in the "S" of Seiketsu (Hirano, 1995, Suárez-Barraza et al., 2024), which allows integrating standardized work, as well as organization (Seiri), order (Seiton) and cleanliness (Seiso). Finally, these empirical results begin to shed a theoretical light to explain that on-site organization and visual control facilitate the standardized operation of operational processes, leading to stable and standardized performance that can improve over time.

Finally, the third hypothesis, which indicates that the management technique or practice of kaizen teams has a positive effect on operational performance, was not verified. Different reasons can be glimpsed in the manufacturing companies studied that have implemented kaizen teams. Perhaps one of the strongest arguments for rejection found in this study is that the kaizen teams implemented in these improvement efforts are temporary. They are created for a kaizen event to improve a certain problem, and then disappear (Laraia et al, 1999; González-Aleu et al., 2018). Therefore, the possible effect that could be generated on performance is isolated and not very sustainable. On the other hand, the commitment that can be expected from both middle managers and operators is low and practically "null", because as the kaizen event is temporary in nature, the sense of urgency or conversion to positive improvement routines also fades away. This hypothesis rejection confirms previous literature regarding the topic by Suárez-Barraza (2011) and Nguyen et al. (2023). Finally, these types of improvement activities are generally performed to meet the requirement of a corporation very focused on achieving short-term results and with little involvement, without really delving into the true impact of kaizen, the growth and revitalization of the people in it.

Conclusions

The original purpose of this study was to test, with a theoretical model extracted from the literature, a group of three hypotheses that would allow linking quantitative relationships between kaizen practices and the operational performance of companies. The result was that two of the three hypotheses were corroborated; the ones that were corroborated were those indicating that the basic kaizen techniques or practices of problem-solving (Kata type), the 5S and standardized work have an impact on performance (H2) or on the kaizen teams (H1), respectively. The one indicating the impact of kaizen teams on operational performance (H3) was not supported.

According to the data obtained in this sample of multinational manufacturing companies in Mexico, what the great authors (masters) of the subject have indicated since their origins (Imai, 1986; Ohno, 1988; Shingo, 2007) is once again substantiated, which is to say that the management techniques or practices of the basic elements such as the 5S, standardization and problem solving are fundamental in any management system of an organization. In fact, they are so fundamental that they have a direct impact on operational performance. However, there is still a lot of empirical research to be done in the field to demonstrate the impact of these techniques; more work needs to be done to determine these relationships quantitatively, and to go deeper into the kaizen phenomenon under study.

The research has limitations because it focused only on manufacturing companies mainly in northern Mexico; it should be expanded to more companies, in other territories and with greater depth. In addition, other operational performance variables and their direct relationships with specific techniques can be observed. In this sense, future research opens the door to further investigate the true impact of kaizen on the operational performance of companies.

Acknowledgements

This work was supported by Grant PID2022-137379NB-I00 funded by MCIN/AEI/10.13039/501100011033 and by "ERDF A way of making Europe".

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Evaluation of the Lean Management implementation level and continuous improvement maturity level of an industrial cooperative of the Mondragon Corporation

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Abstract

Continuous improvement (CI) stands as a pivotal facet for the successful evolution and longevity of organizations, particularly amidst the prevailing VUCA (Volatility, Uncertainty, Complexity, and Ambiguity) environment where advancements and enhancements in processes demand promptness. Consequently, organizations necessitate a well-structured continuous improvement model (CIM) that encompasses crucial elements for instigating a sustainable continuous improvement process (CIP) over time. The primary aim of a CIM is to cultivate an enabling environment and framework (both organizational and informational) for nurturing and executing a CIP, thereby fostering the development of a CI-centric organizational culture adaptable to the organization's dynamics. This CIP typically comprises multiple phases, with the evaluation and monitoring phase of the improvement system assuming paramount importance. This paper delineates two evaluation systems, employed in an industrial cooperative of the Mondragon Corporation. The first system aims to gauge the degree of Lean Management philosophy implementation, benchmarked against the normative framework of the SAE J4000 standard. It encompasses six dimensions: Management/Trust, People, Information, Supplier/Organization/Customer chain, Product, and Process/Flow. The second system is geared towards assessing the maturity level of the CI system and the cultivation of an improvement-centric organizational culture. It is grounded in the development and evolution of the eight improvement routines outlined by Bessant. A comparative analysis of the outcomes from both evaluation systems reveals their compatibility and utility in identifying areas for improvement within the CIP, essential for augmenting the organization's maturity level.

Keywords: continuous improvement routines, quality organisational culture, continuous improvement assessment systems, leanness, SAE J4000

Relevant Topic: Quality culture, leadership, and human factor in quality management

Introduction

The results of implementing continuous improvement (CI) have been thoroughly documented in literature. (Bhuiyan & Baghel, 2005; Marin-Garcia, Pardo del Val, & Martín, 2008; Singh & Singh, 2015; Unzueta, Esnaola, & Eguren, 2020b). However, in numerous instances, the initial benefits of CI techniques diminish over time, resulting in reduced effectiveness (Dale, 2015). Consequently, many scholars advocate for the adaptation of CI systems to the specific needs of individual organizations (Unzueta, Esnaola, & Eguren, 2020a). Organizations must establish a CI deployment strategy to select appropriate CI methods and tools. Additionally, they must systematically monitor and follow up to cultivate a CI culture and institutionalize CI routines and behaviours within the organization. (Bessant, Caffyn, & Gallagher, 2001). To effectively implement a CI strategy, organizations must first establish a continuous improvement model (CIM). This CIM must consider several key elements (Unzueta et al., 2020a): E1- Management. (Costa et al., 2018; Garcia-Sabater, Marin-Garcia, & Perello-Marin, 2012a; Gonzalez Aleu & Van Aken, 2015; Readman & Bessant, 2007; Stankalla, Koval, & Chromjakova, 2018); E2: Company culture (Bateman, 2005; J A Eguren, Elorza, & Pozueta, 2012; McLean & Antony, 2017), E3: Strategy. (Gómez, Martínez Costa, & Martínez Lorente, 2017; Daniel Jurburg, Viles, Tanco, Mateo, & Lleó, 2019); E4: Leadership and structure (Fryer, Antony, & Douglas, 2007; Gómez et al., 2017; ISO, 2015; Lodgaard, Ingvaldsen, Aschehoug, & Gamme, 2016; Stankalla et al., 2018; Wu & Chen, 2006); E5: Resources. (Bateman & Rich, 2003a; Gómez et al., 2017; ISO, 2015; Wu & Chen, 2006); E6: Projects and E7: Areas. (Bateman & Rich, 2003b; J A Eguren et al., 2012; Lodgaard et al., 2016); E8: Operating method and improvement tools. (Bhuiyan, Baghel, & Wilson, 2006; Dale, Boaden, Wilcox, & McQuater, 1998; Daniel Jurburg, Viles, Tanco, & Mateo, 2018; Kosieradzka & Ciechańska, 2018); E9: Training. (Costa et al., 2018; Gonzalez Aleu & Van Aken, 2015; McLean & Antony, 2017); E10: Monitoring and communication (Bessant et al., 2001; Gonzalez Aleu & Van Aken, 2015); E11: Level of involvement. (Costa et al., 2018; Garcia-Sabater et al., 2012a; D. Jurburg, Viles, Tanco, & Mateo, 2016; Lleo, Viles, Jurburg, & Santos, 2020); E12: Facilitator (CI leader) (Garcia-Sabater et al., 2012a; Gonzalez Aleu & Van Aken, 2015; Heavey, Ledwith, & Murphy, 2014). Unzueta, (2020), considering these elements and other CIM (Bessant et al., 2001; Jose Alberto Eguren & Errasti, 2007; Wu & Chen, 2006) defined CIM presented on *Figure 4*.

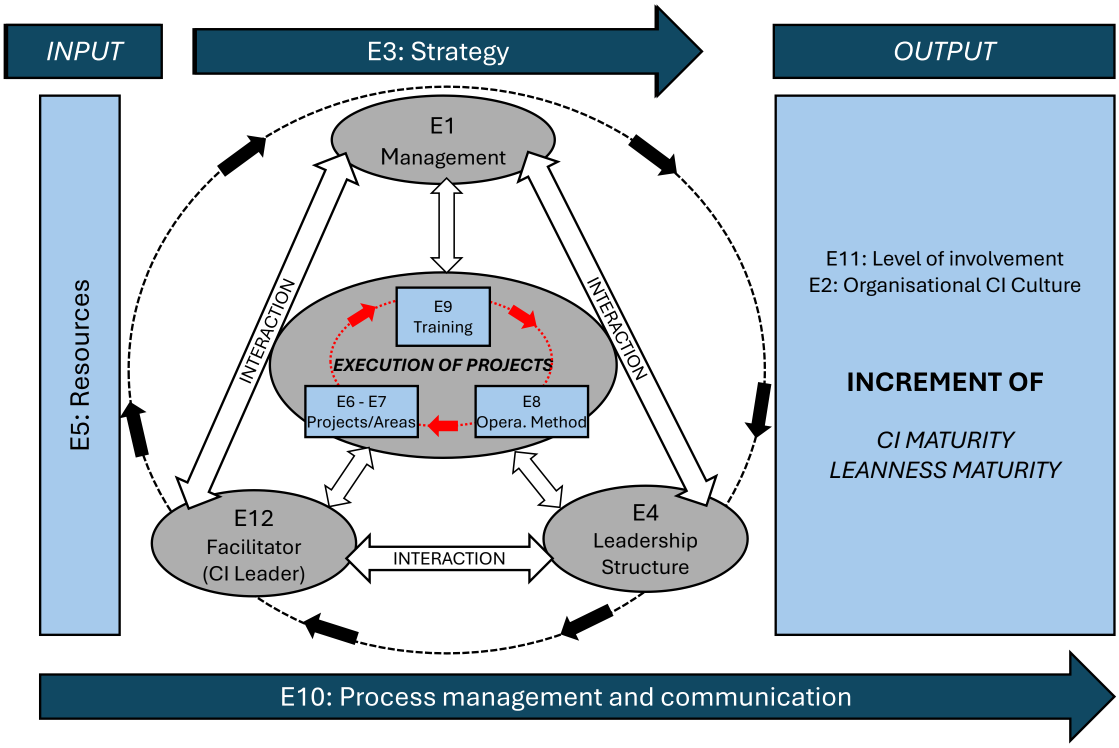

Figure 4. Continuous improvement Model (CIM). Based on (Unzueta, 2020)

Based on this model (CIM), the company should develop a continuous improvement process (CIP) to guide the implementation. The CIP typically comprises multiple stages, with the monitoring and periodic review of the CIM being of paramount importance (Figure 5). These periodic reviews allow the CIM to be adapted to the organisation, and in turn to transform the organisation itself in order to raise the level of CI maturity and move towards excellence.

According to Jorgensen (Jorgensen, Boer, & Laugen, 2006), a higher level of continuous improvement (CI) maturity—reflected in the adoption of CI routines and behaviours—correlates with enhanced organizational performance. Several models have been developed to implement CI systems and explain CI sustainability (Bateman, David, & Bateman, 2002; Bessant et al., 2001; Eguren Egiguren, 2012; Kaye & Anderson, 1999; Kumar, Antony, & Tiwari, 2011; Ljungstrom, 2005a; McLean & Antony, 2017; Upton, Professor of Technology, & Management, 1996; Wu & Chen, 2006)

The evaluation of the outcomes of the CI culture has garnered significant interest from both researchers and practitioners. These assessment systems have different point of view, and are based on; the development of routines an abilities (Bessant et al., 2001; Caffyn, 1999; Jorgensen, Boer, & Gertsen, 2003), the economic data achieved under the lean transformation projects (Cwikla, Gwiazda, Banas, Monica, & Foit, 2018), the lean culture development (Lucato, Calarge, Junior, & Calado, 2014; Narayanamurthy & Gurumurthy, 2016; Navarro, Eguren, & Unzueta, 2024; Urban, 2015), or the excellence models evaluation systems (Bou-llusar, Escrig-tena, Roca-puig, Beltrán-Martín, & Beltra, 2009), among others.

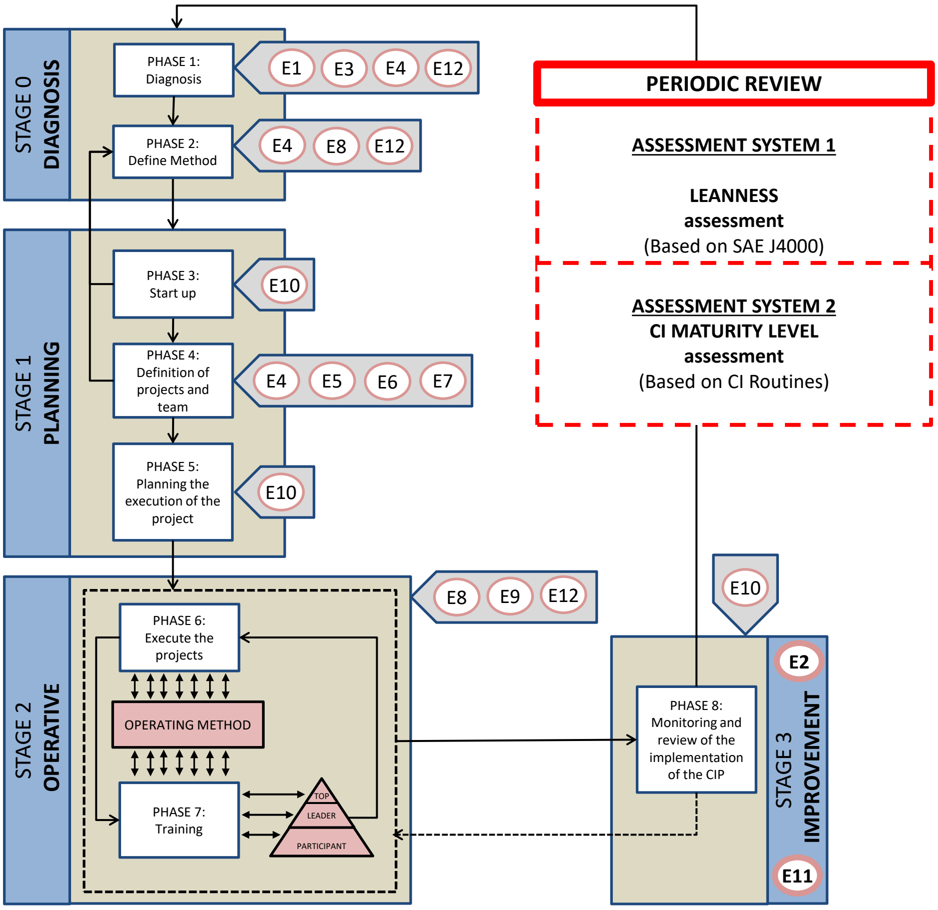

Figure 5. Continuous improvement Process (CIP). Based on (Unzueta et al., 2020a)

The current paper presents two different but compatible assessment systems to develop a periodic review of the CIM. The first system is based on the normative framework of the SAE J4000 standard (*SAE J4000*, 2021; *SAE J4001*, 2021), which measure the Lean implementation grade and the lean culture development, Leanness (Felipe, Fabio, Eduardo, & Luis, 2012; Lucato et al., 2014). And the second one is based on the evaluation of the CI routines and abilities presented by Bessant et al., (2001), which assess the CI culture development across the organisation. These two evaluation systems were employed in an industrial cooperative of the Mondragon Corporation, and because of the evaluation several lines of improvement were proposed.

Methods

The methodology applied was the case study (Yin, 2013). In selecting the case study, several characteristics were considered. The organisation should be a large, industrial company, and have experience in implementing CI methodologies and tools. The company selected was an industrial cooperative belonging to the Mondragon Corporation. Mondragon Cooperative Corporation, one of Spain's largest companies, was established in Arrasate (Guipuzkoa). Founded by Father José Maria Arizmendiarrieta, it was conceived on principles emphasizing collaboration, participation in management, innovation, social responsibility, democratic organization, education, and social change. Mondragon Corporations vision encouraged the establishment of worker-driven enterprises, fostering a landscape grounded in worker democracy and social consciousness. At its core, Mondragon emphasizes worker ownership, democratic decision principles, and social responsibility. One of its key principles the “one worker, one vote” system symbolizes equality among members in governing their cooperatives, ensuring each voice carries equal weight. Mondragon Corporation serves as a shining example of a successful cooperative enterprise, encompassing various sectors such as education (Mondragon Unibertsitatea), retail (Eroski), finance (Caja Laboral), and industry (Danobat, Fagor, Orkli, Maier, etc.).

The analysed cooperative company develops machine tools for various sectors such as Aerospace (grinding of aero engine components), Automotive & e-mobility (suppliers of solutions for grinding and hard turning), Bearings (grinding and hard turning machinery), Energy (solutions for grinding and hard turning tailored for companies in wind power and natural gas generation), Hydraulics (solutions in grinding, hard turning, and hybrids designed for high-precision hydraulic components), Railway (solutions for the maintenance of rolling stock), and Healthcare (machines and technologies providing optimal solutions for machining ceramic implants, components for medical machinery, surgical, and dental instruments). The analysed company is cooperative with a global presence, with production facilities and commercial offices, operating in numerous countries such as Spain, Germany, the United Kingdom, India, Brazil, Russia, the United States, and China. The evaluation system was used in one of the production plants in Spain. Since 2016, this company has been immersed in a Lean transformation plan, which encompasses both the transformation of the organisational model and the production model. The transformation of the production model includes the application of Lean methodologies and tools such as; 5S's, analysis of bottlenecks in the order-to-cash process and consequent changes in the critical chain planning model, kanban for component procurement, kanban for project management, etc.

Leanness assessment system

Various qualitative and quantitative methodologies have been proposed to track and measure the degree of leanness (DOL) achieved. A competitive company possesses the capability to design, manufacture, and market its products more effectively than its competitors, thereby meeting the expectations of its customers globally while maintaining a high average profitability (Lucato et al., 2014). According to (Lucato, Vieira, Vanalle, & Salles, 2012), eight critical competitive factors must be considered when assessing and measuring a company's degree of competitiveness: design, modularity, pricing, kaizen, lean, proximity, management, and finance. Additionally, any model aimed at measuring a company's competitiveness should be based on a competitive standard for comparison (Lucato et al., 2014; Navarro et al., 2024). In this context, the SAE J4000 standard proposed as a valid model for measuring the DOL or competitiveness of companies (Lucato et al., 2014; Navarro et al., 2024). The J4000 standard specifies six critical elements necessary for implementing a lean operation: Element 4 (management/trust), Element 5 (people), Element 6 (information), Element 7 (supplier/organization/customer chain), Element 8 (product), and Element 9 (process flow). To assess the extent to which these elements are implemented, the standard specifies components, which are statements designed to characterize pertinent aspects of the principles of lean operation implementation. In total there are 52 components or statements. These components are divided among the elements, so that the most important elements have more components. The Table 5 shows the elements, number of components, and their relative weight in the overall assessment of leanness. As can be seen, the sum of elements 6, 7 and 8 has a relative weight of 27%, while elements 4 and 9 each have a relative weight of 25%, and element 5 have a relative weight of 23%. The relative weight of elements 4, 5 and 9, is higher than that of elements 6, 7 and 8.

Table 5. Number of components of each Element, and its relative weight in the overall assessment of leanness

Element	**Number of components (n)**	**Element relative weight**
4 – Management / Trust (4.1 – 4.13)	13	25%
5- People (5.1 – 5.12)	12	23%
6- Information (6.1 – 6.4)	4	27%
7- Supplier / organisation / customer chain (7.1 – 7.4)	4	
8- Product (8.1 – 8.6)	6	
9- Process flow (9.1 – 9.13)	13	25%
Total of components	52	100%

According to the J4000 standard, implementation levels for each component are categorized into four distinct levels: Level 0 (L0) indicates the component is either absent or has significant inconsistencies in its implementation; Level 1 (L1) signifies the component is present but with minor inconsistencies; Level 2 (L2) denotes the component is fully implemented and effective; and Level 3 (L3) means the component is fully implemented, effective, and has demonstrated improvement over the past 12 months. However, certain components have specific exceptions: components 4.9, 4.11, 4.12, 4.13, 5.6, 5.10, 5.11, 5.12, and 6.2 are evaluated only at two levels, either L0 (not present) or L2 (present). Additionally, components 5.9 and 6.4 are assessed at three levels: L0, L2, and L3. The specific criteria for each implementation level for each component are detailed in the J4001 standard (SAE J4000, 2021; SAE J4001, 2021). For each level of implementation of a component, a specific number of points will be assigned: L0 – zero points, L1 – one point, L2 – two points, and L3 – three points. Components that have only two levels of implementation (L0 and L2) are assigned 0 points to L0 and three points to L2. And in components 5.9 and 6.2, the score of L0 is zero of L2 is two and of L3 is three. Based on this score, the Degree of Leanness (DOL) of each element (g_e) is calculated, equation (1).

$$g_e = \frac{\sum_{k=1}^{n} L_{ek}}{3n} \tag{1}$$

L_{ek} = Points obtained by each one of the “k” components of Element “e”

n = Number of Components of Element “e”

The DOL of the company is calculated by extracting the arithmetic mean of the DOL of each element (Lucato et al., 2014; Navarro et al., 2024).

Continuous improvement assessment system

The degree of implementation of an organisation's CI system is assessed by levels, level 1 is the lowest level of implementation. According to several author CI maturity could be divided on five levels (Bessant et al., 2001; Garcia-Sabater, Marin-Garcia, & Perello-Marin, 2012b; Jorgensen et al., 2006; Lindemulder, 2015). One of the most referenced is that formulated by Bessant and colleagues (Bessant et al., 2001). Some authors have identified the improvement methodologies and tools that should be used at each level, in order to make progress in the development of both the organisational model and the production model (Kosieradzka, 2017; Kosieradzka & Ciechańska, 2018; Ljungstrom, 2005; Theisens & Harbone, 2018; Unzueta et al., 2020b), a summary is shown in *Table 6*.

Table 6. CI maturity levels and methods and tools recommended on each level (Unzueta et al., 2020b)

	CI MATURITY LEVEL	METHODS AND TOOLS USED AT A GIVEN LEVEL
Level 1	Pre-CI: Interest in the concept of CI. Nevertheless, implementation is on an ad hoc basis. No formal efforts or structure for improving the organisation.	Using employees' tacit knowledge General control
Level 2	Structured CI: There is a formal commitment to building a CI system. CI initiatives have been introduced.	5S Standard operating procedures Autonomous maintenance Provisioning Kanban Quality goals and standards Seven quality tools OEE Training plan
Level 3	Goal-oriented CI: Commitment to linking CI behaviours to the strategic concerns of the organisation. Formal deployment of strategic goals. Monitoring and measuring CI against these goals. CI activities are part of the main business activities. Most of the staff participate in CI activities.	Production and supply process maps Value stream mapping (VSM) Waste identification and elimination Work station layout adjusted to the process requirements Collecting data on quality Maintenance system (TPM, RCM) Kaizen events (Blitz)
Level 4	Proactive CI: There is an attempt to devolve autonomy and to empower individuals and groups to manage and direct their own processes. High level of experimentation.	Quality and productivity measures established SPC identification of special causes DMAIC (Six Sigma) SMED Production Kanban Presentation of productivity and quality performance

	CI MATURITY LEVEL	METHODS AND TOOLS USED AT A GIVEN LEVEL
Level 5	Full CI capability: Approximates to a framework of a 'learning organisation'. Extensive learning behaviours, systematic finding and solving of problems and capturing and sharing of learning.	Process re-engineering Kaizen in the whole organisation SPC identification of common causes DMAIC (Six Sigma) Teamwork, culture of 0 defects, 0 equipment failure, 0 time waste

According to Bessant, advancing through maturity levels requires the assimilation of CI routines by acquiring the relevant skills and behaviours. Bessant described the eight routines and constituent behaviours of each one (Bessant et al., 2001). These are the 8 routines:

- R1: 'Understanding CI' - the ability to articulate the that basic values of CI
- R2: 'Getting the CI habit' - the ability to generate sustained involvement in CI
- R3: 'Leading the way' - the ability to lead, direct and other support the creation and sustaining of CI behaviours
- R4: 'Focusing CI' - the ability to link CI activities to the strategic goals of the company
- R5: 'Aligning CI' - the ability to create consistency between CI values and behaviour and the organisational context (structures, procedures, etc.)
- R6: 'Shared problem-solving' - the ability to move CI activity across organisational boundaries
- R7: 'Continuous improvement of continuous improvement' - the ability to strategically manage the development of CI
- R8: 'The learning organisation' - generating the ability to enable learning to take place and be captured at all levels

Learning must occur both within a particular stage or level, involving the establishment and embedding of routines, and between stages, which involves the introduction of new routines and their integration with previously established ones. The incorporation of these new routines is acquired as the methodologies and tools shown in the *Table 6* are applied progressively. These methodologies oblige the organisation to create new teams, new structures, and at the same time oblige the people in the organisation to be continuously trained (Unzueta et al., 2020a; van Assen, 2021). Based on Bessant's previous work, some authors have related the levels of assimilation of the improvement routines and the 5 levels of CI (Garcia-Sabater et al., 2012b; Milner & Savage, 2016; Unzueta et al., 2020a). The *Figure 6* shows that as people in the organisation acquire new improvement routines, the maturity level of the organisation increases.

CI MATURITY LEVEL	CI ROUTINES	CORE ENABLERS OF CM
5	**R8: The learning organization** **R7: Continuous improvement of the CIP**	*Method to capture and share knowledge* *Complex improvement methods*
4	**R7: Continuous improvement of the CIP** **R6: Align the CI** **R4: Focus the CI** **R5: Shared troubleshooting**	*CI structure* *Operational method (Standardized for the organization)* *Objectives defined by the work team*
3	**R4: Focus the CI** **R5: Shared troubleshooting** **R3: Lead the CI**	*Definition of objectives* *Full-time CI (Lean) Leader* *Employee engagement through public recognition* *Interdepartmental teams*
2	**R3: Lead the CI** **R1: Understanding CI** **R2: Acquire the habits of CI**	*Employee involvement through recognition system* *Elimination of resistance to change* *Selection of processes and critical areas* *Leadership*
1	**R1: Understanding CI** **R2: Acquire the habits of CI**	*Need for measurement system* *Training and education* *Strategy,* *Clear structure and hierarchy*

Figure 6. CI Maturity level and CI routines relation. Based on (Garcia-Sabater et al., 2012b)

Considering this progressive evolution of CI maturity through the assimilation of new improvement routines, Unzueta (2020) quantified the objective degree of assimilation of each routine for each maturity level. Figure 7 shows the target assimilation level for each CI maturity level.

	CONTINUOUS IMPROVEMENT MATURITY LEVEL				
	Level 1 objective	Level 2 objective	Level 3 objective	Level 4 objective	Level 5 objective
R1 Understanding CI	80%	100%	100%	100%	100%
R2 Getting the CI habit	80%	100%	100%	100%	100%
R3 Leading the way	60%	80%	100%	100%	100%
R4 Focusing CI	40%	60%	80%	100%	100%
R5 Shared problem-solving	40%	60%	80%	100%	100%
R6 Aligning CI	40%	60%	80%	100%	100%
R7 Continuous improvement of continuous improvement	20%	40%	60%	80%	100%
R8 The learning organisation	20%	40%	40%	80%	100%

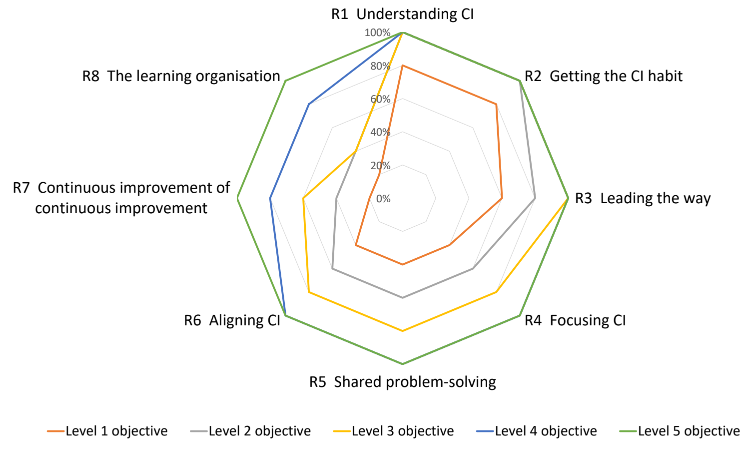

Figure 7. Benchmarks at each maturity level of each routine

The level of CI maturity of the organisation is defined by measuring the level of uptake of the 8 improvement routines. To advance in the levels, it is necessary to develop and assimilate the "constituent behaviours" associated with each improvement routines (Bessant et al., 2001). To measure the development of each routine, Unzueta et al. (2020b) proposed a questionnaire that assesses the development of these routines based on the evaluation of each of the "constituent behaviours" defined by Bessant using a liker scale (1 little assimilation – 4 maximum assimilation) for each routine (Figure 8). The results can be displayed on a radar graph (Figure 7) in order to visualize the organization's progress.

Routines evolution		**Likert**
R1 Understanding CI' - the ability to articulate the that basic values of CI		
1. People at all levels demonstrate a shared belief in the value of small steps, and everyone can contribute by being actively involved in making and recognising incremental improvements.	Are people involved in developing and implementing small improvements in their jobs?	-
2. When something goes wrong, the natural reaction of people at all levels is to look for reasons why rather than to blame individual(s).	Faced with problems, are solutions sought before the guilty?	-
3. People make use of some formal problem finding and solving cycle.	Are problems and solutions discussed in appropriate discussion forums using troubleshooting tools?	-
R2 'Getting the CI habit' - the ability to generate sustained involvement in CI		
4. People use appropriate tools and techniques to support CI.	Are appropriate techniques and tools used to solve the problems?	-
5. People use measurement to shape the improvement process.	Are measured the improvements made?	-
6. People (as individuals and/or groups) initiate and carry through CI activities – they participate in the process.	Do workers propose improvements? Do workers participate in CI activities?	-
7. Closing the loop – ideas are responded to in a clearly defined and timely fashion and are either implemented or otherwise dealt with.	Are management members (leaders) adequately responding to improvement suggestions?	-

Figure 8. example of questions to evaluate routines (Unzueta et al., 2020b)

Results and Discussion

The two evaluation questionnaires were completed through interviews with two managers in the organisation: the Chief Operating Officer and the head of a business unit. The results section contains an analysis of both measurement systems.

According to the Leanness assessment, presented in Table 7, the organization exhibits a 49% degree of Leanness (DOL). The lowest scores were observed in the value chain, specifically in the "supplier-organisation-customer" element, with a 33% compliance rate, followed by the "product" element at 44%, and the "management and trust" element at 49%. Conversely, the highest scores were noted in the "Information" and "People" elements, with compliance rates of 58% and 56%, respectively. The superior performance in these two elements— people and information—is logical, given that the organization operates as a cooperative, established by individuals (owners of the organization) to foster competitive quality employment. Effective management of personnel, including their training, aligns with the company's vision.

Table 7. Degree of Leanness determination

ELEMENT (4-9)	COMPONENTS (1-13)													g_e
	1	2	3	4	5	6	7	8	9	10	11	12	13	
4. Management / Trust	L2	L1	L1	L2	L1	L1	L0	L2	L2	L1	L2	L2	L2	49%
5. People	L1	L2	L1	L1	L1	L1	L2	L2	L2	L2	L2	L2		56%
6. Information	L1	L2	L2	L2										58%
7. Supplier / organisation / customer chain	L1	L1	L1	L1										33%
8. Product	L1	L1	L1	L2	L2	L1								44%
9. Process / flow	L1	L2	L2	L1										51%
DOL of the company (*g*)														**49%**

As a qualitative summary, the following was observed:

Element 4, Management / Trust. The achievement of the organization's strategic objectives depends on the success of Lean advancements and is addressed as such in its operational plan. There is business planning within the organization, but without an adequate deployment mechanism. Lean objectives are defined, but they are not systematically communicated throughout the organization. Formal, scheduled training in appropriate Lean techniques is required at medium and low levels of the organization. Participation mainly consists of periodic operational reviews in large groups. Lean objectives are included in the review process, but are given a low priority, and are not clearly communicated. Accountability for lean progress is a requirement and forms an important part of each manager's performance evaluation. Management makes decisions, discernible by the organization, to preserve lean progress against short-term operational objectives. The organisation is immersed in a lean transformation, but there is no fully adjusted deployment mechanism for the model. It is necessary for the organisation to define clear communication mechanisms, prioritising the Lean projects launched, and for management to persevere in lean progress against operational targets.

Element 5, People / training. There are training opportunities to improve skills. But there is no regularly reviewed training plan, and its effectiveness is not periodically evaluated. The organization is structured to respond to the structure and sequence of the company's value chain, but there are inconsistencies in the structure. There are policies and agreements that allow Lean progress within the organization. Although there is a system of improvement teams that operates throughout the organization, with responsibility for specific results identified and included in the organization's operational plan, there are inconsistencies in its structure, which make its periodic review complicated.

Element 6, Information. Members of the organization have adequate and accurate operational data and information available to them according to their needs, but in some cases, they are incomplete or difficult to access. Knowledge is shared throughout the organization naturally, but there is no structured system to do it. Costing is activity-based and reflects the activities of the value stream. Operational financial data is currently available, operating income is recognized at the time of shipment, the focus is on minimizing inventory, but without losing service level.

Element 7, Supplier/organisation/customer chain (Value chain). Suppliers and customers participate incidentally at the earliest possible stage in the organization and are not represented in the product/process/project teams. Customers participate in periodic reviews of product/process/project progress. It is necessary to define a system in which the client is allowed to participate in the initial phases of the projects in a natural way.

Element 8, Product. Product and process design is carried out by fully integrated teams with representation of all internal stakeholders, although there are inconsistencies in the creation of the teams. The design of products and processes is carried out from a life cycle systems approach, with the participation of several teams from the organization's internal value chain. The continuity of the team's knowledge is expected during the launch of the product/process, and the continuity of assigned team personnel is maintained, as well as the integrity of the document control system. Design activities are measured by program timeline charts. Product and process design needs to be done with DFM/ DFA principles in mind in order to be consistent with Lean principles.

Element 9, Process/flow. The 5S programme is fully implemented and shows an improvement in its execution in the last 12 months. Maintenance is carried out on a breakdown basis; the preventive maintenance system needs to be defined. Bills of materials and standard operations are used but are inaccurate or outdated. The current value stream is fully mapped and corresponds to the BOMs and standard operations in use, although deviations from the Material resource planning (MRP) occur regularly. Some workload planning is carried out during a production planning period. Preventive actions are taken and documented, using a problem-solving method, in every case of product or process non-conformance. The flow is synchronous with no excessive backlog of work in process. Documented standard work methods are used that distribute and balance worker loads to eliminate waste. The value chain is defined and recorded, but the information is not used systematically for CI purposes.

Regarding the evaluation of the improvement routines, it can be seen in the Table 8 and in the Figure 9 that the assimilation of the routines is logical, with a lower assimilation of the higher level routines. The understanding of CI is wide in the organisation (R1), but as we have seen in the Leanness evaluation, it is necessary to define systematic communication channels to make the information reach everyone, as well as having clear standards that make it easier to see and analyse possible improvements and measure them, to acquire good habits of improvement (R2). As for routine R3, “Leading the way”, it is necessary to systematise the communication channels that allow improvements to be proposed in a natural way. As for routine R4 "focusing CI", the evaluation indicates that 69% has been obtained, placing the routine between levels 2 and 3. In order to advance in this routine, it is necessary that the organisation puts means in place to formally recognise the improvements that are made, as well as dedicating the necessary resources (time, cost, etc.) for the analysis and implementation of these improvements. Although there are interdepartmental teams in which workers from different organisational levels participate to make improvements in the value chain, some of the participants in the teams do not have a global vision of the value chain. The lack of this global vision is related to the lack of a clear communication system, which hinders the progression in the R5 "shared problem-solving" routine.

Table 8. Assessment of the uptake of the organisation's CI routines

ROUTINES		COMPANY ASSESSMENT	
R1	Understanding CI	81%	Level 1-2
R2	Getting the CI habit	75%	Level 1-2
R3	Leading the way	69%	Level 1-2
R4	Focusing CI	69%	Level 2-3
R5	Shared problem-solving	65%	Level 2-3
R6	Aligning CI	56%	Level 2
R7	Continuous improvement of continuous improvement	50%	Level 2
R8	The learning organisation	46%	Level 2-3

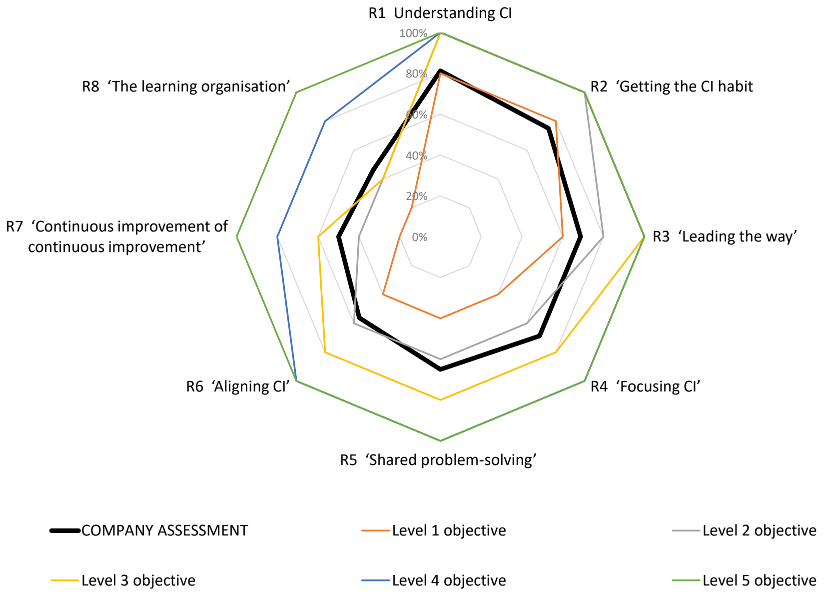

Figure 9. Radar chart of assimilation of the organisation's improvement routines

Regarding routine R6 "Aligning CI", which describes the ability to create a relationship between the values of CI and the context of the organisation (organisational structures, established procedures, etc.), the assessment was 56%, placing the organisation at level 2. Although in recent years, because of the lean transformation process, a great effort has been made to create an organisational structure compatible with CI tasks, the people who compose it are not dedicated full time to CI. There is a CI leader who coordinates the team, but the day-to-day work complicates the analysis, development and implementation of improvements, slowing down the improvement process. The evaluation of routine R7 "Continuous improvement of continuous improvement", reaches a score of 50% and is placed at level 2. Although the CI leader constantly monitors the improvement projects launched, an annual monitoring of the CIM is not systematised. Within the annual management plan process, the evolution of the implementation of the lean transformation process is evaluated, but the improvement model itself is not assessed, only the improvement projects launched. Regarding routine R8 "The learning organisation", it is the organisation that directs and proposes training, it is not the workers themselves who seek training opportunities for personal development. There are internal trainings to socialise knowledge, but they are not systematised, and although basic knowledge is documented through these trainings, more complex knowledge is left in the hands of individuals.

Conclusions

Upon analysing the results obtained from the two evaluations, it can be concluded that the findings are positive. The organization acknowledges the significance of CI but still has substantial progress to make to achieve excellence, characterized by the promotion of continuous learning and a focus on process enhancement. Certain aspects, such as ”people” and ”information sharing”, are more developed. Both evaluations indicate that employees are aware and oriented towards CI, a critical factor since it is the employees who must implement the necessary changes. However, to elevate the maturity level and enhance aspects that received lower scores, the company must not only recognize the importance of CI but also provide the necessary means and resources for its daily implementation. Without such support, CI remains underutilized. Therefore, it is essential to conduct more frequent and consistent follow-ups, rather than annual ones, and to provide training for employees. This training should not only introduce new concepts and methodologies (TPM, Six Sigma, etc.) but also reinforce the importance of CI, ensuring it is a sustained and frequent practice for achieving the desired results.

Regarding the evaluation systems, it has been observed that both systems are compatible. Despite their different approaches—one focused on Lean implementation and the other on actions related to CI system—the proposals derived for improving organizational structure, material and information flow, and the relationships between personnel and client-supplier teams (both internal and external), etc. share many similarities. In terms of limitations, it should be noted that the evaluation was conducted in an organisation that is immersed in a Lean transformation process. The interviews were conducted in an environment where leaders are predisposed to change and organizational improvement, which facilitated obtaining valid results for both the research and the organization itself. In a different context, the results obtained (i.e., the proposed improvements) might not be as valuable.

As future lines, it is interesting to repeat these evaluations in the near future in the same organisation, in order to analyse the progress of the Lean transformation process and its impact on the CI system and in the people mindset. On the other hand, it would be interesting to apply these evaluation systems in other organisations with different characteristics, different sectors, different levels of maturity, different sizes, etc.

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Leading Organizational Transformation toward Sustainable Futures. A systematic literature review of leading for quality in the age of digitalization and AI

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Abstract

Organizations are currently facing increasing complexity with several interrelated phenomena that interact with and challenge leadership. These phenomena include navigating and leading for quality while also transforming to meet sustainability goals, alongside the ongoing exploration of the possibilities of digitalization and artificial intelligence (AI) in fostering innovation and efficiency. This paper revolves around this complexity and the potential synergies and connections among quality, sustainable development and transformation in the age of digitalization and AI. The purpose of this study is to identify the strategies and challenges associated with leading for quality and sustainability amidst the ongoing transformations driven by sustainable development, digitalization, and AI. A systematic literature review was performed using a combination of search terms related to sustainability and sustainable development, quality management, digitalization and artificial intelligence, and leadership to find relevant academic articles via the Scopus and Web of Science academic databases. A total of 15 articles were included in the study after screening the titles, abstracts, and full texts according to predefined criteria for inclusion and exclusion. Each source was carefully evaluated for its relevance, credibility, and quality. As a result, the review identified a need to address a research gap regarding the practical interaction between the phenomena of interest. In the reviewed articles, systems thinking and the integration of multiple disciplines were also deemed essential for holistic organizational management. The findings stress the importance of leadership and underscore the necessity of bridging the theory-practice gap to navigate today's intricate organizational landscape toward sustainability goals. Furthermore, the findings highlight an increasing demand for new leadership skills and competencies, particularly in navigating transformative complex processes, which currently lack clear guidance. This research contributes valuable insights for policy-makers, practitioners, and scholars seeking to navigate the complexities of leading for quality in the midst of organizational transformations toward sustainable futures.

Keywords: Organizational transformation, Sustainable development, Artificial intelligence, Quality management, Leadership

Relevant Topics: Sustainable leadership and change management, TQM in the digital age

Introduction

In today's rapidly evolving landscape, organizations are facing increasing complexity, driven by interconnected phenomena as they strive to meet sustainability goals, posing significant challenges to leadership (Johnson et al., 2018; Lee and Patel, 2021). Industry 4.0 represents a broader industrial revolution driven by digital technology and digitalization, focusing on the creation of smart and interconnected factories and production processes. This revolution has brought transformative changes to many sectors, including quality management (Narkhede et al., 2023; Nguyen et al., 2023). With the emergence of Quality 4.0 and 5.0, quality management has been shown to be highly relevant for digital transformation, where digital tools and data are utilized to enhance quality processes and production performance. However, the widespread impact of digital technologies and artificial intelligence (AI) offers both opportunities and difficulties in the pursuit of innovation and efficiency (Bergman et al., 2022).

The Role of Digitalization and AI in Quality Improvement

Companies are constantly pushing for improved quality and innovative tech solutions such as digitalization and AI because of increasing customer demands and global competition (Bergman et al., 2022). This commitment to improvement is a fundamental aspect of total quality management (TQM). Sader et al. (2022) stress that TQM 4.0 is an advanced approach to quality management for enhancing the effectiveness of quality activities. Nguyen et al. (2023) further elaborat on this by highlighting how emerging technologies including Industry 4.0 technologies such as the Internet of Things (IoT), big data analytics, artificial intelligence (AI), and machine learning (ML) are crucial components of TQM 4.0.

Dias et al. (2022) not that digital transformation has an impact on how we think, assess and manage quality. Duan et al. (2019) point out the lack of knowledge in organizations about how to manage AI investments to generate value from them. Tariq et al. (2021) stress that technologies such as AI have the potential to improve outcomes across various domains. Similarly, the literature review by Corti et al. (2021) highlight the crucial role of AI in efficient improvements, and factors such as organizational culture, strategy, and competence are pivotal for the success of quality initiatives. Implementing technological solutions presents its own set of challenges. As noted by Tariq et al. (2021), a lack of competency, both technically and strategically, causes challenges for many organizations in the successful implementation of AI solutions. Further insights from Ångström et al. (2023) shed light on the common struggle faced by companies in successfully implementing AI initiatives, with a majority failing to achieve significant results. Brynjolfsson (2022) note the risks associated with AI development and deployment, and ethical considerations and the need for responsible AI development are crucial in this context.

Radziwill (2018) stress the significance of competency in quality development, stating that it enhances successful digital innovation implementation through a focus on system thinking, evidence-based decision-making, learning organizations, continuous improvement, and an understanding of the impact of decisions on individuals.

In sum, it appears as if leaders find themselves at a crossroads, tasked with fostering quality, driving sustainability, and embracing transformative change, all while navigating a continuously growing landscape of digitalization and artificial intelligence (AI).

Interdisciplinary Research and Sustainability

Mårtensson et al. (2019) suggest that organizations focusing on quality and sustainability are inclined to prioritize strategies encompassing sustainability and digitalization. Integrating Lilja (2024), this underscores the necessity for holistic approaches, extending beyond sustainability, to embrace regenerative practices and navigate complexity for transformative change.

Mhlanga, 2021 highlighted the need for research on how AI can contribute to achieving sustainable development goals (SDGs). There is a gap in understanding the long-term environmental, economic, and social impacts of these technologies (García-Martínez, 2021). Furthermore, research often overlooks the unequal distribution of benefits and risks associated with digitalization and AI in sustainability initiatives (Robinson, 2020).

Finally, research on how digitalization and AI can enhance the resilience of socioecological systems and support adaptation to climate change is still emerging (Taghikhah et al., 2022) but is crucial for addressing future sustainability challenges.

Leadership and Management in the Digital Age

There are several definitions of leadership and management (Bergman et al. 2022). DuBrin (2016) suggested that leadership is the ability to inspire others to achieve worthwhile goals while the manager's job is to lead, plan, organize and control. Bergman et al. (2022) noted that leadership aims to motivate, inspire, and ensure that everyone develops in line with both individual needs and the needs of the organization. Synder et al. (2017) mentioned that both leaders and managers need to understand and integrate the structure and culture of the organization together with the identity of leadership.

According to Netland (2016), managers' commitment and support are often cited as among the most important critical success factors for any change effort. On the other hand, clarity is lacking in regard to how organizations should initiate, structure and drive change projects (Naslund and Williamson, 2020).

Brynjolfsson (2022) discussed how the choice between automating tasks and augmenting human abilities impacts leadership's ability to maintain quality and promote learning. Steiber and Alänge (2016) underlined various aspects of leadership that are critical in the digital revolution, such as empowering employees, promoting a culture of experimentation, and maintaining a strong customer focus. Nguyen et al. (2023) highlighted that the connection between Quality 4.0 and topics such as digital transformation, sustainability, and quality culture are challenges that scholars need to overcome.

Identifying strategies and challenges

Given the background, there is a need for reviewing what it means to, and might mean to, lead for quality and sustainability in the midst of these fundamental ongoing transformations. What can be found in current research and literature concerning how leading for quality, driving transformation, and advancing sustainable development are connected in the digital age infused with AI?

Purpose and Research Questions

The purpose of this study is to identify the strategies and challenges associated with leading for quality and sustainability amidst the ongoing transformations driven by sustainable development, digitalization, and AI.

The following research questions (RQs) have been addressed:

RQ 1-What are the potential synergies and connections between leading for quality, transformation, and sustainable development in the age of digitalization and AI?

RQ 2- How do organizations navigate the transformation toward sustainability goals while integrating digitalization and AI?

Methods

A systematic literature review (SLR) was employed. A SLR is a standard tool in many fields of management and are increasingly used to explore phenomena (Kraus et al., 2020). A SLR is critical for exploring quality management, as highlighted by Tranfield et al. (2003). A SLR relies on a structured, transparent and reproducible method of selecting and assessing scientific contributions, as noted by Davis et al. (2014), while also aiming to facilitate replication of the process and systematically compile research findings, as highlighted by Grant and Booth (2009).

Tranfield et al. (2003) argued that the purpose of conducting a literature review is to provide the researcher with opportunities to both map and assess the existing state of knowledge and to specify a research question for further advancing the existing knowledge. The process outlined by Tranfield et al. (2003) consists of three key stages: (1) planning the systematic literature review (SLR), (2) conducting the SLR, and (3) reporting the results. This process entails formulating the purpose and research questions, identifying keywords, creating search blocks, determining the appropriate databases, determining the inclusion and exclusion criteria, documenting the selection process, ensuring the quality of the relevant articles, extracting the data from the relevant articles, analyzing the results and writing an article or conference paper.

The inclusion and exclusion criteria for this SLR were as follows: articles published between 2020 and 2024; articles written in English; peer-reviewed articles, conference papers, and reviews for which the full text was available; and articles aligned with the defined search terms and eligibility criteria.

Search strategy

The search was conducted in two electronic databases, Scopus and Web of Science, using the same combination of keywords and search terms covering sustainability, sustainable development, quality management, digitalization, AI and leadership. Each article underwent careful review to ensure its relevance, credibility, and quality, only articles that met rigorous standards of quality and relevance were selected. This involved a thorough evaluation of each article to ensure that it was well executed, credible, and directly pertinent to our research focus.

See Table 1 for a complete list of the keywords and search blocks. The databases were searched on April 29, 2024, encompassing the period from 2020 to 2024. The search was restricted to studies published in English within peer-reviewed journals. Each of the relevant articles was assigned a unique identifier code for easy reference. Subsequently, relevant citations directly addressing our research question were identified and collected.

Results and Discussion

This section presents the results of the research and data analysis. The findings are discussed in the context of potential synergies and connections between Quality Management (QM), Sustainable Development Goals (SDGs), digital transformation, and leadership for quality and sustainability in the age of digitalization and AI.

Results of the search

The search in “Scopus” resulted in 10 papers, three of which lacked access to the full paper; an additional article was identified from the reference list of one of the 10 Scopus articles. All 11 articles met the inclusion criteria and were included in the research. Similarly, the “Web of Science” search resulted in 7 papers, all of which met the inclusion criteria. Table 1 provides an overview of the database search strategy and results.

Table 1. *Presentation of the database search strategy*

Search in Scopus Date: 2024-04-29	Search terms	Filters used	Number of results
# 1	"quality management" OR qm OR tqm OR "quality 4.0" OR "quality 5.0"	Search within the article's title, abstract and keywords; Year 2020-2024; English; Include articles, conference paper and reviews	38,298
#2	ai OR "artificial intel*" OR "intelligent automation*" OR "digitalization" OR "digitalisation" OR "machine learning" OR genai OR "information system*" OR "industry 4.0" OR "industry 5.0"	Search within the article's title, abstract and keywords; Year 2020-2024; English; Include articles, conference paper and reviews	672,341
#3	"sustain* dev*" OR sdg OR "organi* sustain*" or " sustainability"	Search within the article's title, abstract and keywords; Year 2020-2024; English; Include articles, conference paper and reviews	262,063
#1 AND #2 AND #3			147
Included after reading the title and abstract			51
Included the terms "leadership and management"			12
Included after reading the article			10
Included by checking the reference lists			1
Total included in this search			11

Table 1

continued. *Presentation of the database search strategy*

Search in Web of Science Date: 2024-04-29	Search terms	Filters used	Number of results
# 1	"quality management" OR qm OR tqm OR "quality 4.0" OR "quality 5.0"	Topic; Year 2020-2024; English; Include articles, proceedings papers and review articles	10,887
#2	ai OR "artificial intel*" OR "intelligent automation*" OR "digitalization" OR "digitalization" OR "machine learning" OR genai OR "information system*" OR "industry 4.0" OR "industry 5.0"	Topic; Year 2020-2024; English; Include articles, proceedings papers and review articles	412,173
#3	"sustain* dev*" OR sdg OR "organi* sustain*" or " sustainability"	Topic; Year 2020-2024; English; Include articles, proceedings papers and review articles	202,104
#1 AND #2 AND #3			95
Included after reading the title and abstract			44
Included the terms "leadership and management"			9
Included after reading the article			7
Included by checking the reference lists			0
Total included in this search			7

After screening the titles, abstracts and full texts, a total of 15 papers met the inclusion criteria and were included in the study. Figure 1 provides an overview of the database search strategy, resulting in a total of 15 articles being included in the study.

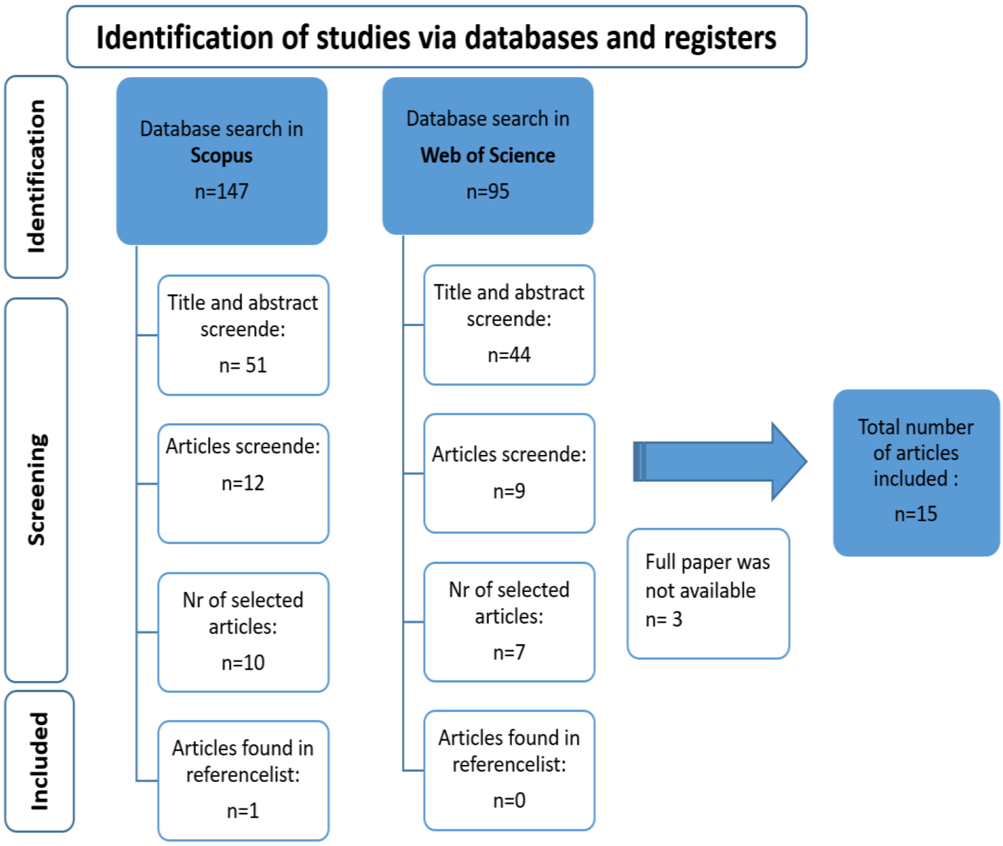

Figure 1. *Overview of the database search strategy*

The included articles were carefully chosen and managed effectively. To analyze the results, a tree diagram was used, utilizing color coding to group and categorize the collected data effectively. This approach not only facilitates a structured analysis process but also enables patterns and relationships within the literature to be more efficiently identified, according to Bergman et al. (2022). Furthermore, an open coding process was used to identify themes and categorize the data according to emerging patterns and concepts. This systematic approach ensures a comprehensive exploration of the findings, allowing for deeper insights into the research topic. As highlighted by Davis et al. (2014) and Grant and Booth (2009), a SLR offers a structured, transparent, and reproducible approach to systematically compile research findings.

Potential synergies and connections between QM, SDG and digital transformation

Concerning the initial research question about the potential synergies and connections among leading for quality, transformation, and sustainable development in the age of digitalization and AI, several patterns were highlighted in the reviewed articles. The first involved a strong notion about potential synergies and how the phenomena are interconnected. For example, Santos et al. (2021) argued that *"...while Quality 4.0 is fueled by technology, the true transformation occurs in the culture of quality, leadership, and quality processes"* (p. 3).

There were also notions about the potential synergetic connection with sustainability, as demonstrated in Nasir et al. (2022), who stated that *"a smart utilization of Industry 4.0 technologies to upgrade the innovativeness in the organization at product, process and administration ultimately leads to the sustainable development"*

(p. 7). On the other hand, Karbekova et al. (2023) highlighted sustainability as a driver of product quality in terms of *"the mix of Quality 4.0 and sustainability through the combination of technological and marketing management generates a synergistic effect expressed in higher product quality than when these management practices are carried out separately"* (p. 274).

However, regarding practice and empirical evidence, synergies were often seen as potential, which is in line with the findings of Sader et al. (2022) and Nguyen et al. (2022), who stressed that Industry 4.0 technologies are crucial components of TQM 4.0 for meeting sustainability goals (Johnson et al., 2018; Lee and Patel, 2021). There is a remaining research gap concerning actually studying them as they interact in practice. This gap was, for example, noted by Aichouni et al. (2022), who concluded that *"there is a research gap in combining the three emerging management concepts (Total Quality Management; Industry 4.0, and Sustainability) within the same study"* (p.15).

In sum, it is evident that there are strong indications of potential synergies and connections between leading for quality, transformation, and sustainable development in the age of digitalization and AI.

Leading for quality and sustainability in the age of digitalization and AI

The results indicated that there is an ongoing search for how organizations can navigate the transformation toward sustainability goals and at the same time integrate digitalization and AI. Systems thinking is an area that was highlighted from various perspectives and was seen as an important area for further development as shown in the following: *"Researches and understands the ecosystem, including megatrend implications, and the consequences of it on the United Nations Sustainable Development Goals and Global Compact ambitions"* (Fonseca et al., 2023, p. 13), and *"Adapting TQM with I 4.0 technologies results is an ecosystem that supports the integration between technology, quality and people in the industrial context"* (Aichouni et al., 2022, p. 15).

Both systems thinking and the integration of multiple areas were identified as relevant from the perspective of the holistic management of organizations' operations; this can be seen in, for example, the quote from Aichouni et al. (2022, p. 10*) "A clear link between I4.0 technology and Total Quality Management can also be seen, highlighting how modern technologies and management aspects lead to sustainability".* Another example highlighting a holistic view of the integration of several fields can be seen in the following quote from Fonseca et al. (2023, pp. 14-15): *"The EFQM 2020 model is a step in that direction. It is a comprehensive and updated business model that shares with Industry 4.0 the emphasis on transformation and improved organizational performance"*; moreover, *"...the new EFQM digital platforms (AssessBase and KnowledgeBase) are good examples of the EFQM vision for digitalization, and EFQM key stakeholders have been prepared and trained to take advantage of these tools. Moreover, sustainability and the United Nations Sustainable Development Goals (SDGs) are emphasized through the EFQM 2020 model"*.

At the same time, it turns out that the navigation of transformation complexity places demand on the employees in organizations. The development of abilities and skills is a requirement; specifically, in leadership, this need is expressed as necessary: *"The professionals that work on quality management must have creative thinking, be leaders, know how to communicate and work as a team, as well as, to have knowledge and understanding of ICT (Information and Communications Technology), and main pillars of Industry 4.0"* (Santos et al., 2021, p. 1), *"…it is necessary to be a leader, to have analytical thinking, to have creativity, originality and initiative, and sometimes to be capable of complex problem-solving with emotional intelligence"* (Santos et al., 2021, p. 14), and *"…we found important points that indicate that issues of leadership and people management and culture are keys to the success of a Lean to I4.0 integration model"* (Moraes et al., 2023, p. 11).

The search for new ways to lead and develop quality where digitization is also to be incorporated is also in line with Dias et al. (2022), who stated that digital transformation affects thoughts about quality and management and the assessment of quality. Blythe et al. (2020) noted the gap in interdisciplinary research, which is essential for identifying innovative solutions. They emphasized that expertise from different domains needs to be combined to address complex sustainability challenges effectively.

As a reflection of the emerging need for new abilities and skills, which is linked with Corti et al. (2021) and Tariq et al. (2021), factors such as organizational culture, strategy, and competence are pivotal for the success of quality initiatives. This study emphasizes the importance of systems thinking in achieving sustainable development during digital transformation. Radziwill (2018) also highlighted that competency in quality development, particularly through systems thinking, enhances the success of digital innovation. The results of this study show that the dissemination of knowledge about how to navigate transformation in practice is unclear.

Conclusions

This study have identified potential synergies and connections among quality management (QM), sustainable development goals (SDGs), and digital transformation. The findings highlight the pivotal role of leadership and organizational culture in driving transformative change, emphasizing that while technology drives Quality 4.0, true transformation occurs through human elements. A notable finding is the significant potential of Industry 4.0 technologies to foster innovation and sustainable development. However, a gap exists between theoretical understanding and practical implementation, underscoring the need for empirical research to bridge this gap and inform effective practices.

Furthermore, this study emphasizes the evolving role of leadership in this complex landscape, advocating for human-centric approaches that foster collaboration, innovation, and sustainability. This finding underscores the importance of systems thinking and integrating multiple disciplines for holistic organizational management. The findings highlight the necessity of bridging the theory-practice gap to navigate today's intricate organizational landscape toward sustainability goals. Additionally, the emerging need for new leadership skills and competencies is noted, with a lack of clear guidance on how to navigate transformational processes in practice.

The study offers valuable insights for policy-makers, practitioners, and scholars seeking to navigate the complexities of leading for quality amidst organizational transformations toward sustainable futures.

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Promoting Sustainable Traction towards an Environment of Continuous Improvement. The CITF Framework.

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Abstract

Although the pursuit of Continuous Improvement (CI) is regarded as plausible aim by many organisations in their journey towards excellence status, the current adoption of CI tends to be carried out in a rather linear pattern of development. In this paper we propose a framework driven by thematic analysis that provides a guide for organisations to establish an environment of Continuous Improvement (CI) in order to reach higher levels of CI maturity. This is achieved through a holistic pursuit of operational and behavioural excellence within a dynamic and creative environment of CI. The proposed framework is configured in such a way that it follows an interactive dynamic pattern of interactive double loops of Actualisation and Realisation, referred to as a 'leminscates'. The conceptualisation of the framework is informed by two case studies across a seven-year longitudinal study.

Keywords: Continuous Improvement, Creative Environment, CI Maturity, Sustainable Traction, Thematic Analysis

Relevant Topic: Continuous Improvement

Introduction

Although incorporating Continuous Improvement (CI) as an underpinning feature of both Total Quality Management (TQM) and Lean and Six Sigma quality systems, short-term Kaizen events may create a burst of excitement that is shallow and short-lived and, therefore, is not sustained.

Historically, the failure and abandonment rates for CI initiatives have been high (Bessant et al., 2001), Mendelbaum (2006) reporting that just 11% of organisations considered their efforts to develop a CI environment as successful. Initial successes can encounter a series of impediments to sustaining CI in the longer term (Bhuiyan, et al., 2006), a common feature of which being the demonstration of value added. Yet, while organisations may not have achieved the intended level, or the aspired sustained level of activity, denoting the lack of sought after or expected success as failure should be questioned, and the recognition of the DNA strands left from organisational CI efforts better considered.

Failure to communicate the intended long-term-goals of CI initiatives (Bernett & Nentl, 2010), and lack of information and measurement regarding short-term wins, can result in negative views, reluctance, mistrust, and scepticism (Audretsch et al., 2011) which serve to inhibit staff engagement. It is important therefore that the CI infrastructure incorporates mechanisms for selection and performance measurement of CI activity (Linderman et al., 2003), ensuring that they add value to the organisation rather than simply targeting improvement for improvements sake (Bateman, 2005). CI thus requires performance measurement and evaluation, so that outcomes lead to informed action (Jha et al., 1996).

One problem with CI is the mirror of a key benefit, that at its core it relies on 'many small wins'. This needs a high level of organisational maturity in both quality and resilience. Organisations usually have in place a 'system' that captures failures such as machines downtime in the form of either a Computerised Maintenance Management System (CMMS) or Enterprise Resource Planning (ERP) systems. However, the more they grow in maturity towards excellence the more they are able to have more of an attitude of 'preoccupation with failures' (PwF), which is one of the core ingredients of High Reliability Organisations (HRO). Such PwF implies having in place a 'system' that can also capture 'near misses', which are incidents that did not actually cause any drastic failure just due to good luck. These near misses in a failure context are analogous to small wins in CI context; an organisation needs to be of high maturity to be able to capture small wins adequately and continuously.

McChrystal (2015) having previously stated that, while efficiency remains important, the ability to adapt to the increasing complexity in operations and the business environment, and respond to continual change, are of growing importance. The COVID 19 pandemic (2020) has further highlighted how unexpected factors can alter the internal organisational setting and economic landscape alike.

CI in its evolved state embeds a culture of Organisational Learning (OL), in which new knowledge and capabilities are created, acquired, and applied (Martinez-Costa & Jimenez-Jimenez, 2008) through a series of single, double, and triple loop learning (Argyris, 1990; Pemberton & Stonehouse, 2000), which collectively promote organisational renewal, and prevent the ossification of practices and processes (Cole, 2001). OL therefore relates to the possibility for organisations to be both proactive and reactive in their practices; to learn from the past, anticipate the future, respond to threats (Roche,2002) and to adapt to changing environments, thus becoming a learning organisation that can facilitate the learning of all its members and continuously transforming itself.

Therefore, the aim of this paper is to propose a framework driven by thematic analysis that provides a guide for organisations to establish an environment of Continuous Improvement (CI) in order to reach higher levels of CI maturity. In doing so, we identify three key Research Objectives (ROs), as follows: RO1) Identify, explore, and critically review the key components for developing a system of continuous improvement (CI) in a 21st Century service organisation. RO2) Analyse and critically evaluate the role of a dynamic Creative Environment (CE) in promoting traction to CI and innovative practice in organisations. RO3) Contribute a novel Framework to guide sustainable traction in realising both behavioural and operational value from a dynamic and creative environment of CI.

This paper offers an introduction of the proposed Continuous Improvement Traction Framework (CITF). Heightened rigor and the practical evaluation of each leminscate and its component parts is presented in a series of aligned papers.

Methods

The research embraces an Interpretivist philosophy, guiding 'the way the problem is seen (ontology), how it is understood (epistemology), and the research methods accepted within the chosen research paradigm' (Joslin & Müller, 2016, p.1046). An abductive approach was adopted, deductively applying CI and CE theory, whilst inductively allowing additional themes and codes to emerge from empirical data collected via a longitudinal, embedded case study strategy.

With the choice of the mixed method complex option, the research is predominately qualitative, this offering the flexibility (Silverman, 2000) required to gain an in-depth understanding of the wider social context. Multiple methods of data collection and analysis were used to triangulate sources of evidence (Yin, 2012), Interviews were the core component, analysed via a rigorous protocol of thematic analysis, based on the work of Braun & Clark (2006), and King & Brooks (2018), these were supplemented by a series of focus groups and a quantitative questionnaire.

The time horizon of any research can be classified as either cross-sectional, or longitudinal, and since the 1990s academics have embraced the value of collecting longitudinal data over periods of real and retrospective time, viewing the co-existence of different opinions and mismatched competing perspectives, not as an obstacle, but as a key part of the rich data set (Pettigrew, 1985). To achieve this, the study adopts Dawson's (1997) key elements of success: 1. the notion of tacit knowledge and the researcher getting their hands dirty by engaging in on-going in-depth fieldwork; 2. the design and implementation of a longitudinal case study research programme; and 3. the advantages and concerns combining a range of different data collection techniques in carrying out studies.

In the adoption of a longitudinal time horizon, empirical data has been collected from the Case Organisation (CO), and analysed through a series of research cycles, exploring CI and CE within Case 1 (CS1) and Case Study 2 (CS2) Units of Analysis (UoA). The initial empirical findings, and review of literature, served to mutually guide each other through a virtuous cycle of development, allowing the direction and focus of the research to evolve and refine naturally. Figure 1 presents the Research Timeline, incorporating the associated annual timing, data items range, data sets numbers, and data collection and analysis points, for each Research Cycle. The research initiated with a pilot study, followed by three empirical research cycles, each incorporating a series of data collection (DC) points, (seven in total, ranging from one to five days in duration), and initial data analysis (DA) points (one for each cycle), and finally a cycle of thematic analysis, from which the findings and corresponding discussion have been drawn. The empirical data and analysis sourced from the interviews and focus groups conducted though Research Cycle 1 is labelled Data Set 1 (DS1), Research Cycle 2 as Data Set 2 (DS2), Research Cycle 3 as Data Set 3 (DS3), and the Questionnaire as Data Set 4 (DS4).

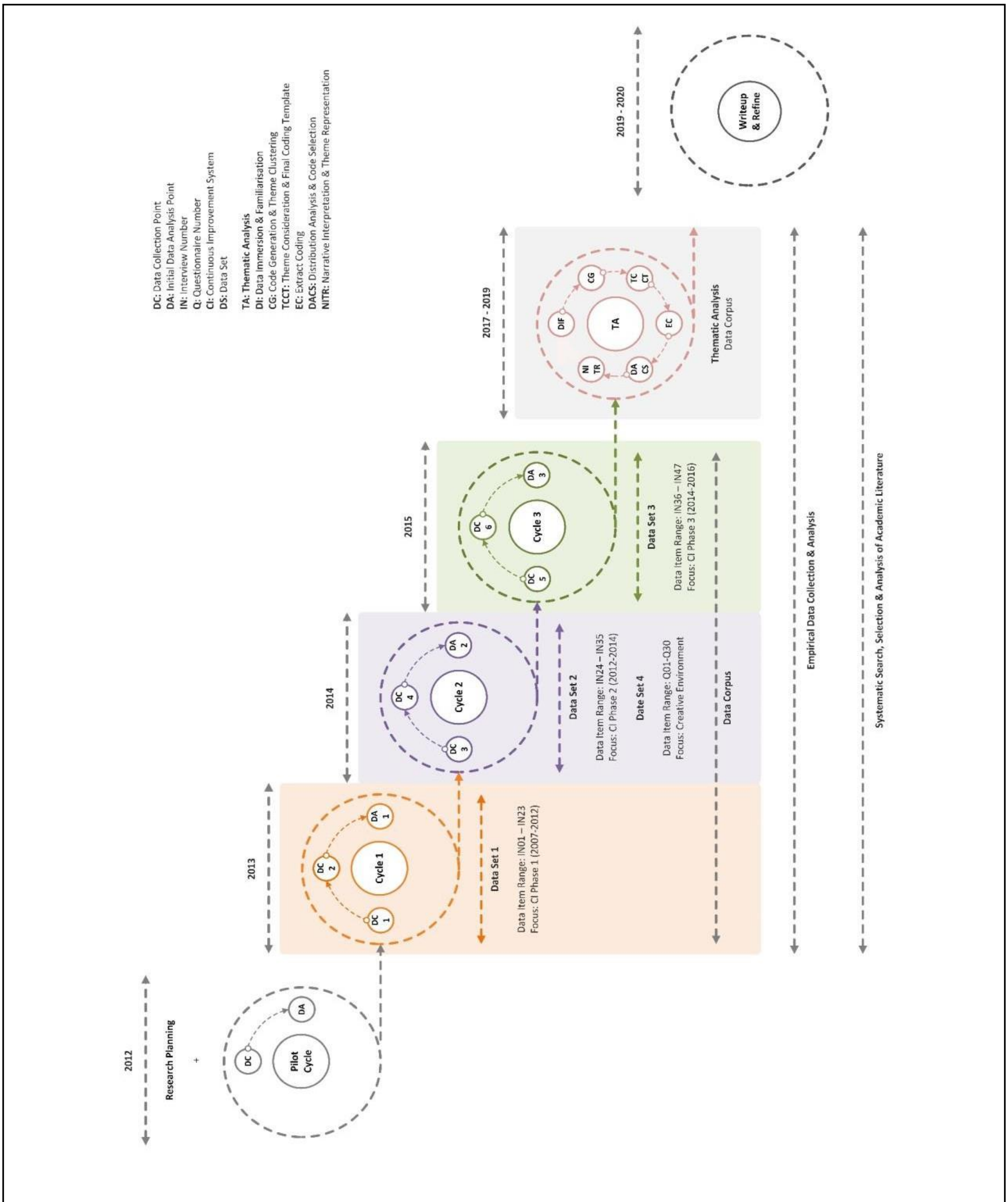
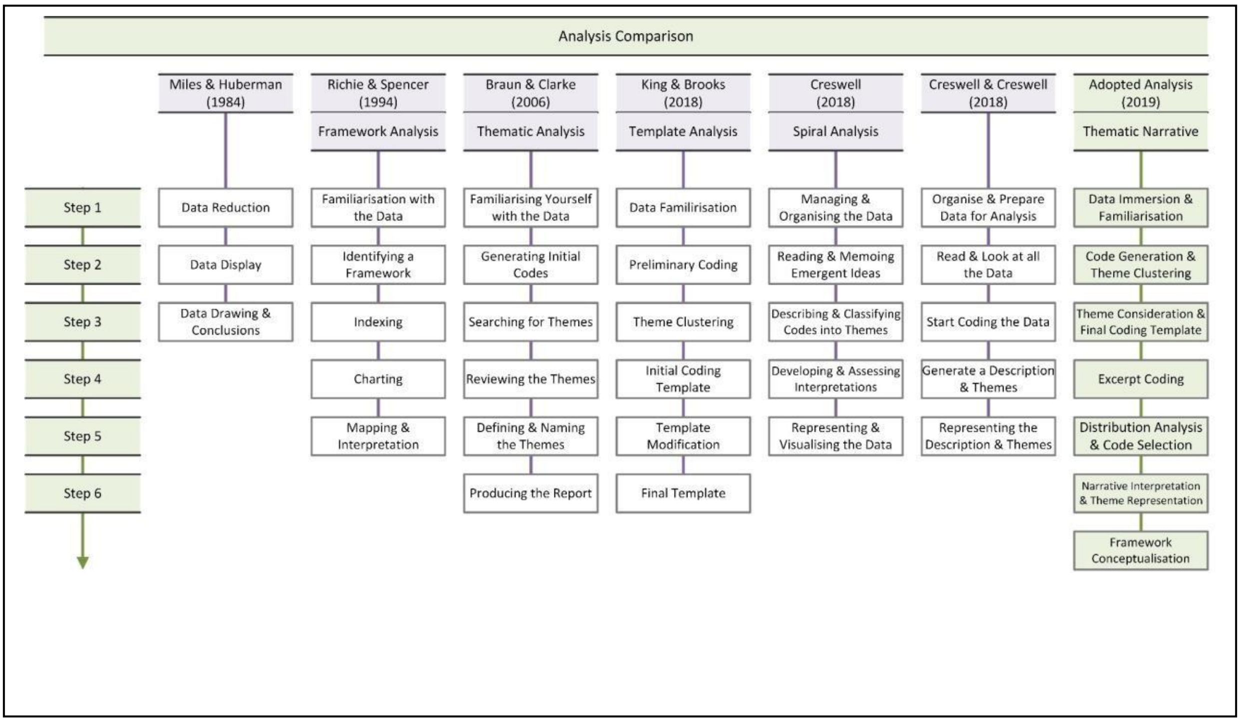


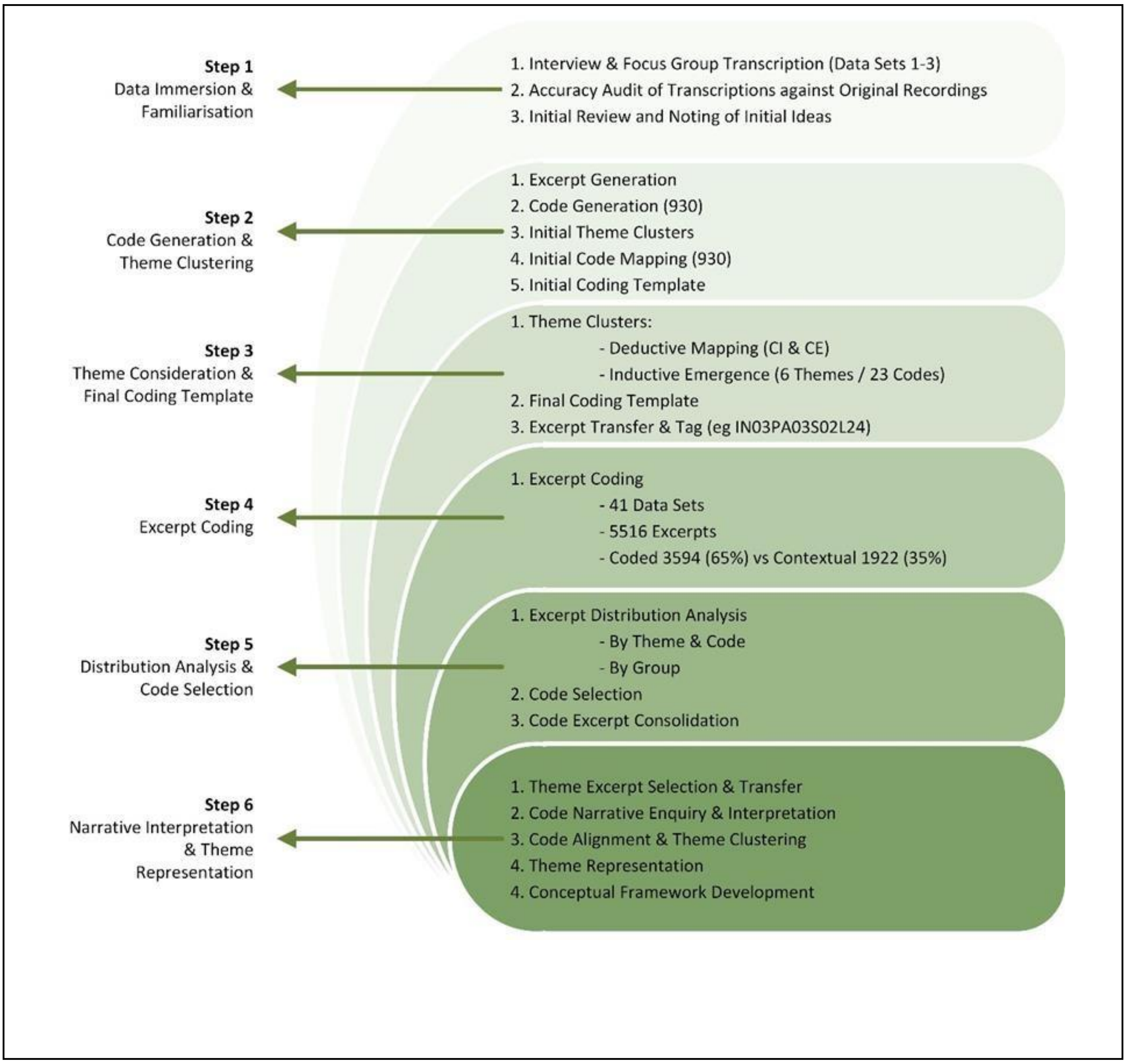
Figure 2 presents an evolution and comparison of the thematic protocol, which underpins the analytical process adopted for the data gathered through the qualitative methods used in this study.

The final column shows the adopted protocol moved through six steps of what the researcher has termed thematic narrative analysis (TNA), cumulating in Framework Conceptualisation. The process, (further detail is shown in Figure 3) commenced with a period of data immersion and familiarisation and concluded in the development of a narrative interpretation and thematic representation. The six steps allowed the researcher to better comprehend Braun and Clarke's (2018 p. 591) perception of 'qualitative research as creative, reflexive and subjective', allowing the telling of stories, from which the "the final analysis is the product of deep and prolonged data immersion, thoughtfulness and reflection, and something that is active and generative'. Following the initial DA points within Research Cycles 1, 2, & 3, between 2017 and 2020, the researcher invested two-and-a-half years completing the thematic narrative analysis and writing the interpretative report.



'Data Immersion and Familiarisation' allowed the emergence of initial ideas, codes, patterns, and candidate themes, this 'providing the bedrock for the rest of the analysis' (Braun & Clarke, 2006, p.87) and formal codification. To ensure contextual understanding (Bryman, 2001) and richness of data, the excerpts were coded inclusively during 'Code Generation and Theme Clustering', a diverse range of accounts capturing *'a cross-section of the issues and experiences presented in the data overall*' (Brooks & King, 2014. p.7). While the majority of the 930 2nd tier codes were aligned with the conceptual findings (literature), their organisation into meaningful groups (Tuckett, 2005) allowed for inductive clusters and themes to emerge, from which the construction on an initial coding template.

The final consideration and combination of *a priori* (deductive) and emergent (inductive) themes and codes designed to allow all relevant data to be adequately captured and applied to the data sets to draw together the interpretation. Decisions were made regarding validity of the themes; to ensure the Final Coding Template design ensuring an accurate representation of entire date set. In alignment with the literature review the final design included the themes and codes associated with the Bessant et al., (2001) CI Maturity Model, the McLean, et al., (2017) CI Failure Factor Model, the CE Conceptual Model, drawn from the comparison of the Amabile et al., (1996) KEYS Model, the Ekvall (1996), modified by Moultrie & Young (2009) Creative Climate (CCQ), and the Andriopoulos, (2001) Five Enhancements Factor Framework. The final template also mapped the inductive codes that had emerged from the data (steps 1 & 2) and the inclusion of columns to allow operational and behavioural, benefits and impediments to be captured through the coding process.



'Excerpt Coding' was completed manually, where each empirical excerpt (5516) was identified by a tag and further filtered with the level/group of participants (Executive/Manager/Staff). The number of coded excerpts was reduced to 3594 (65%), in the removal of those decided to be solely contextual, ensuring all contained an important thread of data. Through the 'Distribution Analysis & Code Selection' those themes and codes identified as both significant and potentially important areas were chosen, being careful to consider those less prominent through the numbers. Grouped under the conceptual categories of Internal Traction, System and Value, justification and a line of reasoning regarding their importance individually, and in the context of the overall story/research was ensured. In preparation for Stage 6, the excerpts for each selected theme and code required consolidation. This included the filtering and construction of sheets for each theme/code, including all applicable empirical excerpts, with distinction between and alignment with the three data sets and participant groupings.

The 'Narrative Interpretation and Theme Representation' protocol adopts what Creswell and Creswell (2018, p.195) state to be the most popular approach, the '*use [of] a narrative passage to convey the findings of the analysis*'. The review follows a chronology of events to present a detailed discussion for each selected code. The narrative interpretation retells the participants' stories, experiences, and perception using structural devices, such as plot, setting, activities, climax, and denouement (Creswell & Creswell, 2018, citing Clandinin & Connelly, 2000), amalgamating a selection of vivid, compelling excerpts which capture the essence of the point being demonstrated. In selecting the excerpts to include in the narrative interpretation (full report from which this paper is sourced), those most compelling enable the telling of a thematic story formed from multiple perspectives and levels. The aspiration of the narrative interpretation was to tell the complicated story of the '*data in a way which convinces the reader of the merit and validity of the analysis*' (Braun & Clarke, 2006, p.93), and provide sufficient evidence to demonstrate and illustrate the prevalence and potential positioning of the selected theme/code in question, moving beyond description and towards a justified line of reasoning. '*Discrepancy between the views of different groups is not problematic, but part of the rich data which is accessible through processual research*' (Dawson 1997, p.400), where reflecting upon and conveying multiple perspectives from participants through detailed descriptions of the setting and individual experiences adds a depth to the narrative, supported with relevant and applicable excerpts and the researcher's interpretation, in the development of a passage that delivers merit and validity.

Results and Discussion

This research expands existing knowledge by building an in-depth understanding of how SBOs can establish and sustain incremental performance improvement. It offers an interactive framework that supports holistic pursuit of CI, with a desire to achieve operational and behavioural excellence. The review of literature and empirical examination together suggest the need for interactive relationships between key components and associated factors of Continuous Improvement (CI), Organisational Learning (OL), and the Creative Environment (CE), to promote and sustain traction towards an inclusive culture of CI. In this study, exploration led to identification and justification of the key components and associated factors for CI. These are clustered under:

- *Actualisation* to facilitate a creative and collaborative wave and build CI traction;
- a set of cohesive *System* factors within which the Actualisation Lemniscate best operates; and
- *Realisation* capturing the generation of operational and behavioural value.

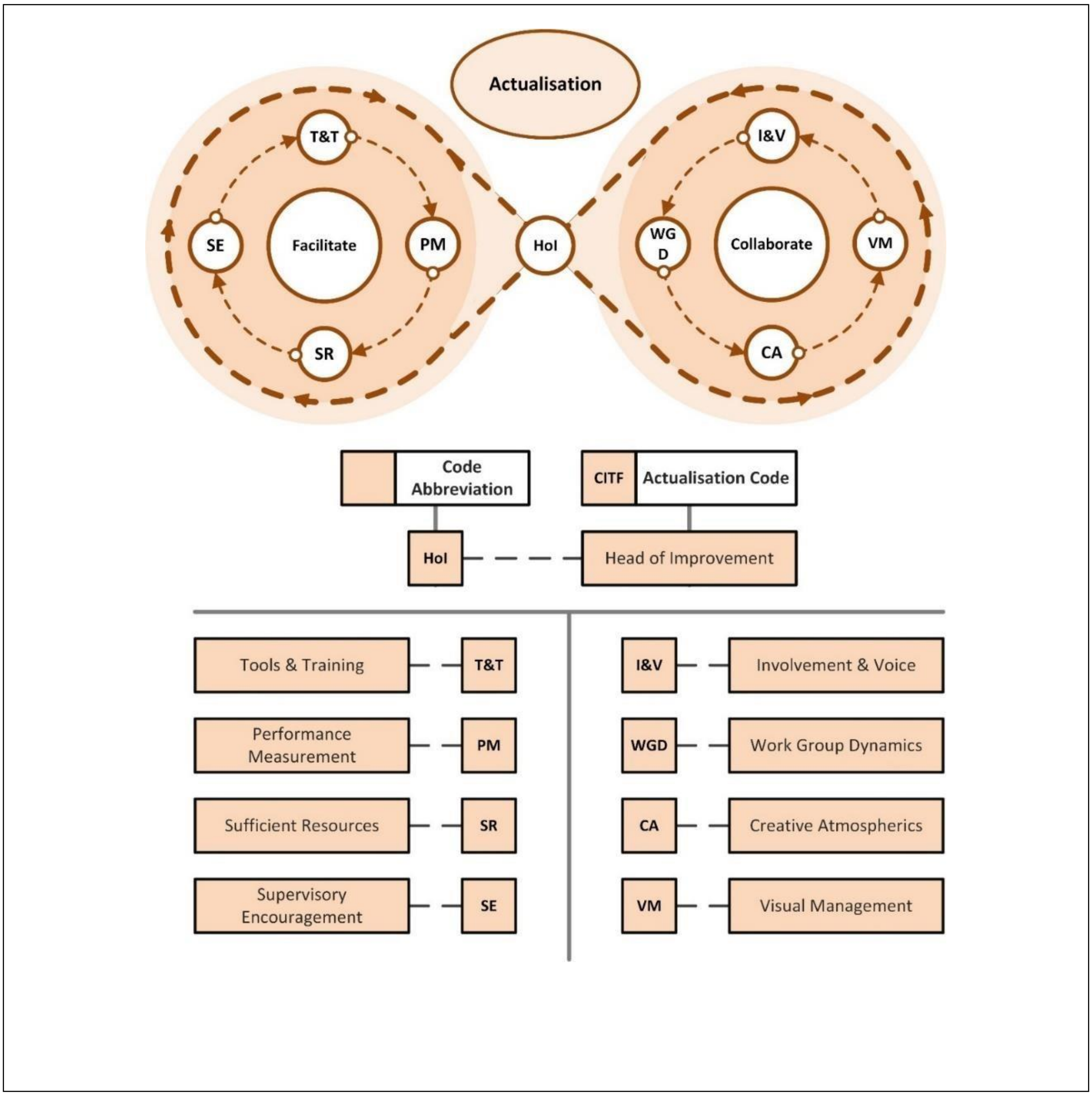
Various authors (Jorgenson et al., (2003), Antony & Douglas (2007), Fryer et al., (2013), McLean et al., (2017), and Paipa-Galeano et al., (2020) offer a range of CI enablers and critical success factors which recognise the challenges associated with developing and sustaining CI. Some authors have offered maturity models (Bessant et al., (2001), Jorgenson et al., (2006), and Fryer at al., (2013) that focus on the relationships between the acquisition and integration of key behaviours, and corresponding evolutions in practice, and so performance. These models outline the different stages in evolution of CI capability, and the positioning of organisations on their CI journeys. While such models can provide a powerful basis for reviewing key attributes of CI and can offer an evolutionary path for organisations looking to reach higher levels of maturity, 'due to the complexity of the implementation process, many companies fail' to develop an effective CI environment (Sánchez-Ruiz et al., 2019, p.51) and there has been a continued call for a framework to better guide organisations in the journey towards and environment of CI.

The CITF moves away from the existing and relatively linear patterns of development to an interactive combination of Lemniscates. With greater clarity than other models, these move beyond prescription of key CI considerations, to a structure and guide for SBOs to develop and sustain traction towards an environment of CI. The Framework deploys a level of coordination, execution, and support, through the 'Actualisation' and 'Realisation Lemniscates', positioned within a set of 'System' factors, to integrate CI into the organisation's structure and cultural mind-set (Milner & Savage, 2016). The CITF lessens any disconnect between Strategic CI Initiatives, and selection/application of CI tools. Through its dynamic design, the framework moves beyond describing 'what' are the key CI factors, to evoke greater consideration of their interactive inclusion, i.e., 'why' each serves an important role, and 'how' they interact to build sustained traction towards a CI culture. The Framework's design enables and encourages the lemniscates, cycles, and associated factors to combine and generate the necessary traction for long-term benefit. The CITF embraces the important role of creativity and innovative practice, within the 'Actualisation Lemniscate', to generate and support CI, thus the cultivation of 'Creative Atmospherics' (CA) and productive 'Work Group Dynamics' (WGD) aid in the development of a 'Creative Wave' (CW), and within the 'Realisation Lemniscate' in the form of 'Creative Energy' (CE). Furthermore, their perpetual connection, when nurtured, drive the formation of virtuous cycles of CI traction.

The following review presents a summary of the role, purpose, and proposed interaction between the 'Actualisation' (figure 4) and 'Realisation' lemniscates (Figure 6), and 'System Component' (Figure 5). The Framework is then presented in in entirety (Figure 7) where the dashed lines within signify the interactive movement and relationship between the aligned cycles and distinguished parts, the grey lines between the 'Actualisation' and 'Realisation Lemniscates' symbolising the sought-after CW and desired perpetual motion of a virtuous cycle.

The Actualisation Lemniscate

Jurburg et al., (2019, p.359) state that '*CI initiatives fail mostly due to a lack of employee engagement and participation*'. They join Anand, et al., (2009) in calling for further research to explore how leaders might capture tacit knowledge, and the creativity possessed by staff, to better promote bottom-up generation of process and improvement ideas. The 'Actualisation Lemniscate' (Figure 4) brings together a combination of factors, that collectively support an organisation to build traction where all staff are willing and able to engage and participate. Here, creativity can be unleashed, encouraged, and harnessed to generate value through innovative practice. Employees can challenge present practice and feel empowered to act beyond received wisdom. This lemniscate utilises a bundle of tools and routines (Bessant et al., 2001) in '*establishing collective visions of where we are now and 'where we want to be'* (Borzsony & Hunter, 1996, p.26). It helps staff to seek out and apply new ways of working (Anand et al., 2009), and supports and encourages horizontal and vertical collaboration among staff members, where ongoing interaction with partners in the immediate and broader working environments is supported and encouraged. The 'Actualisation Lemniscate' embraces the role of creativity in establishing and sustaining CI traction, however, '*creativity doesn't just happen by chance, the prepared environment nourishes it'* (Peterson, 2002, p.7). The emergence of the Actualisation Lemniscate answers Martens' (2011) call for further research to elaborate the connection between creative thinking, the working environment, and its role in value-generating improvement activity.

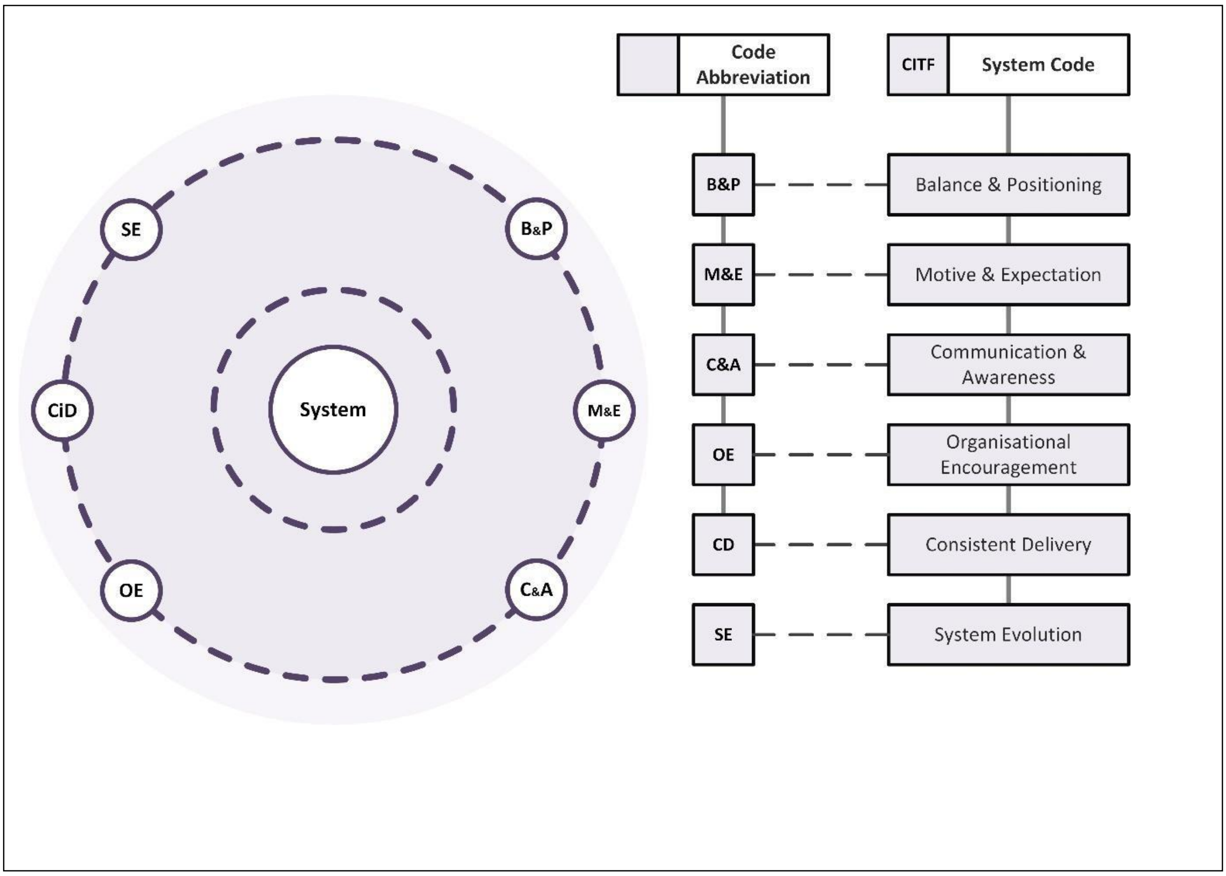


The two interactive cycles within the 'Actualisation Lemniscate' are 'Facilitate' and 'Collaborate', which together drive initial and sustained traction in the introduction and development of a CI system. The Facilitation cycle relates primarily to the roles of management in generating a creative wave. Appropriate 'Tools and Training' (T&T) need to be in place, and suitable arrangements made for application of 'Performance Measurement' (PM) to ensure that results are captured for the benefit of the organisation, and that staff receive appropriate recognition for their efforts. 'Sufficient Resources' (SR), including time, information, skillsets, and space need to be provided, together with a consistent level of 'Supervisory Encouragement' (SE) for staff to engage in improvement activity. In facilitating these elements, an effective cycle of 'Collaboration' can be triggered, the effectiveness of which is amplified via cross-function and multi-level representation and participation. This cycle involves organising the composition of the 'Work Group Dynamic' (WGD), with appropriately diverse skills, perceptions, and roles. Networks of skilled work groups must be able to interact and share knowledge within a culture that places a value upon creative thinking. Creativity has long been regarded as '*critical for success and survival through its role as a key input to innovation*' (Litchfield & Gilson, 2012, p.108), to '*fundamentally challenge existing ways of doing things within as well as across organisations*' (Andersen & Kragh, 2013, p.82). Employees need to feel empowered to initiate and engage with CI practice, challenge current ways of working and explore new ideas via the effective use of CI tools. Heightened levels of collaboration bring opportunities for the cultivation of appropriate 'Creative Atmospherics' (CA), within which engagement and learning can evolve. In a space where humour, openness and debate of differing perspectives are welcomed and supported, new solutions can be found, relationships built, and trust developed. Within CI practice, there is an emphasis on problem- recognition and problem-solving. Fresh challenges arise continually; staff must be empowered and encouraged to use their individual and collaborative creativity to address process issues, and departmental and organisational challenges. The effective nature of idea generation, engagement and collaborative efforts can be enhanced via the use of 'Visual Management' (VM) techniques. Collectively, all these elements can help management ensure that employees can participate and feel involved, are able to question and challenge the status quo, and have their ideas taken seriously within a no-blame culture. When staff feel empowered to be 'Involved', and comfortable to share their 'Voice' (I&V), levels of participation rise; this is a key obstacle and motivator in the development of CI.

At the heart of the Actualisation Lemniscate lies the crucial role of the 'Head of Improvement' (HoI), who alongside the executive group is responsible for the design of and drive behind the CI system. In the adoption of a CI mantra and use of appropriate vocabulary, they serve to spearhead the CI effort, assigned to structure, and apply the most suitable CITB and methods of facilitation and intervention, and build CI traction and the desired CW through the 'Facilitate' and 'Collaborate' cycles. Aiding in the development of system legitimacy, the HoI needs to bring credibility and experience of CI and with charisma inspire staff members, through their own ongoing levels of sponsorship and participation, to buy-in and engage with the CI endeavour. The HoI should serve as the touchpoint between executive, senior, middle management, and staff, through whom their support is seen to flow and via whom feedback into strategic thinking and resourcing is achieved. S/he should embrace the contextual knowledge of front-line staff and be able to adapt the shape of the CI system to changing strategic needs and the internal organisation mechanisms in play. If the underlying dimensions of CI are people, process, product, and performance, then the HoI adds to these purpose and perspicacity.

The System Component

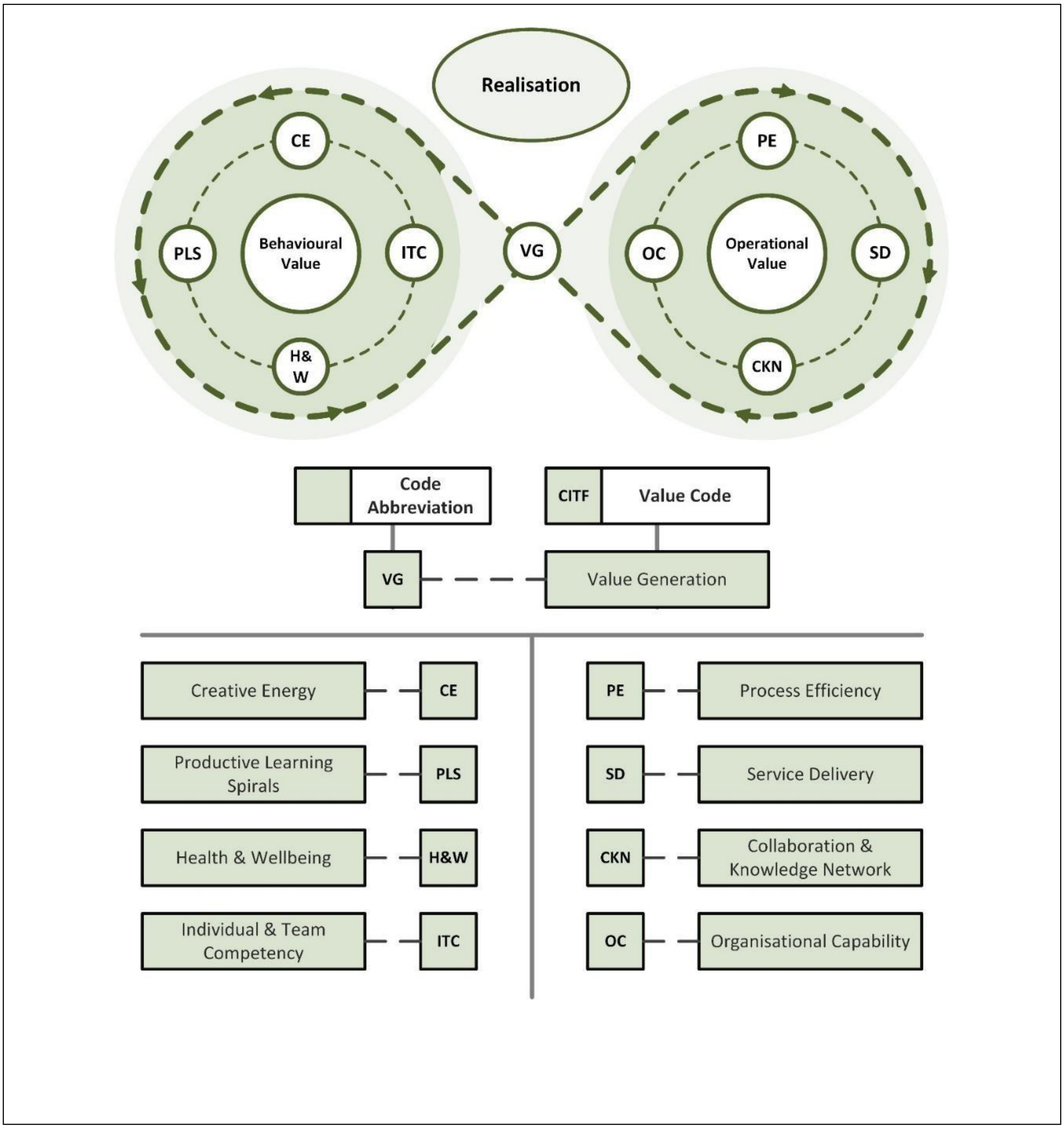
While the 'Actualisation Lemniscate' could be adopted to work independently, the 'Facilitate' and 'Collaborate' cycles will not yield sustainable improvements unless they are in synergy with the CI 'System' within which they are positioned (Figure 5). It is vital that the key factors of the CI system design, within which CI activity is developed and value created, are considered carefully to ensure co- ordination, control, and coherent positioning. A focus on organisational viability and coherence is desirable, rather than simply alignment between separate units of activity. Effective policymaking is needed, based on intelligence about the environment, within and beyond organisational boundaries. This will offer a platform for creative facilitation and ongoing collaboration and provide the mechanics for value to be recognised and shared. It is important that policymakers, as well as those in roles that spearhead the improvement mind-set, allow for the system to evolve, mature, and achieve sustainability. By exploring key CI considerations, this research proposes that CI requires organisation coherence through System 'Balance and Positioning' (B&P), enabled via the integral standing of CI within the organisational structure.



To be effective, the CI system must align with departmental objectives and organisational strategy, supporting the 'Actualisation Lemniscate' in building CI traction, credibility, legitimacy, and buy-in. The 'Motive and Expectation' (M&E) of the CI system should be applicable, feasible, and agreed collaboratively. The HoI is responsible for drawing together a CI coalition, whereby executive, senior, and middle management can align with front-line staff to collectively represent all functions and levels within the organisation and consider the system's desired outcomes. The CI purpose, role, positioning, motives, and expectations should be continually shared via appropriate and effective 'Communication' mechanisms, to drive the required levels of organisational 'Awareness' (C&A). 'Organisational Encouragement' (OE) is provided via the ongoing sponsorship, support and participation of board and senior managers, whereby top-down endorsement aids traction in bottom-up 'Actualisation'. To develop a cohesive and stable CI environment, and to negate cynicism and 'hot spotting' of CI activity and levels of buy-in, middle managers and line supervisors must convey and act upon the CI message with a 'Consistent' level of 'Delivery' (CD). Since this notion is more difficult when there is a lack of cohesion between CI activity and departmental and organisation need (B&P), the CITF proposes the use CI interventions through the 'Actualisation Lemniscate' to configure a clear value bearing proposition. Through a process of continual reflection; single- and double-loop learning; and response to economic, market and organisational variations, the CI system must transition through both incremental and transformative change; this represented on the CITF as 'System Evolution' (SE). All amendments to the system should be planned collaboratively, agreed, and communicated to ensure awareness, and adopted collectively to facilitate ongoing CI legitimacy, evolution, and traction.

The Realisation Lemniscate

The purpose of the 'Realisation Lemniscate' (Figure 6) is to ensure recognition of 'Value Generation' (VG), challenging an organisation to ask questions such as: Do we create value? How do we capture value? How is that value-creation disseminated to promote and underpin CI through meaningful interaction? It is important to ensure that improvements are fully embedded, both in operational processes and in associated staff behaviour and learning, so that beneficial change is consolidated, recognised, and shared. Bessant et al., (2001) identified that much of the literature and theoretical constructs surrounding CI fail to deal well with this behavioural aspect of CI; a call for further work which this research has strived to answer.



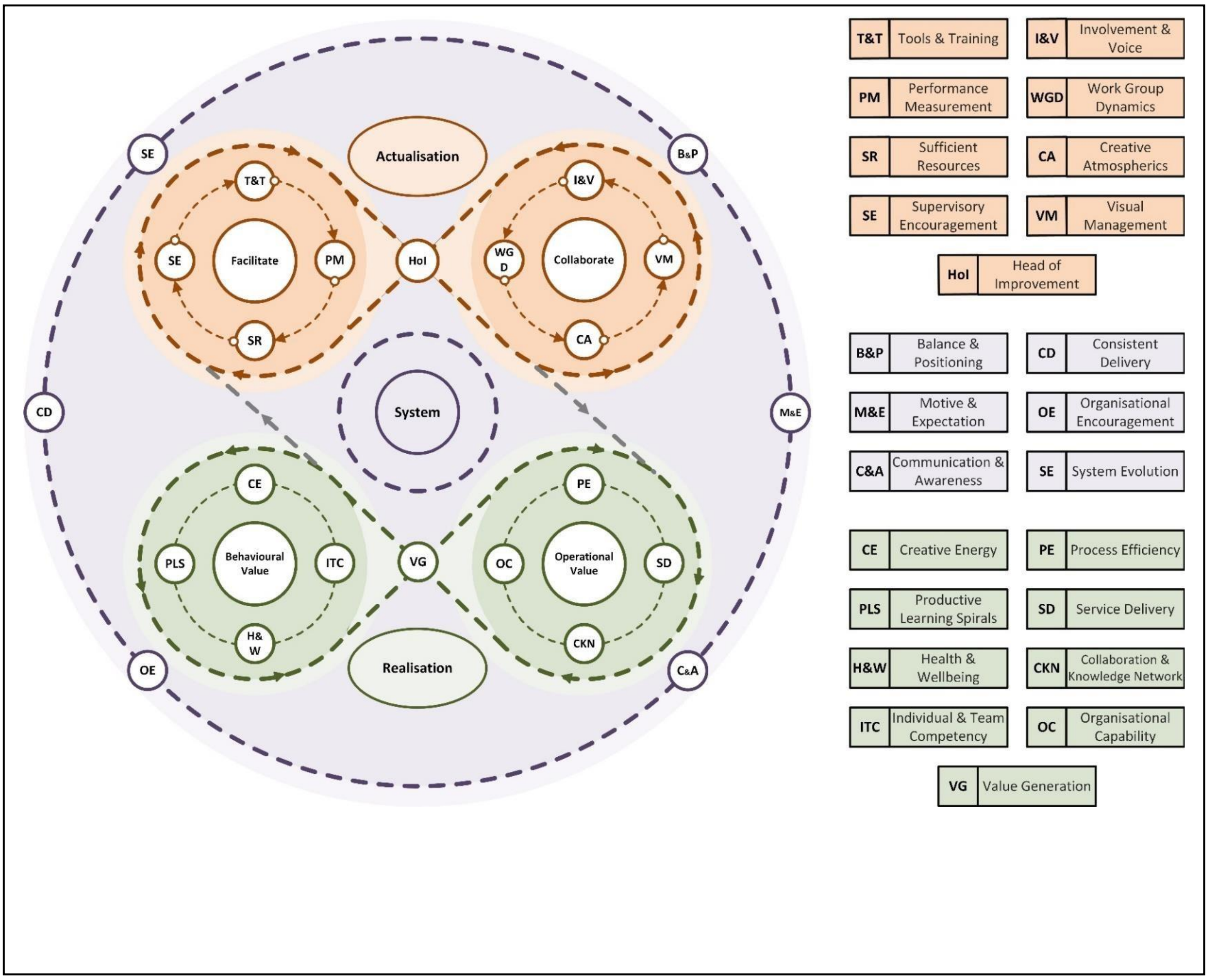
The purpose of business operations is to realise value for stakeholders. This clearly depends upon determining, at an early stage, what constitutes 'value' in the eyes of stakeholders and establishing appropriate measures of performance. This can be optimised by managers engaging with the whole business system collaboratively, establishing self-healing flows of value, and ensuring that wastes are reduced. In establishing appropriate CI System factors, and actualising CI activity through creative facilitation and vertical/horizontal collaboration, an organisation must realise and share 'Value Generation' (VG). The CITF 'Realisation Lemniscate' presents two cycles of Value: 'Operational' and 'Behavioural'. Both are essential for organisational legitimacy of the CI system, and development of initial and sustained CI traction. The 'Realisation Lemniscate' is positioned within the CI 'System Component', the VG cycles evidencing the 'Operational' and 'Behavioural' impact and verifying the value of the 'Actualisation Lemniscate'.

The ‘Operational’ Value cycle promotes increased levels of ‘Process Efficiency’ (PE), the removal of unnecessary complexity, the recognition and reduction of all forms of waste, and heightened levels of ‘Service Delivery’ (SD). It utilises ‘Visual Management’ (VM) in taking a customer-centric view to better understand the customer journey touch points, and so close the gap between customer expectation and perception. To sustain traction, such improvements in operational performance must capture numeric measures, and be shared with transparency. Through the ‘Facilitate’ cycle comes the ‘Collaborate’ cycle, and through increasing levels of collaboration the emergence and development of ‘Collaboration and Knowledge Networks’ (CKN) whereby individuals and teams build bridges within and across organisational boundaries, and these potentially long-term and value-enabling relationships are creative. Via the combination of the sustained collaborative CI activity, and the associated ‘Actualisation’ elements, individual and team competencies evolve. Acknowledging and harnessing these competencies will subsequently support the creation of a fresh wave of operational improvements, with, in turn, the potential for the development of existing and new ‘Organisational Capability’ (OC), and hence enhanced organisation performance and renewal.

The Behavioural Value cycle absorbs the cultural dynamic, recognising ‘Creative Energy’ (CE) as both a result and a driver of CI traction. This cycle reflects the development of ‘Productive Learning Spirals’ (PLS) and the generation of a creative wave, the objective being to set in motion so that all members are caught up in its energy, with excitement and ambition to achieve. It is important that the overall skill profile within the organisation is developed to support its operations, since the only sustainable source of competitive advantage for an organisation in the long run is the know-how of those who work in it (Davenport & Prusak, 2000). The CITF supports organisations in capturing and harnessing both explicit and tacit staff knowledge, and enhancing, through training and participation, ‘Individual and Team Competency’ (ITC). Through participation in CI and creative activity, an enhanced sense of togetherness and ‘Health and Wellbeing’ (H&W) can emerge that contributes towards a healthier workplace culture, improved teamwork, and creativity, and hence supports productivity and traction in CI. Whist these factors are difficult to quantify, their existence and role in the evolution of CI must be acknowledged and recognised as a form of attained CI value.

The CITF

The dashed grey lines through the CITF (Figure 7) present the ongoing motion and relationship between the two lemniscates. In pulling value from the ‘Actualisation Lemniscate’, the ‘Realisation Lemniscate’ turns provider, and becomes a driver of enhanced traction, embodying the evolution of the CW into the desired motion of a virtuous cycle. The creation, capture and dissemination of operational and behavioural CI value, builds natural momentum towards an environment of CI, and enhances the harmony between the CITF ‘System’ component, and the ‘Actualisation’ and ‘Realisation’ Lemniscates.



Conclusions

As long ago as 2007, Shingo (2007, p.170) suggested that 'improvement usually means doing something that we have never done before', or in the words attributed to Henry Ford, 'If you always do what you've always done, you'll always get what you've always got' (Doyle et al., 2012, p.57). An accumulation of small wins, leading to a magnification of results can have a major impact, where focused and continuous innovation takes place across an organisation, yet excellence should never be regarded as a point of arrival, but rather as a temporary condition needing to be re-evaluated on a continual basis. On the journey towards the development of CI, ad hoc initiatives alone will not be effective in sustaining either CI or creative practice, and while there is a plethora of CI based resources, the need for an effective road map remains.

This research expands existing knowledge and has answered the call for a framework to better guide organisations in the implementation of a CI system and progression towards an environment of CI and innovative practice. The research proposes the Continuous Improvement Traction Framework (CITF), supporting the holistic pursuit of operational and behavioural excellence, designed to guide initial and sustainable traction towards a dynamic and creative environment of CI. The CITF moves away from the existing, and relatively linear patterns of development to an interactive combination of Lemniscates. The framework moves beyond the prescription of key CI considerations, to a structure that better guides service-based organisations to initiate, develop and sustain traction towards an environment of CI. The Framework deploys a level of coordination, execution, and support, through the Actualisation and Realisation Lemniscates, constructed within the System component to better integrate CI into the organisation's cultural mind-set. The research offers how the encouragement and nurturing of collaborative creative practice should become a feature for all organisations, proposing the facilitation and actualisation of a creative wave to promote collaborative value generation. The research recommends that CI, nor creative processes will yield actionable improvements or sustainability without synergy, and so it is vital the processes by which a CI system is developed, are co-ordinated, controlled and positioned coherently to ensure organisational viability and coherence.

This investigation has moved beyond current theory in the identification and presentation of three components pivotal to the successful development of a system of CI (RO1), which collectively embrace and substantiate the important role of creativity in promoting and sustaining CI traction (RO2) and innovative practice. In the formulation and assembly of these three CI components as interactive lemniscates, a socio-cultural approach to improvement is proposed (RO3), constructed to guide SBOs in the design, implementation, and evolution of their CI endeavours. The CITF acknowledges the need to recognise and distinguish between the behavioural and operational value attained from a dynamic and creative environment of CI and recognises the contextually dependent nature of work and need to harness the company's entire intellectual capital. To empower people to contribute their contextually relevant knowledge, it is essential to promote an open culture of mindfulness, so that people feel supported to participate and express new ideas, even if these conflict with the *status quo*. Through enhanced levels of facilitation and collaboration, organisations develop a foundation for creativity in the cultivation of creative atmospherics and the introduction of useful and usable methodologies for inquiry and design of future practice.

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Track 13: Management System

Error Prevention and Error Management are two sides of the same coin: the application of Reason's Swisse Cheese Model before and after the incident in the case of Costa Concordia.

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Abstract

Due to the complexity of the environment, organizational processes, and technical and professional skills required, there are numerous risk factors that expose the possibility of errors, and most importantly the consequences of errors can be serious or catastrophic. Different approaches have been used for the study of errors in organizations. In particular, the safety and security literature recognized the importance of the error learning approach. In this perspective, Reason's Swisse Cheese Model represented a revolution in reading errors from a psychosocial and organizational approach. Past research has considered this model as a tool for reading and analyzing errors once an incident occurs. The present paper, on the other hand, aims to use the model not only after but also before an incident occurs, taking a dual perspective on error, prevention, and management and highlighting the relevance of mitigation. To do it, the Costa Concordia incident is examined using the Swisse Cheese Model. The study attempts to consider the two temporal phases, before and after the incident, in the analysis of psychosocial, cultural-organizational, and technical factors. In doing so, the importance of the intermediate phase between the occurrence of the incident and its management emerges, in the aggravation of the consequences of errors. Overall, this research contributes to a more granular understanding of errors and incidents and to increasing the adoption of the Swisse Cheese Model, not only in the error management phase but also in the prevention. Findings offer implications for both theory and practice.

Keywords: incident, error management, error prevention, error culture, mitigation

Introduction

Someone says "Mistakes are the stepping stones to wisdom", but yet almost always mistakes are associated with derogatory behaviors or feelings. This happens because they are mostly considered a threat and not an opportunity. But think of the greatest scientific discoveries, the striking discovery of America, that of Penicillin or gorgonzola cheese. Even the bell tower of the cathedral of Santa Maria Assunta in Pisa, remembered by all for its strange inclination, was born from a mistake. And it was that mistake that made it become "the Tower of Pisa." Errors can be defined as actions that fail to achieve the goal in situations where failure could have been avoided (Hofmann & Freese, 2011). They are actions that occur without there being an intention for these to exist, often occurring when we fail to perform a task we intended to do or to continue a plan of action or when the latter is inappropriate or inadequate to achieve the goal (Rasmussen, 198; Reason, 1990). Finally, errors in organizations are unintended and potentially avoidable deviations from organizationally specified goals, standards, or procedures (Frese & Keith, 2016; Hoffman & Frese, 2011).

Reason (1997) is the leading scholar when it comes to errors. Indeed, he has theorized the Swisse Cheese Model, which explains that when an accident happens, it is due to both latent and active errors. All the slices of cheese, which together represent the various procedural phases of an organization, can contain potential errors, the so-called "latent errors," just waiting to emerge. This usually happens when the holes in the various slices align, meaning there are no more tolerance and compensation mechanisms in the process. This alignment transforms "risk" into an "event".

Starting from the suggestions of Reason's model, many authors in studying errors and accidents have highlighted the importance of the approach, until it has become one of the most widely accepted and adopted models by scholars in the detection, and analysis of errors downstream of their occurrence. Reason's model was highly successful from the outset both because it laid the foundation for future theorizing (Frese, 2015; Catino, 2008; Rasmussen 1997; Shulman 2004) and for subsequent applications of the model in different contexts (e.g., Chornobyl, Linate), and fields. Next is a mirror of the fields of application of subsequent scholars who have reproduced the model (*Tab. 1*).

Secctor	Bibliographical reference
Aviation	Maurino (1993) Shappell (2000)
Marine	Ren et al. (2008)
Healthcare	Vincent et al (1998) Carthey et al. (2001) Lederman &Parkers (2005)
Defense	Jennings (2008)
Nuclear	Reason et al. (2006)
Oil & Gas	Hudson et al. (1994)
Rails	Reason et al. (2006) Baysari et al. (2008)
Roads	Salmon et al. (2005)

Tab.1*: Non exhaustive list of sectors applying Reason's work (Larouzée et al., 2014, p.1)*

Prevention & Management: a fine line

Although Reason's model is very popular, it is mostly used to analyze the risks and errors that caused an accident, before the critical situation happens. This approach is effective for understanding how an incident occurred and for preventing it. However, considering the rapid succession of errors that lead to an incident, it's worth asking how Reason's model can help understand not only the trigger point of the incident from a prevention perspective but also the event itself from a management perspective.

Indeed, some scholars discuss the "time lag" (Lai et al., 2016), "error handling" (van Dyck, 2009), and "error chain" (Lai et al., 2016) to indicate the phase between an incident occurred and its (possible) resolution. By tracing what might happen during an incident, we can reconstruct the situation from the errors that, like Swiss cheese holes aligning, cause the incident. However, once it happens, the handling of the incident can either resolve or worsen the situation. So, timing is crucial not only for prevention when someone notices the errors, but also for intervention during the transition from one phase to another. Research suggests there is a small window of time to act between errors and their negative consequences (Frese & Keith, 2015). The sequence of events and errors highlights the total lack of mitigation between the initial phase and the aftermath. Error mitigation, or controlling the consequences of errors through correction (van Dyck, 2009), is essential for containing situations that could escalate into more serious events.But the literature has mainly focused on error prevention, believing it is more important to learn how not to make errors rather than learning from and managing them.

Thus, considering the rapid series of errors once an incident occurs, it's worth asking if and how Reason's model can help understand not only how the incident started (for prevention), but also the management of the incident. So, the present study seeks to integrate both error prevention and error management on Reason's model, emphasizing the importance of mitigating error consequences (Helmreich, 1999) and making sense of a critical event both before and after it occurs (Weick, 1988). The study aims to apply and extend the theoretical Reason's model to the post-incident phase to assess its effectiveness in terms of error management, so that this may be useful in understanding not only the importance of prevention but also of management.

In light of these considerations, the paper seeks to analyze the case of an Italian incident of the Costa Concordia, exploring the multiple latent factors that may have contributed to it, in particular focusing on psychosocial factors; and adopting a temporal perspective that also includes the post-accident phase, in which these factors can play an equally important role in mitigating the consequences.

The paper presents the relevant literature, and the qualitative method used for case analysis is explained, taking as a point of reference Reason's model, which proposes the assumption of a 1) systemic (not individual-centered), 2) diachronic perspective (not only the mistakes made after the incident but also the underlying factors that increase the likelihood of these mistakes happening over time). The main findings are then listed and analyzed, including the differentiation into categories of errors (psychosocial, cultural, technical) and the intertwining of these within and between the same time phase (before and after). Finally, in the last section, the conclusion of the study is reached.

Method

Case Study

The case of the Costa Concordia shipwreck was one of the most serious maritime incidents in Italy. The Costa Concordia, at the time the largest Italian cruise ship ever built (Di Lieto, 2012), was making a short overnight

journey along the Italian coast, the last before ending its cruise in Savona. There were more than 4,200 people on board (3208 passengers and 1023 total crew on board). At 9:45 p.m. (Italian time) on January 13, 2012, the ship ran aground on the rocks near the island of Giglio, following a practice called "bowing", which is a dangerous approach to the coast to show the beautiful island the lighted ship to passengers and tourists. This maneuver is not in the route and is prohibited, but within the organization, it has been made a habit.
Following is the timeline of events that occurred before and after the ship struck the rocks (Tab. 2).

Time	Event
18:57	Cruise sets sail from port of Civitavecchia (Italy)
21:04	Starts 'salute' approach to Giglio Island
21:45	Traveling at 15 knots, ship strikes the Scola Piccola rock off Giglio
21:45-21:55	Ship decelerates to zero knots and turns more than 180 degrees
22:12	Passengers advised to "return to their cabin"
22:14	Officers begin contact with Port Authority of Livorno (Italian mainland)
22:25	Captain admits to Port Authority that the situation is critical and requests the use of a tug
22:25-22:51	Ad hoc unofficial evacuation begins
22:51	Captain gives instruction to heed the abandon ship order
22:54	Staff Captain orders the abandon ship
23:10	The official evacuation starts
1:30	Captain communicates to Port Authority he left the ship
1:45	Harbor Master of Livorno 'orders' Captain to return to ship (he does not do so)
4:46	Evacuation officially ends
6:17	Search and Rescue teams leave the ship

Tab. 2*: Timeline degli eventi (Bartolucci, 2021, p.2)*

Following the incident, the media and public opinion have mostly attributed total responsibility for the accident to the commander. He was not exempt from having made some of the most serious deviations from the Rule, but the media ignored the role of other actors and/or factors and made accusatory judgments.
Before proceeding to the analysis of the results, we want to specify that by using the press as a source and thus secondary data, what emerges is a reworking of the incident that is not intended to take into account the legal implications of culpability of the actors but rather aims to apply and extend a theoretical model.

The method used, according to Braun's (2006) conceptualization, is the thematic one: a method of identifying, analyzing, and reporting patterns/themes within the data. It allows organizing and describing a dataset in the detail identified before, during, and after analysis (Braun, 2006).
The theoretical model decided to take as a reference point for data analysis, which in this case amounts to examining errors, is Reason's (1997) model of incidents in organizations. In contrast to many studies that have examined incidents and emergency situations by means of Reason's model, in the following research we have chosen to adopt the same (1997) in both the pre-impact and post-impact phases with the aim of bringing out

the effectiveness of the method not only in the pre-impact phase, given the incident that caused the emergency, but also in the post-impact phase by highlighting the importance of management and not only error prevention; moreover, we want to highlight how much from one phase (e.g., the immediacy of handling minor errors) one can move quickly to another (e.g., emergency situation) without there being a clear boundary indicating the end of one and the beginning of the other.
Thus, if traditionally the literature has considered the classification of technical factors in the analysis of incidents, in this case, we want to focus on psychosocial factors, particularly process and culture ones.

Data collection and analysis

Articles from major Italian newspapers such as "Corriere della Sera", "La Repubblica", "Ansa", and "Il Mattino", published in the ten days immediately following the shipwreck (January 13-January 24), were identified to collect data. These articles were written at different times: some when there was still no official information about the mistakes made or the communications between the crew and others, and some from later periods like July 2012 or November 2013, after the harbormaster's report (June 2012) and the official Technical Report on the shipwreck (September 2012) had been released. Our objective was to gather as much non-redundant and comprehensive information as possible to reconstruct the events. The information from these articles was then supplemented with details from the Technical Report prepared by consultants appointed by the Grosseto court in September 2012.
According to Reason's (1997) model, the categories used for the analysis were separated into technical and psychosocial factors, the latter still divided into process and cultural psychosocial factors. Technical factors are those errors of a technical-procedural nature, that is, the main misalignments between procedures and norms written and shared by the marine world and procedures implemented; when considering psychosocial factors, the focus is on communication, roles, and leadership; finally, Considering cultural aspects means reflecting on how the entire organization views errors, the unwritten norms that shape this perception, and whether an error culture exists within the organization. These factors were examined in two-time phases: before and after the impact with the rocks.
The analysis was carried out through considerations by two independent researchers. In addition, during training sessions on error prevention and error management attended by safety experts from different organizations, the analysis of this case was proposed by asking participants to identify the main risk and protective factors concerning (a) the occurrence of the incident and (b) its management. The analyses made by these groups were included in the material used by the researchers for the case analysis.

Results and Discussion

MAIN PROCEDURAL AND TECHNICAL FACTORS	Examples
• Inaccurate route change planning	• For navigation near the island, reliance was placed on the words of a local • Captain Schettino declared: "We were navigating close to the coast, along a permitted tourist route, when the ship struck a rock on its side that was not marked on the nautical chart. In theory, that rock should not have been there" [2]
• Incorrect assessment of distance from radar echo	• The radar echo "hit" only the first rock, but there were actually two [1]
• Inadequate electronic chart system	
• Non-compliant nautical chart	
• Neglected SOLAS regulations	• Although Italian was the designated language to be used on the bridge, the captain spoke with the helmsman in English
• Ignored behavioral norms for the Bridge Team (use of mobile phones during watch)	• The use of mobile phones is prohibited, but in the command cabin, during the watch, someone uses it
• Adoption of a lower margin of safety than those established	
• Wrong direction of pull-in	
• Repeated non-functioning of the black box	• "It was in fact established that the machinery had been malfunctioning since January 9, a full four days before the sinking. [5]
• Fire doors left open to facilitate passage	• "It is the officers on board who confirm that instead the devices were open because, as Simone Canessa who was on the bridge states on the record, "this was a practice used during navigation to facilitate the flow of people who had to work"[5]
• Broken radar	
• Rule of giving instructions to passengers in case of emergency not upheld	• First doctor on board says "A few things could have been done better. Drills for example. People board from different ports. Ours was scheduled in Savona. We never got there. People have to know what a ship is, and to know you have to explain." [4]
MAIN PSYCHO-SOCIAL FACTORS	Examples
• Lack of exchange of information about the dangers of the approach and doubts about the unsuitability of the nautical chart	• "some behaviors suggest that it is expected from the outset that the skipper will assume command having requested such a marked change of course." [1]
• Discordant communications, inaccurate information regarding the number of passengers on board	
• Incorrect assessments in assigning roles in dangerous situations	
• Delayed role assignment	• The captain when the helmsman leaves the lookout role should consider whether to increase the number of lookout personnel
• Leadership overconfidence	• "Mò faccio una salva di fischi e salutiamo a tutti" (Schettino) [1] • "It is therefore at the discretion of the captain to choose the sailing distance from the coast, and this time he dared too much" (crew member) [4] • "I knew Commander Schettino for a short time. I know he was a good pilot but the sea, the arrogance of a man does not forgive it" (doctor on board) [4]
• Neglect of role assignment	• "The commander could have ordered Ambrosio to take charge of horizon control as the latter was the deck officer." [1]
• Delayed responses to the dangerous situation	• "Ambrosio (first officer) telling investigators about the long minutes between the time of the accident and the order to abandon ship." [5]
• Lack of authoritative leadership	• "Schettino turns to Ambrosio without actually assuming control of navigation" [1]

	• "The captain at the time of the tragedy was at dinner" [3]
MAIN ORGANIZATIONAL CULTURE FACTORS	Examples
• Lack of sharing of doubts regarding decisions made	• Although the bow was being made, until 9:43 p.m., "if other Officers had any doubts regarding the maneuver, none of them expressed any concerns about it." [1]
• Condescension to comply with requests not pertinent to navigation	• Mr. Tievoli, first maitre d' of a restaurant on Giglio Island, in a communication to Schettino "Since you have to disembark I would appreciate it if you would stop by Giglio and say hello to the island [1]
• Attitude of superficiality and approximation on the part of the Officers	• an example extrapolated from the Technical Report is that "the configuration adopted by the team was that adopted under normal sailing conditions, but more critical navigation was being carried out by approaching the coast at night and at high speed" [1] • "The missives show how this was not the first time the 'black box' had failed" [5]
• Critical and dangerous navigation practices routinely overlooked	• Bowing practice had been done two weeks before and/or that was often done [1]
• Normalization of the Bridge Team's Violation of Commander's Rules Procedures	• "the helmsman confirms the order and quits the lookout duty leaving the ship without a lookout" as if it were normal contravening the rule of maritime navigation that a lookout must always be secured" [1]
• Ridicule of dangerous practices	• While actions were being taken aimed at achieving the bow, jokes are made about the dangerousness of the situation: "Otherwise we go on the rocks" followed by laughter
• Omission of information	

Tab. 3*:Main factors of the phase before the incident*

MAIN PROCEDURAL AND TECHNICAL FACTORS	Examples
• violation in the lack of communication of the actual situation to External Agencies	
• violation of P12.04 IO 02 SMS code, which concerns the sequence of actions in case of emergency, disregarded	
• failure to announce emergency	
• early abandonment of the ship by the captain (violation art 303 of the Navigation Code)	
MAIN PSYCHO-SOCIAL FACTORS	Examples
• Misunderstandable and contradictory communication of orders	• "The time dilation, as has emerged so far in the trial, in giving abandon ship, I believe is attributable to the use of approximate and often contradictory technical terminology in reporting the necessary data" (Commander) [7]
• Misinterpretations of the emergency situation	
• Untimely and disregarded role assignments after the acciden	• after 3 minutes after impact, the Commander should have made the DELTA-XRAY call to inform the crew and have them deploy according to each person's role, but this was done significantly late
• Misalignment between internal activation of the contingency plan and external information of the same activation	• the general emergency announcement was given 22.33 while it was communicated externally at 22.36 [1]
• Misjudgment of the situation	• "The crew probably imagined at first that they could handle the emergency" [2]
• Absence of leadership role	• "At first I looked for some officers, but then I saw no one. There was not much professionalism, of the crew I saw mostly marshals, it was difficult even to

	make myself understood. So I spent the first 20 minutes, looking. But there was a lack of leadership, people were on their own" (the deputy mayor) [7]
• Inefficient coordination on board	• lacking internal communication of the presence of the leak the roll call roles were not taken and the officers all went to the bridge to be informed of the situation wasting even more time [1]
• Crew loss	• “There was panic on board even among the crew members. Many foreigners. They didn't know exactly what to do either”; “No one was telling us anything and the foreign crew members were shouting out of panic among themselves. We took life jackets by ourselves by breaking the windows in the corridors" (passenger testimonies) [3]
• Lack of internal monitoring on maneuvers to secure passengers	• passengers independently headed to the Muster Stations and got life jackets without staff manning the situation
• Improvisation of rescue	• “There was confusion, people were trying to get off, crowding around, wanting to reach land" (deputy mayor of Giglio Island) [7] • “No one was telling us anything, and the foreign staff were shouting out of panic among themselves. We took life jackets ourselves by breaking windows in the corridors" (victim) [1]
• Poor time management by all involved	• External agencies should have been alerted at 9:51 p.m., but this was not done until 10:35 p.m. [1]
• Heterogeneity of working groups (crew composed of people of different nationalities who communicated poorly with each other)	• “But on board there was panic among the crew members as well. Many foreigners. They didn't know exactly what to do either" (victim) [3]
MAIN ORGANIZATIONAL CULTURE FACTORS	Examples
• Lack of appreciation of the emergency situation	• The seriousness of the situation is not understood or valued until Schettino asks for the second time how many watertight compartments are flooded [1]
• Omertous attitude from the top of the organization	• “Director Onorato defended Commander Schettino: "He has been with us for 11 years. He was on the bridge at the time of the collision." Nothing to object to the rescue operations. "The safety procedures required in these cases were carried out in the correct timeframe," said Director Onorato again. And "correct" was also "the commander's decision to evacuate the Concordia ship when he felt that there were safe conditions" [2]
• Lack of trust in leadership	• “Schettino order all tiller to port, Ambrosio intervenes by shouting "Hard to Starboard," i.e., all tiller to port because he thinks the Commander, confusing port with starboard, was pointing ashore by mistake.” [1]
• Lack of quality control of emergency procedures by the organization	• There was a real assault on the lifeboats with totally untrained personnel, unfit for the situation, so much so that just as they were being lowered there were accidents, so much so that we had to replace the commander of our lifeboat with an engineer officer from a different company" (Team Bridge member) [3]
• Lack of protocol in emergency situations of fragile categories	
• Lack of crew identification signs	• “It is not true that there were no officers on the ship. Many were caught while in the cabin or restaurant in civilian clothes. They couldn't be distinguished maybe, this one could. They didn't stand out in their uniforms in the midst of the chaos but they were there" (Costa Concordia's first shipboard doctor) [4]
• Omission of information	• once the leak was verified, Schettino notified his FCC-the person in the shore-based management company responsible for handling the early stages of a crisis situation-but when he called the Port Authority he did not inform them of the leak but only of the blackout [1] • “The captain assured us that it was only a machinery failure, and that was not true: there was already a hundred-meter gash under the keel" (victim) [3]

[2] ***Tab. 4***:*Main factors of the phase after the incident*

[2] 1: Relazione tecnica;

The tables (*Tab.3 and Tab.4*) show the main errors found for each factor category before and after impact. They should be read vertically, distinguishing first the pre-impact phase and, listing all categories of errors in the pre-impact; then the same analysis is repeated in the post-impact.

The analysis was initially done in the pre-phase in all categories found; the same was then done for the post-phase. Examples from newspaper articles and the Technical Report were given alongside some factors reported for ease of understanding.

Technical factors included some of the most serious failures that caused the impact against Le Scole. Violations of various regulations and codes in the field of maritime navigation occurred in the pre-impact phase. Concerning process psychosocial factors, on the other hand, errors inherent in poorly managed communication within the Bridge Team (e.g., lack of exchange of information about the dangers of the approach and doubts about the unsuitability of the nautical chart, discordant communication of information), failure to assign roles, and consequent absence of leadership are generally highlighted. To cultural psychosocial factors, there is a general attitude of carelessness with respect to the initial situation (e.g., lack of sharing of doubts regarding decisions made, acquiescence in meeting requests not pertinent to navigation, attitude of superficiality and approximation on the part of Officers, routinely neglected critical and dangerous navigation practices), there is evidence of normalization of dangerous practices recognized by the organization as necessary practices for tourist navigation.

After the ship hit the rocks, several violations of maritime navigation codes and rules were found. In terms of social aspects, there were issues with team communication (e.g., misunderstood and contradictory orders) and role alignment (e.g., delayed and ignored assignment of roles after the incident, mixed working groups). This led to a lack of coordination (e.g., improvised rescues, poor monitoring of passenger safety maneuvers, and timing mismanagement). Regarding cultural factors, there was a clear underestimation of the dangerous situation, a lack of emergency control by Costa Cruises, and a tendency to hide information.

To summarize, from reading the tables on error identification emerge:

2: La Repubblica (2012), *Fermato comandante si cercano i dispersi. Tre morti, trovati dei superstiti. "Sentiamo dei rumori dal ponte3"*, https://www.repubblica.it/cronaca/2012/01/14/news/tragedia_al_giglio_panico_per_oltre_4000_persone_tre_morti_14_feriti_dispersi_non_quantificabili-28084193/?ref=HREA-1;

3: Corriere della Sera (2012), *I testimoni: "I salvagenti? Presi da soli". "Alcune persone si sono gettate nel mare"*, https://www.corriere.it/cronache/12_gennaio_14/testimone-personale-impreparato-costa-concordia-sette-miglia-fuori-rotta_f8fe9368-3e81-11e1-8b52-5f77182bc574.shtml;

4: La repubblica (2012), *La notte del medico di bordo. "Tirammo su la gente con le corde"*, https://www.repubblica.it/cronaca/2012/01/20/news/medico_di_bordo-nave-concordia-28487123/;

5: Corriere della Sera (2012), *La Costa Concordia e la scatola nera. I periti: un'avaria quattro giorni prima"*, https://www.corriere.it/cronache/12_luglio_03/costa-concordia-scatola-nera-periti-avaria-quattro-giorni-prima-fiorenza-sarzanini_3f27ece0-c4ce-11e1-a141-5df29481da70.shtml;

6: Il mattino (2013), *Costa Concordia, testimonianza choc: "Vidi una bimba cadere in acqua"*, https://www.ilmattino.it/home/concordia_testimonianza_bambina_acqua_naufragio_processo-219396.html;

● the intertwining of different categories of errors within each time step;

● the intertwining of different categories of errors between time phases;

● the ongoing neglect and indifference to the initial condition (before impact) allowed the problem to become widespread;

● more technical factors emerge in the pre-impact phase than in the second phase where psychosocial factors are more evident

The intertwining

Although the errors are divided into categories, they are interwoven both vertically and horizontally. Regarding the “intra-phase” interplay among different categories, it is noted that some technical errors coincided with process errors. For example, the violation of SOLAS regulations before the impact, requiring the use of Italian among the crew (categorized as a technical error), led to numerous communication errors among the Bridge Team, who communicated in English.

There is also a parallel between cultural and technical errors. For instance, the organization's habitual compliance with non-navigational requests and the trivialization of dangerous practices resulted in the adoption of a safety margin lower than established (technical error). Additionally, the general attitude of the officers within the organizational culture allowed the ship to leave port with non-compliant nautical charts, a broken radar, and malfunctioning watertight doors.

There is also a parallelism between psychosocial process factors and cultural factors. For example, the lack of error-sharing, considered a cultural factor, could be related to a malfunction in communication management (process factor).

Similarly, in the post-impact phase, the violation of the code regarding the sequence of actions in an emergency (technical error) caused a lack of team coordination, which then generated panic and confusion (process factor). The secretive attitude, thus considered a cultural factor, led to the failure to communicate the real situation to external authorities (technical error). The widespread lack of quality control of procedures (cultural factor) caused process errors such as uncoordinated improvisation of rescues and inefficient onboard coordination.

The flow

The flow previously described between a category of the same time phase is also repeated over time, and also between different categories. For instance, the failure to have instructed passengers with respect to emergency situations is a technical error (pre-accident phase) that goes hand in hand with the absence of internal monitoring on maneuvers to get passengers to safety once an accident has occurred (process error); or, the normalization of violating the Captain's orders by the Bridge Team (cultural error) continues and worsens in the next phase with widespread distrust in leadership (cultural factor); habitual dangerous navigation practices can be seen as a warning for later underestimating the emergency situation; lack of role assignment in the initial phase leads to confusion and lack of crew coordination in the later phase (both process factors).

The absence of mitigation

The analysis highlights how the lack of prevention is just as severe as the failure to manage errors because both led to serious consequences in different phases. Initially, it became evident that failing to address certain errors, regardless of their type, resulted in the impact on Le Scole. Subsequently, the prolonged nature of the situation and delays in taking action, both socially and technically, led to the rescue effort being conducted under critical conditions, ultimately failing to save all passengers despite initial opportunities for effective intervention.

Therefore, the analysis suggests that delays in managing pre-existing errors allowed them to manifest in subsequent phases without mitigation, transforming some initial errors into subsequent ones. This connection between the before and after phases not only reflects temporal succession but also underscores a consistent deficiency in error prevention and management practices across both phases, indicating a systemic issue in error culture.

Does the technical error disappear?

Between the two temporal phases pre and post-impact, a difference in the relevance of certain types of factors over others becomes evident. Specifically, it can be observed that technical errors decrease in favor of psychosocial and cultural errors in the second phase. This is presumably because, in the pre-impact phase, those technical errors occurred that subsequently led to psychosocial and cultural consequences. It seems that the technical factors in the subsequent phase are not as diverse as those in the first phase but rather primarily relate to delays or omissions in the communication of official information. In contrast, the phase preceding the impact involves discussions of unauthorized dangerous maneuvers, neglect of equipment in use, and norms related to communication, mostly.

Conclusion

The analysis of the Costa Concordia case study provides evidence for the valid use of Reason’s model of Swisse Cheese Model not only before the occurrence of the incident but also after. Using this model from a prevention and management perspective highlights the importance of the intermediate stage as a time window in which events can dramatically escalate. Finally, analyzing the psychosocial factors helps provide a comprehensive view of the case study without resorting to a blame-oriented approach. Indeed, applying the Swiss Cheese model to this case reveals two different approaches to interpreting errors and responsibilities. Whenever errors or incidents happen in an organization, the organization can recognize errors and responsibilities in two ways: adopting either the Individual Blame Logic (IBL) or the Organizational Function Logic (OFL) (Catino, 2008). Reason's model, responding to the question "How did the incident happen?", supports the OFL perspective because it interprets organizational dynamics, not individual decisions.

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Translation of standards: balancing contextualisation and standardisation

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Abstract

With 2.4 million companies certified to one or several ISO standards, realization of anticipated benefits is essential. However, organizations sometimes decertify due to reasons such as lack of perceived value or high costs. As organisations seek efficient QMS certification, multi-site certification is promising. However, the lack of research on managing it risks a superficial QMS imposed by headquarters. This study, using a global company's experience, aims to enhance understanding of this. Using translational theory, the paper explores harmonizing company-wide standardization and specific site characteristics for added value at both. Research on adoption of new practices underscores the importance of contextualization to move beyond superficiality. Thus, there is an inherent contradiction between standardization in a multi-site QMS and contextualization that this paper investigates. The paper focus on translation when implementing standard practices from headquarters (source) to sites (recipients). The paper is based on a qualitative, multiple cross-case study in a company with 13 sites, with data from interviews at four sites and headquarters. The conceptual framework builds on Røvik's (2016) three modes of translation. The findings are that *reproducing* is the dominant translation mode, which is often seen by recipients as non-value-adding. Headquarters (i.e. source) also question relying solely on *reproducing*, as it can backfire, placing responsibility for the certification solely on them. *Modifying*, though not explicitly acknowledged, is seen as a potential means to enhance benefits across recipients and thus support their value-creation. *Radical* as a mode of translation remains unrecognized by both source and recipients. However, it could be utilized, allowing recipients to select among standardized practices supporting their value-creation, or presenting alternative practices to source/headquarters for consideration.

Keywords: Quality management systems, translation, multi-site, standardisation, contextualisation, value-creation

Introduction

In the cases where a company has a multi-site management system, the parent company has several responsibilities in order to show that the sites included in the certification are all integrated with each other (IAF, 2018). The requirement in general certified global standards (ISO standards) or industry-specific standards (i.e. IATF16949) are supposed to be transferred and implemented throughout the organisation from top-management down to shop floor. Every management system standard (MSS) from ISO, regardless of if it is a Quality Management Systems (QMS; ISO 9001), an Occupational Health and Safety Management System (ISO 45001), an Environmental Management System (EMS; ISO 14001), or a combination of all three, have the same requirements when it comes to a multi-site management system (IAF, 2018). In essence, there is a requirement on headquarters to make sure that the processes and practices with central guidelines are pervading in the organization, including key performance indicators (KPI) and action plans. In order for the management system not to become a ceremonial system that only exist in a document at the site with no real use (Boiral & Amara, 2009), it is argued that the organisation should focus on motivational drivers, transparency, stakeholder involvement and flexibility between the sites and headquarters (HQ) (Adler and Bory, 1996; Poksinska, 2007; Bashan and Kordova, 2021; Hedberg et. al., 2023).

One challenge that organisations with more than one site faces is how to implement standard practices in different contexts in a way that results in benefits at all sites. This challenge becomes more complex at various levels in a global organisation (Mehra and Agrewal, 2003). To be able to handle this complexity it is important that organisations are aware of the challenges and are able to create, and implement, practices and systems that are working well throughout the whole organisation (Bashan and Notea, 2017). In this paper, the implementation of a multi-site QMS is in focus; a process referred to as a translation to emphasise the need to contextualise to needs at various sites. The outcome of translations of global practices needs to be in focus to reduce the risk of having different understandings and uses cross one organisation's sites, as the multi-site certification requires complete, organisation-wide standardisation.

The different modes of translation identified by Rövik (2016) are reproducing, modifying and the radical. For each of the modes there are identified rules of translation. The rule of replication is copying, modifying has the rules addition, omission, subtraction or combination, and the radical mode has the rule alteration (Rövik, 2016). The suitability of each of the modes depend on the context of the source and recipient. Rövik (2016) identifies the contextual conditions as translatability of the practice, transformability of the knowledge, and similarity between source and recipients.

For an organisation to ensure that the translation process work as well as possible, and as often as possible, it is important to understand the different knowledge barriers that might exist at the recipient and source. Motivational barriers are well researched and identified from an organisational perspective (Rövik, 2016), however, there is a lack of more insightful understanding of the more practical barriers that might exist for a translation of a practice to become successful. To come closer to practical support for translators working with QMS this paper focuses a specific set of barriers: tacitness, casual ambiguity, lack of absorptive capacity, the quality of the network that connects source and recipients, and differences in culture between source and recipients (Rövik, 2016). Adding the translation perspective to these barriers it becomes important to both be able to handle de-contextualisation and contextualisation. In other words, first to be able to strip away the contextual specificities from the context where the practice has been created to turn it into a translatable idea. As a second step, the idea can then be contextualised to fit the recipient's context and become a useful practice in this new context (Rövik, 2016). This process can further be linked to the concept of value co-creation (Grönroos, 2012).

Value is co-created throughout a service process and is influenced by *how* such a process is carried out (functional quality), and not only by the actual outcome (technical quality) (Grönroos, 2012). Grönroos (2012) argues that value emerges when customers use services in their context, thus the customer plays an active role in the value creation process, not only as recipients of an outcome but also by integrating resources provided by other organisations/providers (Grönroos, 2012). Value co-creation hence involves interactive processes, this would mean shifting strategies from a transactional approach to a relational and interactive approach, with continuous engagement to understand changing needs and the facilitation of the value creation process (Grönroos, 2012). Connecting back to the translation from a source to a recipient in regards a multi-site QMS, this entails a focus not only on the source’s need to move into a multi-site certification but also on understanding how it will be used by recipient sites in their value-creation.

In sum, Rövik (2016) argues for a research gap regarding the prediction of which outcome a certain mode of translation will have on the knowledge-transfer process. Thus, empirical investigation is needed in order to further the use translation theory to understand organisational effects (Rövik, 2016; Wæraas & Nielsen, 2016; Øygarden & Aslaug, 2020). In this paper such investigation is related to multi-site certified QMS as these require a standard way of working cross sites, at the same time as previous research points to a key aspect in translating new practices cross an organization to be adaptation to context specific characteristics. Thus, two contradicting “forces” are in place that both might influence the likelihood of realizing the envisioned benefits of a multi-site QMS. Thus, the purpose is to explore how this contradiction is dealt with in practice when translating standardized global practices from headquarters to sites, with a focus on multi-site certified QMS in specific.

The purpose will be addressed through a case study of a global company with data collected from headquarters and four of the company’s sites. Three of these are included in a multi-site QMS and the fourth is in a process towards inclusion. The purpose is decomposed into three research questions:

- What are the predominant modes of translation utilized by a global organization for implementing global practices?
- How do the perspectives of the source and recipient differ in the view of translation modes in a global context?

- What strategies can be employed to overcome knowledge transfer barriers and achieve more successful outcomes in the translation of global practices?

Methods

The study is based on a qualitative, multiple cross-case study (Miles & Huberman, 1994) in a company with eight of its 13 sites included in a multi-site QMS certification. The sample included one site each in South America, North America, Europe, and Asia. At each site one respondents that worked operationally with the QMS was sampled (referred to as SA1, NA1, E1, and A1). At headquarters three managers, experienced in global rollouts of certified systems were interviewed (referred to as HQ1, HQ2, and HQ3). These interviewees were all in managerial positions with experience of global translations of practices and standards Thus, data was collected through seven interviews at four sites (recipients) and from headquarters (source). Thus, the sampling approach chosen includes the initiator of the translation process (HQ) and the recipients (sites). The interviews were conducted with a the

matic and semi-structured interview guide, recorded and transcribed. The data was analysed in NVivo.

Results

To address the two first research questions on predominant modes of translation and possible differences in perspective of these modes between source to recipients, Table 1 displays illustrative quotes for each mode. Moreover, the table indicates the extent to which each of the modes is present in the case, from unawareness, to recognition, to acknowledged, and finally to being explicated as the main translation mode.

***Table 1**. Translation modes and rules; presence indicated as: A (unaware), B (recognised), C (acknowledged), D (explicated)*

Modes and rules of translation (Røvik, 2016)	**Source**	**Illustrative quote**	**Recipients**	**Illustrative quote**	**Comparison**
Reproducing	C	"we started always to explain a lot, you know (…) harmonise the people. But we learned this is not really needed when we standardise things." (HQ3)	D	"A standard from the headquarter, it's, for example, the legal statements in the headquarters - different than the local [one] -and we need to gain benefits in the local and maybe in many cases you are duplicating [work]" (E1)	Source uses this mode frequently (seen as most efficient) to reach the wanted outcome. Recipients explicate this mode with frustration, seeing it as the root for misunderstanding.
Modifying	B	"Can I have additionally my management review too. So, this was on then the questions popping up. And then we say, OK if you have time, you can use your local one, but we need it in the in the headquarter format." (HQ3)	B	"it means that it's a decision from the company or from the headquarters so. Maybe then it's in our part to do restructuring because you have established systems and you have to review how to match with the other ones." (E1)	Source and recipients are all aware of this mode. Not used by source. Seen by recipients as the wanted mode for increased positive outcomes.
Radical mode – Alteration	A	-	A	-	No awareness at source or recipient.

First, reproducing is the dominant translation mode, perhaps natural as it is linguistically associated with standardisation. Recipients see reproducing as a main source of resistance towards multi-site QMS: "you need to show that it will have benefits - the change that you want to make, or in this case the multisite certification - that it will have benefits for the site" (A1). Headquarters (source) also question the effects of relying on reproducing as the main translation mode. One reason being that such a mode sometimes backfires with recipients at the sites put all responsibility for a multi-site QMS and possible deviations at headquarters. As stated by a manager at headquarters, if "they couldn't explain [a deviation] to the auditor […] so this was always, always the same; 'ohh, it's not, it's not me' - that was required by headquarters, ask headquarters" (HQ3).

Second, modifying as a translation mode is not acknowledged or explicated as being currently applied, but recognized by both HQ (source) and sites (recipients) as a possible way to enhance perceived benefits cross sites. From an HQ perspective this is shown through reflections on how to adapt to local sites e.g. in training and communication to enhance the acceptance of a new way of working according to a multi-site QM. Such reflections can be operationalized by modifications: "Instead, I have set up own training sessions with them, providing them the tailored content of the same module from Headquarters' perspective instead of giving them this [standardized] training" (HQ2) From the sites' (recipients') side, modifying is perceived as something sought-after as something closely connected to a two-way communication and openness: "Instead of having it being dictated from the top down, you know. Have to go the other way too, you know. I'm having these various ties in projects that people work on. And, you know, makes them feel that they're part of the process." (NA1)

Lastly, neither source nor recipients have experiences (or even think about) radical mode of translation, which is natural as a standardized multi-site QMS carries with it external certification and re-certification focused on it being applied in its standardized form across sites. In summary, however, there is an awareness of challenges in translation of standards in a way that maintains the needed level of standardisation but allows for modifying e.g. in how the system is introduced. Much responsibility for such modifications lies on HQ, but there is also an awareness of sites' responsibility: "it can also be good for the [local] departments to maybe think about what they do and think about 'what can we do differently?' and so that they don't become too rigid." (A1) Thus, one means of overcoming translation barriers is improved relations between HQ (source) and sites (recipients), to address the third research question on overcoming knowledge transfer barriers Table 2 conveys illustrative quotes on such barriers from both HQ and site interviewees.

Table 2. *Exemplary quotes and categorisation of strategies to overcome knowledge transfer barriers*

Knowledge transfer barriers	Source	Recipients
Tacitness	"It's [the management system] getting more and more open, which makes it easier to work together." (HQ2)	"take simple steps and improve on that instead of, you know, this real big project so to speak, that it's really not ascertainable in a relatively short period of time." (NA1)
Casual ambiguity	"Why you need such a lot of data? 'Can I have additionally my management review too?' So this was on then the questions popping up." (HQ3)	"In my experience you need to show that it will have benefits […] in this case the multi-site certification - that it will have benefits for the site." (A1)
Lack of absorptive capacity	"I would say this was a failure here in HQ to prepare all the things for the sites Nowadays I would do in a different way […] if there is a line in the management review which they couldn't explain to the auditor – 'this was HQ required'." (HQ3)	"Sometimes it's not so easy for us to implement something that we they have in HQ because of the capacity of the site, but everything comes from them [HQ], so it's very important to have their support." (SA1)
Quality of network between source and recipient	"What I learned from them is when people are afraid, their hearts and minds close down and nothing will work. The more they feel at home and comfortable and seen and valued, the more open they will talk about things, the more improvement we can make together." (HQ1)	"So that's the feeling - that you give your feedback. From the work in the local space [site], but you don't receive any [from HQ]." (E1)
Source and recipient being located in different nations and/or cultures of table	"I found that the interlink between the sites is pretty poor. I found that even here in HQ people did not know what had happened on site […]. So, one of the very first things I did and that was kind of like a revolution […] was to establish a digital agency community." (HQ1)	"The restructuring of, maybe, different processes. We could have been trying to do certain things here, but there's cultural differences between [site and HQ]". (NA1)

In terms of tacitness from the HQ side it is clear that this will be a hands-on way to improve collaboration. Interesting, however, that many of the examples of improved collaboration is that HQ will have an easier time following up on the sites' results. From the sites, on the other hand, tacitness relates more to how to implement in a way that make it hands-on and concrete, i.e. incremental and iterative changes rather than one giant implementation project. Thus, one strategy advocated is an incremental and step-wise roll-out of a multi-site QMS.

Barriers in terms of causal ambiguity – not fully seeing cause and effect of the new multi-site QMS – and lack of absorptive capacity – not being able to absorb the new practices – are touched upon in similar ways. There is a need for the sites to both understand new practices and their intended results, and to be open to changing their practices. In addition, sites need to feel sure about that the change does not jeopardise the sites' performance. This insecurity might be the reason for not wanting to let go of current practices but rather just add additional practices. Further, HQ realises the need to create 'ownership' in sites and to do that there is a need to also ensure that there is capacity at the sites to absorb the new ways of working. Examples of strategies to achieve this is the establishment of on-line communities for sharing of best practices and accessibility to dashboard following up on performance to decrease the causal ambiguity.

Finally, in this global multi-site QMS most barriers appear to be linked to the quality of network between HQ (source) and sites (recipients) and them being localised in different countries. This leads to many doubts about the relevance of the system, the risk of loosing well-functioning practices in existing local QMS, and concerns of HQ not being open to feedback from the sites. In relation to these barriers the strategy of establishing a community for discussion and sharing of best practices has also been of use. Interesting though, there is also examples of practices to be implemented where HQ changed direction from an open, feedback-based approach to one being more direct and top-down required. The reasons being that the feedback-based approach simply required to many resources and certain speed was needed in implementing the new practices with the associated performance reporting.

Discussion

In response for a request on more empirical research focusing practical use of translations theory with a focus on understanding organisational effects (Rövik, 2016; Wæraas & Nielsen, 2016; Øygarden & Aslaug, 2020), this paper focused on perceptions of a translation of a certified multi-site QMS at both HQ (source) and sites (recipients).

First, and referring to the research question on "What are the predominant modes of translation utilized by a global organization for implementing global practices?", the predominant modes of translation utilized by the studied global organisation is *reproducing* (Rövik, 2016), which comes natural as standardisation of practices is required in multi-site QMS (IAF, 2018). Thus, focusing organisational effects in terms of becoming certified to the multi-site QMS this is a feasible route. It is, however, visible in the data that *reproducing* is a source of resistance and scepticism towards possible value generated at sites, which can be traced in quotes like: "we need to gain benefits in the local and maybe in many cases you are duplicating [work]" (E1). Relating to previous research on what it takes for a QMS to be perceived as enabling and value-adding (Poksinska, 2007; Bashan and Kordova, 2021; Hedberg et. al., 2023), a more feasible way forward would be *modifying* (Rövik, 2016). However, this can argued to be problematic, as a set standard practice cannot be modified into being different across sites. Instead. *modifying* could be used early in the process towards a multi-site certified QMS, for example, when deciding on what practice to standardise inviting sites to present their practices, which if well-functioning might become the global standard practice. In such an approach the translation rules of the *modifying* mode, that is addition and omission (Rövik, 2016), could be balanced in a proactive way.

Second, and referring to the research question on "How do the perspectives of the source and recipient differ in the view of translation modes in a global context? Based upon the results it can be argued that differences between source and recipients on the translation modes appear to be related to the view on what is the outcome in focus, and even differ among HQ interviewees. If focusing on the outcome of being certified as fast as possible with as little resources as possible, *replication* (Rövik, 2016) is a straightforward choice of translation mode: "you can use your local one, but we need it in the in the headquarter format." (HQ3) If, however, focusing on specific needs at sites and in gaining a shared ownership of the QMS, more time is spent on *modifying* - foremost as a means of creating involvement, and perhaps eventually shared ownership: "makes them feel that they're part of the process." (NA1) Overall, much of the reflections from the interviewees (both from HQ and sites) have to do with the relations between HQ and local sites and how they influence the barriers that might occur when moving towards a certified multi-site QMS. If instead also the process of translation would be seen as an opportunity for value co-creation (Grönroos, 2012), where the recipient is involved in creating the practice they will use, it would possibly not only lead to improved relations but also an outcome that is accepted and used. Thus, it would enhance functional as well as technical quality.

Finally, referring to the research question on "What strategies can be employed to overcome knowledge transfer barriers and achieve more successful outcomes in the translation of global practices? there are examples of strategies to overcome knowledge transfer barriers in the translation of global QMS practices. One strategy in balancing standardisation and need for contextualisation might be to use tailored training sessions as a modifying strategy. In other word, avoid alterations in the actual standard practices but focus on modifying how they are rolled-out and the associated training to support that. Training could, thus, put the practice in relation to the specific context and exemplify by context-specific needs and challenges as a means to enhance receptiveness and acceptance for the new standard at the sites. Such tailored trainings could arguably support transparency, involvement of stakeholders (recipients), and show evidence of a flexibility at HQ (Adler and Bory, 1996; Poksinska, 2007; Bashan and Kordova, 2021; Hedberg et. al., 2023). Furthermore, this would also address the possible barrier of *causal ambiguity* (Rövik, 2016) as it would facilitate for the sites to understand the possible positive effect of the standard practice in their own context. Other suggested strategies to overcome knowledge translation barriers are incremental and step-wise roll-out of a multi-site QMS so sites gain experiences from the system that can enhance *tacitness*, on-line communities for sharing of best practices to decrease the *causal ambiguity* and strengthen *absorptive capacity*, and, finally, to establish a feedback-based approach, (, to open for two-way communication and openness to enhance the *network between source and recipient* although *located in different nations*.

Limitations of this study is the limited interview data that could be complemented by, for example, focus groups or surveys with recipients and sources in global organisations to enhance the validity of the findings. It could also possibly be complemented by future research based on a quantitative study of, for example, how often a global practice is translated with a positive outcome, and how often the process of translation is seen as value creating by both source and recipient. Another avenue for further research can be an in-depth exploration of the similarity aspect of recipient and source (Rövik, 2016), by, for example, applying the concept of perceived proximity (Boschma, 2005). This could lead to useful insights in how to approach the different knowledge barriers in a more refined way, depending on how close - or far away - the recipient (site) is perceived to be from the HQ. This might support in improving the handling of contextual differences in a multi-site QMS.

Conclusions

With a purpose to explore the contradiction between standardisation and contextualisation is dealt with in practice when translating standardized global QMS practices from HQ to sites, this paper underscores the importance of contextualising new practices to move beyond superficial adoption. Contextualisation is, however, extra challenging due to the obvious need for standardisation in a certified multi-site QMS. Focusing on the translation of standard practices from headquarters (source) to sites (recipients), findings indicate that reproducing is the dominant translation mode, which is often perceived by recipients as non-value adding. Not only sites (recipients) but also HQ (source) question the reliance on reproducing, noting that it can backfire by placing the responsibility of certification and possible deviations solely on HQ. Although not explicitly acknowledged, modifying is seen as a potential strategy to enhance perceived benefits across sites and support their value creation. The radical mode of translation remains unrecognized by both HQ and sites. However, this mode could be leveraged, allowing sites to choose from standardized practices that support their value creation or to present alternative practices to HQ for consideration. In addition, the translation process itself should be seen as an opportunity in which the different knowledge barriers can be handled continuously to reach an outcome that is a valuable practice - and not something superficial which the sole purpose is to achieve certification of the QMS.

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Output Standardization Scheme for Business Processes

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Abstract

In Japan, reforms in people's work methods have led to reduced working hours in various industries. However, overtime is a frequent occurrence in the construction industry. One solution to reduce the need for overtime is to implement shift work utilizing Business Process Outsourcing (BPO). Specifically, BPO covers not only general tasks, such as organizing documents and taking minutes, but also tasks that require construction knowledge, such as cost estimates. In this study, these tasks are referred to as support tasks. If support work is standardized and efficiently carried out using this type of BPO, site supervision efficiency is expected to improve. However, the support tasks requested by general contractors and site supervisors are not currently standardized. Consequently, the implementation methods for support work differ depending on the request, thus necessitating training tailored to individual implementation methods. Furthermore, personnel must be allocated according to the work execution method, although this does not improve the overall efficiency of the construction industry. This study aims to understand the differences in support work between general contractors and sites and to propose measures to achieve greater efficiency by standardizing work across the industry.

Keywords: Business Standardisation, Business Process Outsourcing(BPO), Construction Industry

Relevant Topic: Sustainable quality management, standards and certification

Introduction

In recent years, working in Japan has required reforms to reduce working hours in various industries. A cap on overtime work has been applied since April 2024 in the construction industry. However, overtime occurs frequently, even after the cap has been applied. According to the Ministry of Health, Labour and Welfare (Koseirodosho. 2023), in April 2023, the average total actual working hours for all industries was 141.0 hours per month, while in the construction industry, it was 168.1 hours per month, approximately 27 hours longer.

Furthermore, the working environment in the construction industry is expected to deteriorate further as the construction workers age significantly and the number of workers in the construction industry decreases (Kokudokotsusho. 2021).

The reduction in overtime hours and the decrease in the number of workers will lead to delays in construction and delivery. It is necessary to improve work efficiency and change to a system that maintains the current construction and delivery periods to be further shortened, even with fewer working hours and fewer workers. If this is achieved, the industrial competitiveness of Japan's construction industry will increase, and further economic development can be expected.

Supervisors are in short supply in various occupations in the construction industry. In addition to the supervisory duties performed on-site, site supervisors need to prepare documents such as steel reinforcement quantities, other cost estimates, and minutes of meetings. Reducing and improving the supervisory and documentation efficiency is necessary to reduce the working hours of site supervisors.

One solution is to shift work by using business process outsourcing (BPO) in the construction industry. Documentation work is also outsourced in the on-site supervision work. Specifically, general tasks, such as organizing documents and taking minutes, and tasks that require construction knowledge, such as cost estimation, are covered. In this study, general assignments and tasks requiring construction knowledge are referred to as support tasks.

Outsourcing documentation conventionally carried out by the site supervisor to another person using support work is possible. However, outsourcing documentation work may add new tasks, such as transmitting required information for documentation and confirming the content. Therefore, it is unclear whether site supervisors' work is reduced or increased by simply utilizing support services.

Therefore, improving how these tasks are carried out is necessary to reduce the workload of site supervisors in support tasks. Hence, standardizing the support work at construction sites by accumulating knowledge is considered effective. This will make it easier for support practitioners to carry out their work and improve efficiency. Furthermore, standardizing the content of information provided by site supervisors to support service practitioners enhances efficiency in the construction industry.

However, although BPO for support work is currently implemented at each general contractor/construction company (hereafter collectively referred to as construction companies) and at the construction site, it is not standardized, and the implementation method of support work differs for each request. This requires training for support work practitioners tailored to individual implementation methods. Furthermore, personnel must be allocated according to how the work is carried out, which has not led to greater efficiency in the construction industry.

Understanding the flow of work is necessary for standardization. The execution process can be understood by observation. However, in support work, documents such as photo albums and minutes are the work output and reflect the work process results, so it is effective to analyze these documents.

Therefore, this study focuses on documents and the output of support work and proposes a method to analyze the differences in outputs and study standardized outputs as a measure of output standardization.

Using the proposed method to analyze the differences in outputs and examine standard outputs, the process of standardizing outputs of support work becomes clear. Standardized outputs can then be disseminated to construction companies to unify outputs.

Methods

Definition of terms and overall picture of standardization promotion

This study proposes a method for analysing the differences in output as a first step toward achieving the overall objective of this study. The terms used in this report are defined as follows:

Operations are defined as the processes of creating outputs from inputs. The outputs are documents produced by the operations, and the components are the elements that comprise the outputs. An overall picture of standardization using the terms defined above is shown in Figure 1.

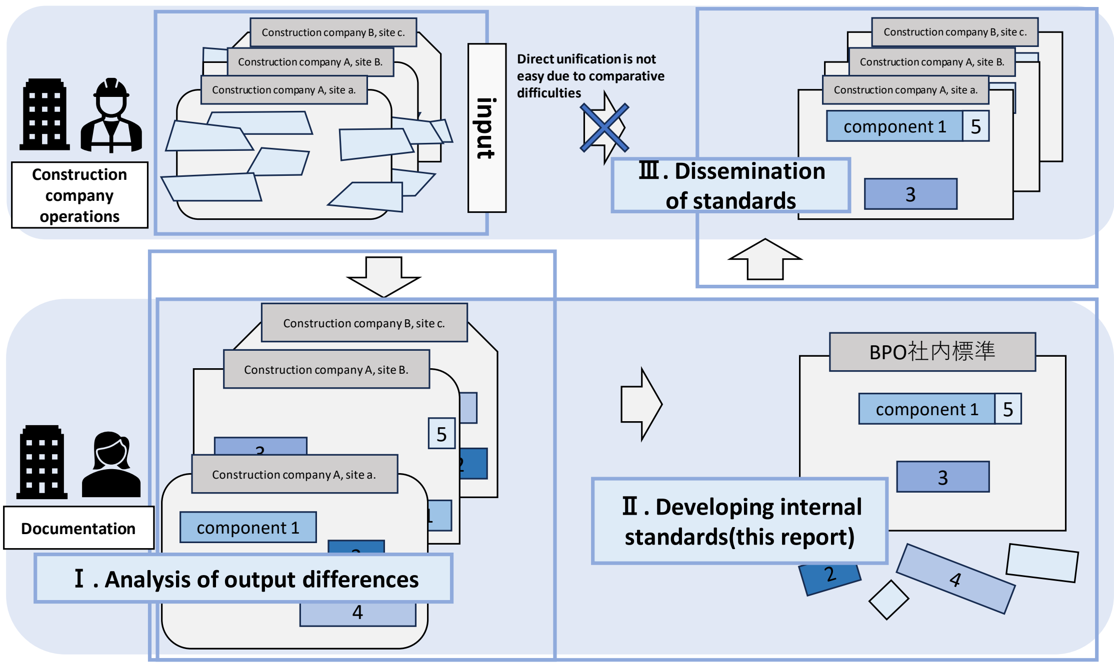

***Figure 1**. Overall picture of standards promotion.*

Figure 1 shows the flow for standardizing the output of the operations in three steps. In Figure 1, the upper side shows the construction company and the lower side shows the support work. The current input from the construction company is shown in the top left-hand corner, where information on construction work is provided for each case; however, it is unclear where and what information is provided. It is not easy to understand the differences between them clearly.

The first step is "I. Analysis of output differences." The differences in the output of different construction companies and sites were clarified by comparing the descriptions from a unified perspective by practitioners in support services. Next, "II. Formulation of the internal standard": Practitioners in support services compare the evaluation results of the presence/absence of components in multiple cases to establish better output content as a standard. Finally, "III. Dissemination of standards:" Practitioners of support services disseminate the standards to construction companies. This process will lead to standardizing support services in the construction industry.

Positioning of this report and research methodology

Within the overall picture of standardization presented in Figure 1, this study focuses on "I. Analysis of output difference", "II. Analysis of output differences," and "II. Formulation of the internal standards

First, the documents analyzed in this report are explained. Next, a model representing the document components was examined. Subsequently, a list of the constituent elements was prepared for the photo album through a survey of business manuals and interviews with support work practitioners. The list of components was used to identify the differences in the output. A method was then proposed to examine standardized outputs using the identified differences.

Documents to be analyzed

This study analyzed documents called photo ledgers. Examples of photo ledgers are shown in Figures 2 and 3.

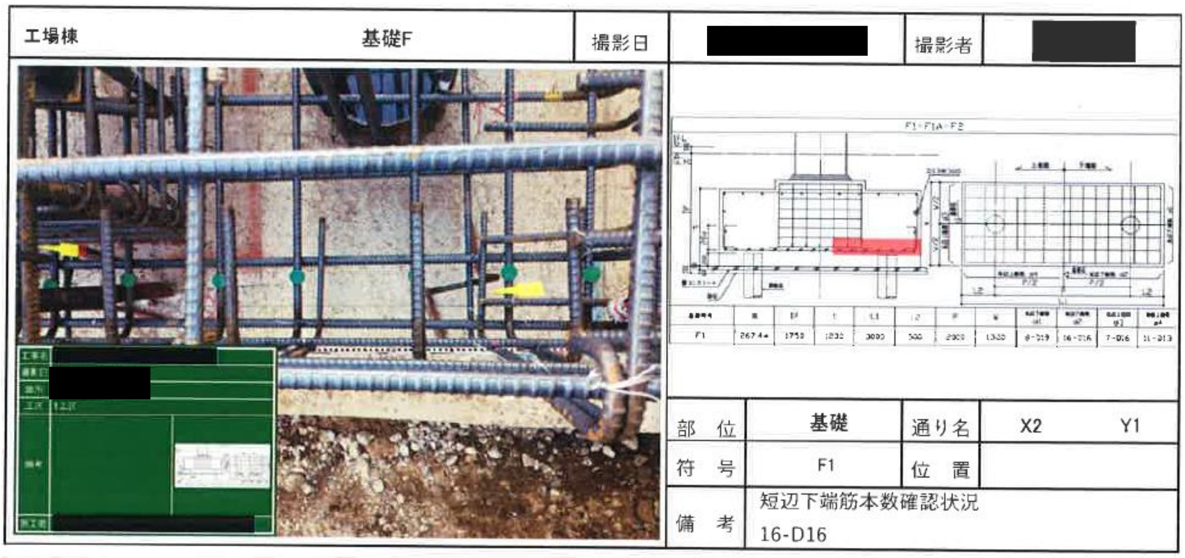

Figure 2. *Example of photo album 1.*

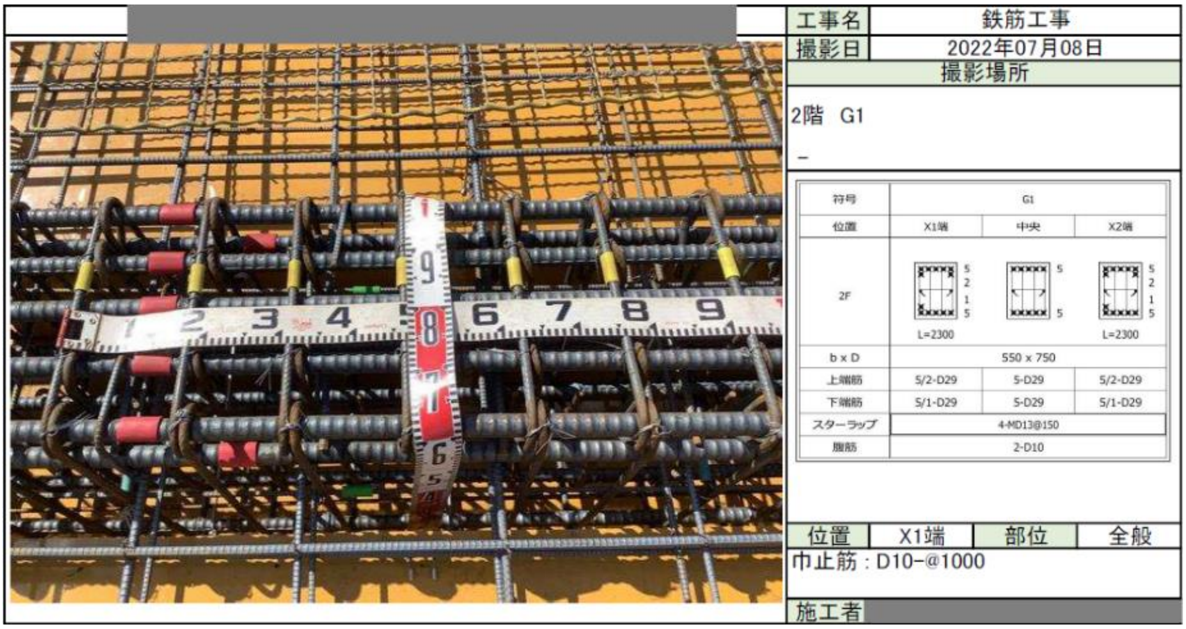

Figure 3. *Example of photo album 2.*

A photo album contains photographs of construction work and related information. The quality of the construction work is proven by producing photo albums, as shown in Figures 2 and 3. There are 22 types of construction work, and a photo album is prepared for every kind of work, as recommended by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), that the details of the work should be described from the perspective of 5W1H (Shadanhojinkokyokenchikukyokai. 2011). However, in practice, a photo album is rarely prepared according to the MLIT recommendations, and the content of the description differs in each case.

Furthermore, the same word is sometimes used with different meanings in photo albums. For example, Figures 2 and 3 contain the information 'site.' However, the information they describe is 'basic' in Figure 2 and 'general' in Figure 3, so the word 'site' is not used with the same meaning. The information 'X2 Y1' in Figure 2 and 'X1 edge' in Figure 3 also have a similar meaning. However, the name of the item in which the information is described differs from the 'street name' in Figure 2 and 'location' in Figure 3. Furthermore, Figure 2 also contains 'location.'

The content of the photo album differs significantly depending on the type of construction work. Therefore, in this report, typical construction and rebar works are the subject of analysis.

Understanding differences in outputs to promote standardization

Models of the components of a dossier

To understand the components of a dossier, it is first necessary to determine the kind of components the dossier contains. Therefore, a model of the constituent elements of the documents was studied (Figure 4).

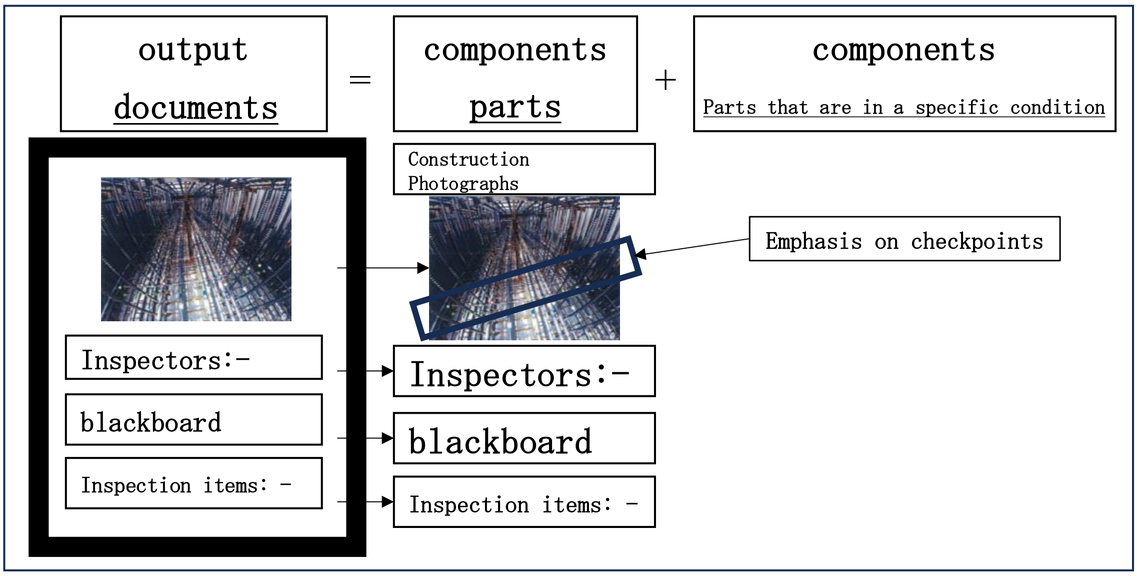

Figure 4. *Model of the components of a document.*

Figure 4 shows that a document comprises components called 'parts' or 'parts in a particular state'. Parts represent the information described in the document. For example, "construction photos" and "inspectors," among others.

Parts are described as input by the customer and may be edited to achieve the document's purpose more effectively and efficiently. Therefore, editing such parts is defined as a 'state'. For example, the 'construction photo' in Figure 4 is in a state where the 'checkpoint is highlighted.' In the example of the photo book in Figure 3, there is a component called 'bean chart' on the right side of the diagram, which is in the state of 'checked points highlighted.' If the components are unified, then the content of the construction information described in the documents is considered the same.

Extraction of document components and evaluation of differences in outputs

The model in Figure 4 was used to extract the document components. First, six photo albums created by support service practitioners on behalf of two construction companies were investigated to understand the information included in them and extracted as components. We also investigated the type of editing carried out on these parts and extracted their state. The requirements for the extracted parts are as follows.

(Requirement 1) Suitable for determining whether they are necessary or unnecessary: In this study, the extracted parts are used to determine differences, but in the subsequent "II. Formulation of internal standards," a decision is made on whether each part is necessary. In this case, if the parts are too coarse, the role of the information possessed by each part becomes enormous, and all parts may be judged necessary. If the parts are too fine-grained, the role of the information possessed by the individual parts may become unclear, and it may not be easy to judge whether they are necessary.

(Requirement 2) No omissions: It is necessary to extract all the information described in the documents as parts without omissions.

(Requirement 3) It should be easy for practitioners of support work: The language that practitioners of support work usually use should be used so that it is easy to judge whether it is necessary.

The following is an example of the extraction of parts and states. For example, a photo book may contain photographs of a construction site. Construction photographs were processed to emphasize the points to be checked. Therefore, we extracted the component 'construction photo,' and the state 'construction photo/confirmation point is highlighted'.

Furthermore, work manuals for preparing photo ledgers were investigated. ICT tools are often used in the current work to create photo books; work manuals are available. These parts were extracted from the manual. For example, in the manuals, there were descriptions of 'registering floors/places' and 'registering code masters,' and the methods for doing so were described. Therefore, we extracted the components 'floor', 'location, and 'code.'

Subsequently, by conducting an interview survey with two practitioners in the support business, we checked for omissions or deficiencies in the extracted components.

By repeating the extraction of components and examining deficiencies in this way, a list of components consisting of 14 parts and three states was drawn (Table 1).

Table 1. *List of components of a photo album of reinforcing steelworks.*

type	No.	name	Definition.
parts	1	Building name	Building Name
	2	number of stairs or stories (storeys)	Number of floors of the building
	3	guide	Information to identify the sequence of parts
	4	part	Structural elements (beams, columns, etc.)
	5	sign	Part type
	6	position	Cutting point of the part (turn of the main bar)
	7	Shooting location	Names of reinforcement to be included in the photograph (top reinforcement, bottom reinforcement, etc.)
	8	constructor	Company name of contractor
	9	miniature map	Part of structural drawing
	10	Construction Photographs	Photos of actual construction
	11	Shooting Date	Date construction photos were taken
	12	examiner	Construction Photographer
	13	checklist	Areas to check and information to compare construction photos
	14	blackboard	Information on planned construction work within construction photos
condition	9.1	Bean diagrams and confirmation points are highlighte	The checkpoints in the bean chart are highlighted.
	10.1	Construction photos, arranged in the order in which tl	Construction photos are arranged in the order in which they were constructed.
	10.2	Construction photos/confirmation areas are highlighte	Checked areas in construction photos are highlighted.

The presence or absence of the components listed in Table 1 was assessed for the six photo books studied. Table 2 summarizes the results.

Table 2. *Results of the presence/absence of the components in the six cases of photo albums.*

Components \ Examples			Company A			Company B		
			1	2	3	4	5	6
parts	1	Building name	●	●	●	●	●	●
	2	number of stairs or stories (storeys)	●	●	●	●	●	
	3	guide				●	●	●
	4	part	●			●	●	●
	5	sign	●	●	●	●	●	●
	6	position	●	●	●	●	●	●
	7	Shooting location	●	●	●	●	●	●
	8	constructor		●		●		
	9	miniature map	●	●	●	●	●	●
	10	Construction Photographs	●	●	●	●	●	●
	11	Shooting Date		●	●	●	●	●
	12	examiner				●	●	●
	13	checklist	●	●	●	●	●	●
	14	blackboard	●		●	●		●
condit ion	9.1	Bean diagrams and confirmation points are highlighted.				●		●
	10.1	Construction photos, arranged in the order in which they were constructed.	●	●	●	●	●	●
	10.2	Construction photos/confirmation areas are highlighted.				●		●

In Table 2, the available components are marked with a '●' for each case in the photo album. Companies A and B represent different construction companies. Cases 1, 2, and 3 represent the three sites at Construction

Company A. However, Cases 4, 5, and 6 represent the three sites at Construction Company B. Table 2 shows that the differences in the documents as outputs can be ascertained using the documents and the list of components of the photo album.

Proposed method for studying standard outputs

Proposed method

The method proposed in Section 3 enabled us to understand the differences in the outputs. Standard outputs should be defined, and output differences should be eliminated. The information that should be included in the standard output is required in practice. Therefore, defining standard outputs by examining the information used in practical situations is needed. We propose the following method for studying standard output based on the above ideas.

Step 1: Understanding the purpose of the utilization

Step 2: Identify the correspondence between the purpose and properties required for utilization.

Step 3: Determine the degree of importance of the properties necessary for utilization.

Step 4: Understanding the correspondence between the properties and components required for utilization

Step5. Derive the importance of the components

Step6. Deriving the product of the importance of components and the number of examples

Step 7: Determination of the components that should be used as standards

In Step 1, we ascertain how the target documents are utilized. Step 2 identifies the correspondence between the purpose of utilization and the properties required. Here, the data quality (Nihonkikakukyokai. 2013) determines the properties needed during utilization. The corresponding relationship is understood regarding whether it exists or not (0 or 1). In Step 3, the number of corresponding objectives is derived as the importance of each necessary property when utilizing the data. In Step 4, the properties required for utilization are identified for each part based on the correspondence between the properties and components. In Step 5, the importance of the components is derived from the inner product of the properties required at the time of utilization and the corresponding relationships. In Step 6, the product of the importance of the components and the number of cases is derived. Finally, in Step 7, the component with the highest value in Step 6 is considered a standard.

Application example

As an example of the proposed method, the results of the study on the standardized components for the photo album are analyzed in Section 3. Table 3 lists the results of this application.

Table 3. *Results of the examination of standard components using the purpose of use, the properties required for it and the number of examples.*

		Properties required at the time of utilization (technical characteristics)																	
		Accuracy	Completeness	Consistency	Authenticity	Currentness	Accessibility	Standards compliance	Confidentiality	Efficiency	Accuracy	Traceability	Understandability	Availability	Portability	Recoverability			
Purpose of use(customer	Post-construction inspections using a photo album	1	1		1	1					1		1						
	Pursuit of causes of construction defects	1	1		1						1	1	1	1					
	Properties required at the time of utilisation. Importance	2	2	0	2	1	0	0	0	0	2	1	2	1	0	0	Importance of the component	Number of cases used (6 in total)	Importance x number of cases
parts	Building name	1		1									1	1			5	6	30
	number of stairs or stories (storeys)	1		1									1	1			5	5	25
	guide	1		1									1	1			5	3	15
	part	1		1									1	1			5	4	20
	sign	1		1									1	1			5	6	30
	position	1		1									1	1			5	6	30
	Shooting location	1		1									1	1			5	6	30
	constructor	1			1							1					5	2	10
	miniature map	1											1	1			5	6	30
	Construction Photographs	1	1			1							1	1			8	6	48
	Shooting Date	1			1	1						1					6	5	30
	examiner	1			1							1					5	3	15
	checklist	1	1			1					1		1	1			10	6	60
	blackboard	1		1													2	4	8

This section describes the application process. First, Step 1 identifies the purpose. In this case, the objectives were "post-construction inspection using a photo album" and "the causes of construction defects."

Step 2 ascertains the correspondence between the purpose and the properties required during use. The properties needed during utilization are the data quality characteristics indicated by the data quality model in JIS X 25012:2013 (ISO/IEC 25012:2008) (Nihonkikakukyokai. 2013). This standard concerns the quality requirements, software product evaluation, data quality characteristics and the attributes affecting data quality. The data quality characteristics are listed in Table 4.

Table 4. Data quality characteristics and their contents (Nihonkikakukyokai. 2013) (Dejitarucho. 2022).

data quality characteristics	Definition.	Definition Summary	Examples of evaluation items
accuracy	The degree to which the data has attributes that correctly represent the true values of the attributes of the intended concept or event in a particular usage situation.	Is it right?	Is the formatting correct? Are there any typographical errors or omissions? Are there any semantic errors? Are there any errors in the data?
integrity	The degree to which the target data associated with an entity has values for all expected	Is there any omission according to the purpose?	Are the items required for the application Are any of the required fields blank?
consistency	The degree to which data has the attributes of being consistent and coherent with other data in a particular usage situation.	Are the data consistent with each other?	Are there any inconsistencies in the Data within the data set? Are there any inconsistencies in the data between data sets?
authenticity	The degree to which data have attributes considered true (real) and trustworthy by users in a particular usage situation.	Can I trust you?	Is the source of the data indicated? Is the date of the data update indicated? Are tamper-evident measures in place?
up-to-dateness	The degree to which the data has an attribute whose value is the most recent in a particular usage situation.	Is the data up-to-date?	Is the update cycle of the published data appropriate for the update cycle of the original data? Is the data available to the public in a sufficiently short period from the time of collection? If provided in the form of a file, etc., does it indicate the date and time of the last update and the location of the latest version so that the updated version can be confirmed?
accessibility	In particular, the degree to which People who, due to some disability, require assistive technology or special equipment configurations can access the data in a particular usage situation.	Is the data available to everyone?	If provided in a file, is the data available to all Persons who have the right to use it? If provided through software, does the software comply with ISO/IEC40500? Is the character set (e.g., Jyoyo Kanji) used correctly?
ndards complian	The degree to which data has the attribute of compliance with standards, agreements or norms and similar regulations relating to data quality in a particular usage context.	Does it conform to certain rules, such as input rules?	Does the data format conform to standards? Is the character set used correctly? Does the selection item contain data other than the specified choices?
confidentiality	The degree to which data has attributes that ensure that it can only be used and interpreted by authorized users in specific usage situations.	Is confidentiality ensured for the purpose?	Is access to the data limited to authorized persons? If users are restricted, are encryption and hacking measures in place?
efficiency	The degree to which data has attributes that can be processed by using the appropriate amount and type of resources to provide the expected level of performance in a Particular	Can the data be processed efficiently?	Are there any duplicates in the data content? Is the data being processed efficiently? Are you using the code effectively? Is the data consistent?
accuracy	The degree to which data have attributes that are precise or that provide discrimination in a particular usage situation.	Is it accurate for its intended purpose?	Is the data set at an appropriate level of accuracy? Does the data have the same level of accuracy? Is the accuracy of the data demonstrated?
traceability	The degree to which the data has attributes that provide an audit trail of access and changes made to the data in a particular usage context.	Can you refer to the origin of the data, etc.?	Is the external data clear? When data is changed, are the person who made the change, the date of the change, etc., recorded?
Comprehension	The degree to which data has attributes that allow users to read and describe the data, expressed in the appropriate language, symbols, and units for a particular usage situation.	Can users understand the data correctly?	Can users understand what the data as a whole and each of its items mean? Is metadata provided for the data as a whole and for each item as needed? Is there an association with a defined meaning, such as a common vocabulary base?
availability	The degree to which the data has attributes that allow authorized users and applications to Retrieve the data in a particular usage situation.	Is it available when you need it?	Is the data accessible whenever it is needed? Is the system that publishes the data in operation at all times?
portability	The degree to which data has attributes that allow it to be implemented, replaced, or moved from one system to another while maintaining existing quality in a particular usage situation.	Can you make a simple transition?	Does it rely on software that cannot output in a standard format? Can the data be exported in a standard format from the system that manages the data?
resilient	The degree to which the data possesses attributes that enable it to continue and maintain a specified level of operation and	Can the data be restored as soon as possible in an accident?	Is a backup of the data stored? Is there a backup system that can continue to provide data even during a system failure?

Table 2 shows the data quality characteristics, their definitions (Nihonkikakukyokai. 2013), a summary of the definitions and examples of evaluation items (Dejitarucho. 2022) when evaluating data quality characteristics. Table 2 shows that the data quality characteristics include accuracy, whether the data are correct and complete and no omissions.

In Step 2, the correspondence between the data-quality characteristics necessary for each purpose of use was examined. For example, accuracy and completeness are required for "post-construction inspection using a photo album."

Table 3 shows the results of applying Steps 3–7. Table 3 shows that the 'inspection items' and 'construction photographs' should be standardized because the evaluation value of Step 6. is high.

Discussion

Significance of this study

Standardizing the work output is necessary to standardize support. However, the content and format of documents, which are the output of support work, are not standardized, making it difficult to judge whether the output is standardized.

In response, this study examines the document model in Section 3 and lists components using this model. Section 4 proposes a method to determine the elements to be standardized. The results will be disseminated to various construction companies, leading to the unification of outputs among construction companies and sites improving efficiency.

This study proposed a series of flows, from creating a list of components to analyzing output differences and examining standard outputs as general methods for photo albums. Therefore, it is possible to formulate standardized outputs for other documents by applying the proposed methods.

Significance of examining the properties necessary for utilization

The method proposed in Section 4 uses the properties necessary for utilization to study the correspondence between utilization objectives and components. A direct examination of the correspondence between the purpose of utilization and the components is also possible. However, estimating the necessary components for utilization is subjective. Nevertheless, objectively judging the properties using the data quality characteristics and their corresponding relationships is possible.

For example, when a photo album is used to prove the quality of a construction project, essentially important information such as 'inspection items' is considered important to confirm whether the project will not collapse during a major earthquake, is resistant to rain leaks, and can withstand strong winds. However, when considering a document called a photo album, information clarifies where the responsibility lies, such as 'Who' is also necessary. When examining this relationship, information such as Who is important because it has 'traceability' among the data quality characteristics.

Conclusions and future tasks

This study developed a model to examine the components of documents and proposes a method to analyze the differences in outputs and standardize work for business improvement. In addition, it proposes a method for examining standardized outputs based on the differences in the identified outputs.

Future tasks will include applying the two proposed methods to other documents and confirming the generality of the proposed methods. In addition, the validity of the results of the analyses in Sections 3 and 4 can be verified for photo albums.

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AI Revolutionizing Customer Service: Unveiling Operational Advantages in the Utility Industry

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Abstract:

In today's rapidly evolving technological landscape, the integration of artificial intelligence (AI) in customer service is becoming increasingly critical for maintaining competitive advantage and operational efficiency, encompassing both pre- and post-sales support. This is particularly true for companies in the energy supply sector, where managing high volumes of customer interactions and providing timely, accurate support are essential. This article presents a case study exploring the implementation of AI in customer service within an energy supply company. Through a structured questionnaire, key aspects such as the motivations for AI adoption, its impact on operational efficiency, and customer perception of service quality are investigated. Findings reveal significant improvements in handling customer queries, scalability with 24/7 support, and personalized interactions driven by AI analysis. Additionally, the study examines cost reduction, operational enhancements, and competitive advantages stemming from AI integration. Challenges faced during implementation and strategies for addressing them are discussed, alongside insights into the evolving role of human resources. The study also includes AI implementation for post-sales processes, including automating customer request management, optimizing maintenance technician routes, and demand forecasting for inventory management. Insights into the benefits and challenges of these implementations are provided, shedding light on their potential to streamline operations and improve service quality. Finally, the article outlines future plans for leveraging AI to further enhance customer service and operational efficiency in the energy supply sector.

Keywords:

Artificial Intelligence, AI Adoption, Utility Industry, Customer Service, Demand Forecasting

1. Introduction

In the current rapidly evolving technological landscape, the integration of artificial intelligence (AI) in customer service is becoming increasingly critical for maintaining competitive advantage and operational efficiency, encompassing both pre- and post-sales support [1][2]. This is particularly true for companies in the energy supply sector, where managing high volumes of customer interactions and providing timely, accurate support are essential [3][4].

The adoption of AI in customer service has been widely discussed in the literature. Studies have shown that AI can significantly enhance customer experience and operational efficiency. For example, AI chatbots can provide 24/7 support, reducing costs and improving customer satisfaction by delivering consistent and accurate responses [5][6]. Furthermore, AI technologies are able to enhance business processes, leading to higher efficiency and effectiveness [7][8].

Research has also highlighted the potential of AI in improving Customer Relationship Management (CRM) by providing personalized and context-aware interactions [9][10]. The ability of AI to understand and process natural language enables more human-like interactions, which can improve the overall customer experience [11]. Additionally, AI plays a key role in data analysis and demand forecasting, helping companies anticipate customer needs and optimize resource allocation [12][13].

This article presents a case study exploring the implementation of AI in customer service within an energy supply company. Through a structured questionnaire and an interview with an AI expert involved in the implementation, key aspects such as the motivations for AI adoption, its impact on operational efficiency, and customer perception of service quality are investigated. The chosen company is a European public company active in the water and energy (generation and distribution of electricity, electric charging stations) sectors. The study investigates operational enhancements, cost reduction, and competitive advantages achievable through AI integration in customer service, addressing challenges and strategies. In particular, it discusses the evolving role of human resources. The study also includes AI implementation for post-sales processes, including automating customer request management, optimizing maintenance technician routes, and demand forecasting for inventory management. The study provides insights into the benefits and challenges of these implementations, highlighting their potential to enhance operations and improve service quality. Lastly, the article outlines future plans for utilizing AI to further enhance customer service and operational efficiency in the energy supply sector.

2. Methods

Questionnaire-based studies are a powerful tool for collecting detailed and structured information directly from stakeholders [14]. In the context of AI implementation in customer service, questionnaires enable researchers to obtain a wide range of data, including perceptions, experiences, and outcomes related to the adoption and integration of AI technologies. This method enables the collection of both quantitative and qualitative data, providing a comprehensive and in-depth analysis of the topic. It should be noted that for this study, only one executive experienced in the implementation of AI for customer service was interviewed. Due to the executive's extensive expertise and pivotal role within the utility sector, conducting an in-depth interview with this single leader offered valuable and comprehensive insights essential for the focus of this article.

The questionnaire includes 23 questions, divided into two sections, as detailed in Table 1. The first section is "Need for AI Implementation in Customer Service" and comprises 13 questions, while the second section is "Request for Information on AI Implementation and Effects on Perceived Quality by Customers" and consists of 10 questions. Finally, in order to analyze the executive's responses, the authors conducted a thematic analysis. This approach enabled systematic coding of the data, identification of recurring themes, and synthesis of the responses into coherent categories, providing a structured and comprehensive overview of the insights obtained.

Table 1. Summary of questions related to the implementation of AI in customer service and its effects on perceived quality by customers.

Section	Topic	Question Number	Question
Need for AI Implementation in Customer Service			
	Primary Reasons for Implementing AI in Customer Service	1	What were the main reasons the company decided to implement AI in customer service?
	Handling High Volume of Assistance Requests Before and After AI Implementation	2	How did you manage the high volume of assistance requests before AI implementation, and how has this changed post-implementation?

	24/7 Customer Assistance Through AI	3	Has AI enabled 24/7 customer assistance? If so, what benefits have been observed?
	Improvement in Service Quality	4	How has AI improved the quality of customer service in terms of accuracy and consistency of responses?
	Personalization of Customer Interactions	5	Can you provide examples of how AI personalizes interactions with customers based on analyzed data?
	Reduction in Operational Costs	6	Has the implementation of AI led to a reduction in operational costs? If so, how?
	Impact on Operational Efficiency	7	How has AI affected the operational efficiency of customer service? Which processes have been automated?
	Competitive Advantage Through AI	8	Do you believe that adopting AI has given the company a competitive advantage? How?
	Customer Data Analysis and Future Needs Prediction	9	How do you use AI to analyze customer data and predict their future needs?
	Technological and Market Changes Driving AI Adoption	10	What technological and market changes prompted the adoption of AI for customer service?
	AI in Post-Sales Service Processes	11	Have you considered implementing AI to automate post-sales service processes, such as managing customer requests, scheduling technical visits, and processing repairs? If so, could you share how you addressed this challenge and what potential benefits you identified in terms of reducing human intervention and speeding up response times?
	Optimization of Maintenance Technicians' Routes	12	Have you evaluated using AI to optimize maintenance technicians' routes to reduce travel times and maximize resource efficiency in post-sales service? If so, could you explain how you examined this possibility and what benefits might arise in terms of improving services offered and reducing operational costs?
	AI in Demand Forecasting and Inventory Management	13	Have you implemented AI for demand forecasting and inventory management, including spare parts? If so, could you describe the process, including the analyzed data and algorithms used? How has this implementation helped maintain optimal inventory levels, including spare parts, minimizing the risk of service interruptions due to lack of materials?
Request for Information on AI Implementation and Effects on Perceived Quality by Customers			
	Main Business Objectives in AI Implementation	1	What were the main business objectives in implementing AI in customer service?
	Specific AI Technologies Used	2	Can you describe the specific AI technologies used in the customer relationship management system?

Integration with Existing Customer Service Systems	3	How was AI integrated with existing customer service management systems?
Types of Requests Handled by AI vs. Human Intervention	4	What types of requests or issues are handled directly by AI, and which still require human intervention?
Metrics for Evaluating AI Impact	5	What metrics have you used to evaluate the impact of AI on the quality of customer service?
Changes in Response Times Post-AI Implementation	6	Have there been changes in response times to customer requests after AI implementation? If so, can you provide specific data?
Customer Perception of AI Introduction	7	How was the introduction of AI perceived by customers? Have you received direct feedback regarding this?
Challenges in AI Implementation and Solutions	8	What were the main challenges faced during AI implementation in customer service, and how did you overcome them?
Impact on Human Staff in Customer Service	9	How has AI influenced the work of human staff in customer service? Have there been changes in training or human resource management?
Future Plans for AI in Customer Service	10	What are your future plans to further improve the use of AI in customer service? Do you have new functionalities or expansions planned?

3. Results

The analysis of the executive's responses provided insightful details on the impact and benefits of AI implementation in the customer service domain of the considered utility industry. As aforementioned, a thematic analysis was employed to systematically code and synthesize the data into coherent categories, facilitating a comprehensive overview of the findings. This approach enabled the identification of key trends, measurement of AI's impact, and the development of recommendations for future improvements in the utility industry's customer service.

Reasons for AI implementation

The primary motivation for adopting AI in customer service was to enhance the quality of interactions and allocate human resources to more complex issues. AI technology is effectively able to handle routine inquiries, such as invoice reprints and general information requests, with a quality comparable to human operators. This shift allows qualified personnel to focus on more significant and intricate customer problems, thus improving overall service efficiency and reducing wait times.

Pre- and Post-AI implementation

Before implementing AI, the company managed high volumes of customer inquiries through human operators, chatbots, and automated responders based on natural language understanding. These traditional methods often failed to provide a continuous conversational experience, leading customers to ask for human assistance. With the introduction of generative AI, the company now manages simple inquiries more efficiently through enhanced conversational capabilities, reducing the need for human intervention and improving the overall customer experience.

Continuous customer assistance

AI has enabled the provision of continuous customer service. The generative AI system fully understands the context of queries, providing polite and accurate responses. This improvement has significantly enhanced customer satisfaction and allowed human resources to focus on resolving complex issues, thus improving overall service quality.

Accuracy and consistency of responses
The implementation of generative AI has significantly improved the accuracy and consistency of responses in customer service. By integrating the AI system with company-specific documentation and procedures, the technology delivers precise and personalized responses, significantly elevating the quality of customer support.

Personalization of customer interactions
AI integration with the company's Customer Relationship Management (CRM) systems facilitates advanced personalization. The AI provides customized responses based on the customer's service history and preferences, adapting the tone and content of interactions accordingly. This approach ensures that customers receive relevant and contextually appropriate support, enhancing their overall experience and satisfaction.

Operational cost reduction
While AI implementation has led to operational cost reductions, the primary objective was to enhance service effectiveness and customer satisfaction. For instance, AI has improved the handling of complaints, classifying and responding to issues in real time, which has significantly improved customer satisfaction. The company reports potential cost reductions of up to 50%, but the primary goal remains to enhance customer satisfaction, for example, by reducing service times.

Enhancing operational efficiency
AI has automated numerous customer service processes, including complaint management and call center operations. The company continues to experiment with these technologies, aiming for full-scale industrialization by 2025. Although AI has already improved operational efficiency, the process is ongoing and evolving. For example, AI assists in real-time classification and response to complaints, dramatically reducing processing times from hours or days to seconds.

Competitive advantage
The company has applied AI across three main areas: employees, customers, and infrastructure. AI supports real-time assistance for technicians, enhances customer service efficiency, and optimizes infrastructure management. This integrated approach has improved operational effectiveness, contributing to a significant competitive advantage. AI also helps in managing critical resources like water and electricity, ensuring continuous availability and efficient service delivery.

Predictive analytics and future needs
AI helps analyze customer data to identify recurring issues and predict future needs. By understanding and anticipating potential problems, the company can proactively improve customer service, enhancing overall satisfaction and effectiveness. This predictive capability extends to managing infrastructure and optimizing resource use and then improving operational efficiency.

Technological and market drivers
The company's AI adoption was driven by the advancements and enthusiasm surrounding technologies like ChatGPT [15]. Partnerships with major tech players such as Amazon, Google, and Microsoft have facilitated the experimental phase, demonstrating the benefits and leading to wider implementation. For example, by collaborating with AWS [16], the company is revising the planning and dispatching logic of interventions using artificial intelligence algorithms. The objective is to optimize the combination of skills, maintenance intervention durations, and geographical locations, thereby improving the deployment of teams for both planned and unforeseen interventions. This collaboration aims to achieve more efficient and predictive operations management, utilizing AWS's expertise in logistics.

Future plans
The future roadmap for AI in customer service includes three phases: handling informational requests, executing common operational tasks, and eventually managing complex operations. This phased approach

ensures a gradual transition to a highly automated customer service system, aiming for full implementation within the next 12-18 months. The company plans to continue refining AI capabilities to further improve service efficiency and customer satisfaction.

Challenges and solutions

The implementation of AI has not been without challenges. The initial immaturity of AI technology posed significant difficulties, with updates sometimes resulting in less effective responses. Overcoming these issues required extensive training and fine-tuning of AI platforms. The company continues to address these challenges through continuous improvement and adaptation of AI systems.

Employee impact and training

The introduction of AI has begun to transform the roles of human operators in customer service. Currently, AI operates as a direct alternative to human agents for specific tasks. Future plans include using AI as a co-pilot to assist human operators in real time, suggesting responses based on customer queries. This transition will necessitate new training programs to help employees adapt to working alongside advanced AI systems.

4. Conclusions and discussion

This article presented a case study exploring the implementation of AI in customer service within an energy supply company. Through a structured questionnaire, key aspects such as the motivations for AI adoption, its impact on operational efficiency, and customer perception of service quality are investigated. Findings reveal significant improvements in handling customer queries, scalability with 24/7 support, and personalized interactions driven by AI analysis. Additionally, the study examines cost reduction, operational enhancements, and competitive advantages deriving from AI integration.

One limitation of this research is the focus on a single executive's perspective, which may not fully represent the experiences and outcomes across different departments or other similar companies. Another limitation is the early stage of AI implementation in the company, which may not capture long-term impacts and unforeseen challenges.

The findings of our study highlight the significance of AI implementation in significantly enhancing operational efficiency and customer satisfaction. The capability of generative AI to manage routine inquiries efficiently allows human resources to focus on more complex tasks, thereby enhancing the overall quality of service. The study also highlights the importance of personalized customer interactions, with AI systems utilizing CRM data to customize responses and enhance customer experiences. These advancements not only improve operations but also provide a competitive advantage by delivering a superior customer service.

Future developments in this area could involve expanding AI capabilities to handle more complex customer interactions and integrating advanced predictive analytics to anticipate customer needs proactively. Additionally, exploring AI's potential in other operational areas, such as smart grid management and energy distribution, could further enhance efficiency and service quality. Continuous refinement and adaptation of AI technologies will be crucial in maintaining their effectiveness and reliability.

In conclusion, while AI presents numerous benefits for customer service in the energy supply sector, it is essential to recognize and address the challenges associated with its implementation. The insights gained from this study can inform strategies for successful AI integration, ultimately leading to a more efficient, responsive, and customer-centric service model. Embracing AI's potential will lead to a transformative shift in the industry, where technology and human expertise harmoniously coexist to deliver superior service.

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Municipal biowaste management: A literature review of case studies, best practices, and life cycle assessments

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Abstract.

Effective management of municipal biowaste is critical for sustainable urban development and for generating environmental, economic, and social benefits from waste valorisation. To evaluate the environmental impacts of biowaste management practices, life cycle assessment (LCA) has been widely applied. However, due to the diversification of waste treatment methods and a large body of LCA studies, scholars, especially practitioners and decision-makers, may be challenged to select a suitable model to be implemented. There are many review studies on LCA for waste management, yet they still have limitations, such as either not focusing directly on biowaste, the sample selection not being comprehensive, or not identifying best practices. This paper employs systematic and bibliometric literature review approaches to analyse a total of 195 articles identified from the Scopus database. The results indicate that research on LCA in biowaste management has drawn much attention from scholars in the last decade. Waste Management is the most productive journal, and most of the collected publications are contributed by authors from China and developed countries. Anaerobic digestion and composting are the two most popular case studies, followed by incineration and landfilling. The combination of anaerobic digestion has been identified as one of the best solutions to manage biowaste due to its environmental benefits. Generally, this paper can contribute to a deeper understanding of the current state of biowaste management and provide a foundation for future research directions aimed at achieving more efficient and environmentally sound waste management practices in urban areas.

Keywords: Municipal biowaste, Waste management, Composting, Anaerobic digestion, Life cycle assessment, Sustainable urban development.

Introduction

It is forecast that global municipal solid waste (MSW) will reach 3.40 billion metric tonnes per year in 2050 (Kaza et al., 2018). The municipal biowaste, i.e., organic waste or organic fraction of MSW, is defined by the European Union's Directive 2008/98/EC as food and kitchen waste from households, restaurants, caterers, retail premises, and food processing plants, as well as biodegradable garden and park waste (Alves et al., 2024). This is the largest single component of MSW, which accounts for more than one-third of the total MSW in the EU-28, or up to 64% in low- to middle-income countries (Arfelli et al., 2023). This waste can cause severe environmental impacts if not treated with an appropriate approach. Indeed, leachates from biowaste can contaminate freshwater, making it uninhabitable for aquatic life and severely affecting human health (Iqbal et al., 2020; Mukherjee et al., 2015). Moreover, methane emissions from the degradation of biowaste in landfills and carbon dioxide emissions from mixed burning of this waste with other fractions of MSW are the main contributors to around 3-5% of the total anthropogenic greenhouse gas emissions globally (Iqbal et al., 2020; Pachauri et al., 2014). In other words, conventional biowaste disposal methods contribute considerably to climate change. Therefore, it is crucial to identify the best practices of biowaste management to mitigate environmental impacts and to yield benefits from valorising this waste towards a Circular Economy (CE).

In order to deal with biowaste in particular and MSW in general, many different methods and approaches have been used. The literature shows that these methods range from open dumping and unsanitary landfilling (Cheela et al., 2021; Xiao et al., 2023) to more environmentally friendly methods like waste-to-energy technologies (Brancoli et al., 2020), composting (Arfelli et al., 2023; Maalouf & El-Fadel, 2018), anaerobic digestion (AD) (Arfelli et al., 2023; Maalouf & El-Fadel, 2018), bioconversion (Salomone et al., 2017), etc. Each technique has pros and cons regarding environmental sustainability, and a better understanding of these aspects is crucial for practitioners and decision-makers to select a suitable model for managing biowaste in practice. To identify such pros and cons, Life Cycle Assessment (LCA), a tool to identify and holistically assess the potential environmental loads related to all phases of a product's life cycle (ISO, 2006), has been widely employed in previous studies. However, due to the diversification of available treatment technologies and the vast number of their LCA studies, practitioners and decision-makers may be challenged to select a suitable model to manage biowaste within a specific context. This suggests that a study that synthesises and analyses case studies, best practices, and LCA of biowaste management is vital to be conducted.

Given the aforementioned importance, many review studies have reviewed the application of LCA for waste management, mostly MSW management in general rather than with a specific focus on biowaste management. Nevertheless, these review studies still provide valuable insights that suit their objectives and scopes. For example, Gentil et al. (2010) review nine modelling tools for LCAs of MSW and Othman et al. (2013) criticise LCAs of integrated solid waste management in some Asian countries. These studies have limitations since the sample sizes are small, leading to findings not comprehensively representing all currently applied methods and identifying the best practices in biowaste management. Other studies with larger samples, such as 222 LCA studies (Laurent, Bakas, et al., 2014; Laurent, Clavreul, et al., 2014) and 153 LCA studies (Khandelwal et al., 2019), also focus on MSW management rather than biowaste and either do not assess the best treatment approach and/or strategy or might be subject to biassed and misleading judgement (Iqbal, Liu, et al., 2020). Iqbal et al. (2020) review 79 LCA studies of MSW management to identify best practices, yet the focal point is not biowaste management, and the selection of the sample is restricted to the timeframe from 2010 to 2020, which may eliminate relevant papers, affecting the accuracy of findings. In terms of biowaste, Bernstad and Jansen (2012) have reviewed 25 studies on LCA for food waste management, yet most of them consider the context of high-income nations. Recently, Batool et al. (2024) conduct a critical review of LCAs for food waste management, yet the sample selection did not rely on a systematic approach with a restriction on the timeframe from 2005 to 2023, which may limit the sample size. This study also does not properly identify the best practices for managing food waste. Furthermore, given that biowaste is not only food waste (Alves et al., 2024), the management of biowaste might differ from that of food waste. Therefore, these studies still have limitations that need to be addressed in the present study.

In this context, this study applies a combination of bibliometric and systematic literature review to (1) review the state-of-the-art of research on LCA in biowaste management, (2) synthesise the case studies of biowaste management, and (3) identify and evaluate the best biowaste management practices. As such, this study can contribute to the body of knowledge for research on LCA for biowaste management. This study aims also to assist scholars, practitioners, and decision-makers in selecting a suitable model for minimising environmental impacts and maximising benefits from the management of biowaste, contributing to sustainable urban development, and transitioning to a CE.

Methods

To carry out the research, this study combines qualitative and quantitative research approaches, comprising bibliometric, systematic, and content analysis. The first approach can be applied to evaluate and measure metadata of published documents like affiliations, authorships, etc., or to demonstrate the interrelationships between published documents and a particular research field (De Bellis, 2009; Fetscherin and Usunier, 2012). The bibliometric method can also be used to evaluate, characterise, and track the evolution of a particular topic or to do meta-analyses in order to find the fundamental concepts and theoretical basis of a field of research (Fetscherin and Heinrich, 2015). Meanwhile, the second research approach, the systematic method, can assist in providing structured examinations of the extant literature to shed light on specific questions, synthesise the most valuable evidence, and widely communicate the results (Zumsteg et al., 2012). Finally, the last approach can help to deep dive into study constructs and their correlations (Homrich et al., 2018). Therefore, this method can allow the identification of current approaches adopted for managing biowaste in practice and discussed in the literature, as well as the identification of the best practices in biowaste management. Moreover, this study is carried out following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (Page et al., 2021) and FLAVIA-LCT - Framework for systematic literature review to analyse vast InformAtion in life cycle thinking studies (Gulotta et al., 2023) to ensure the transparency, robustness, and consistency of the results. The search methodology of this study includes three steps, as presented in Figure 1.

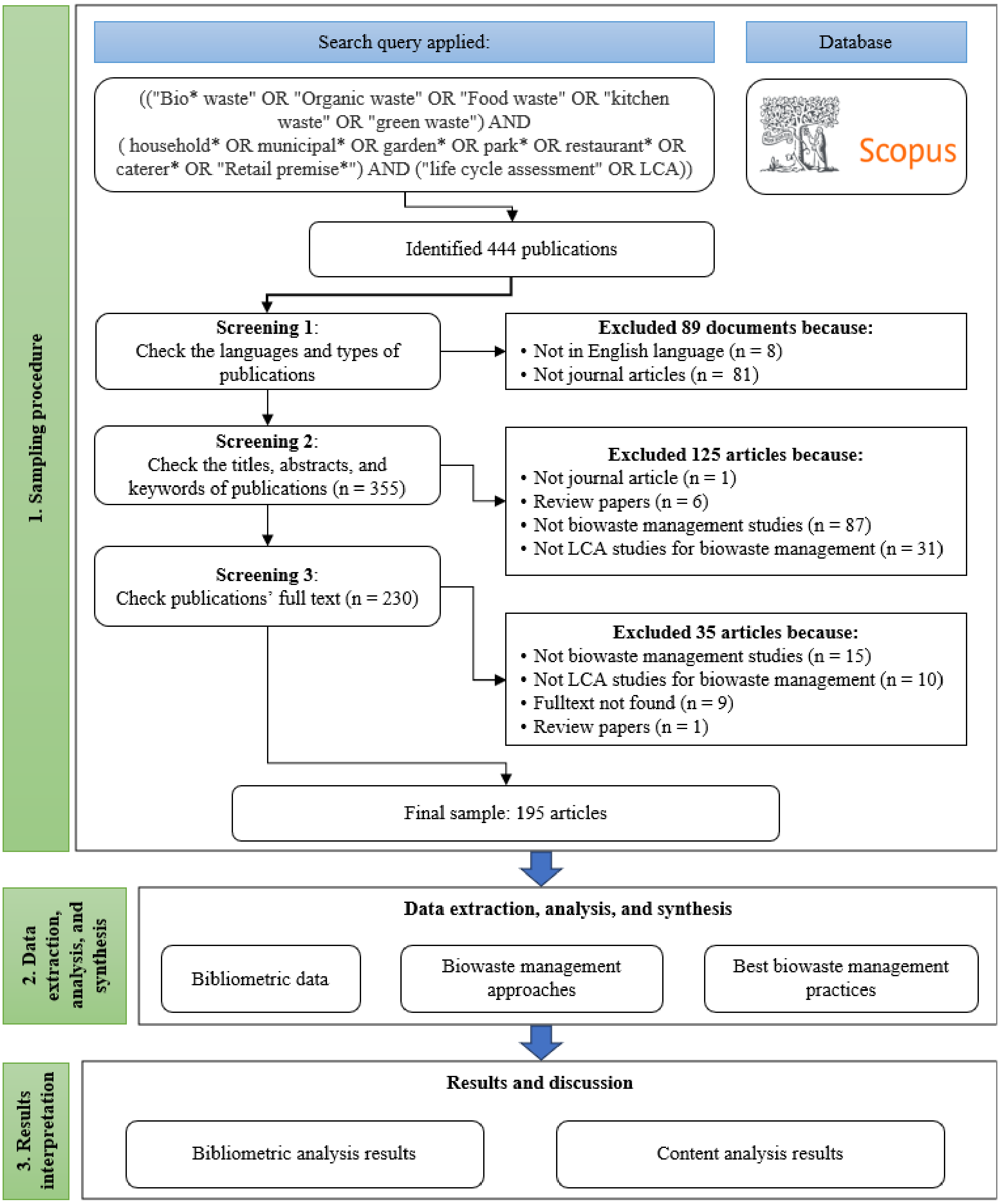


***Figure 1**. Research methodology.*

Sampling procedure

The sampling procedure starts with the selection of the scientific database as well as forming and applying the search query to identify relevant publications to include in the review. In this study, related publications are identified from the Scopus database by applying the search query as presented in Figure 1. This search query is formed based on the definition of biowaste in the European Union's Directive 2008/98/EC (Alves et al., 2024). With this query, technically, all papers related to LCA for the management of biowaste can be identified.

The search was conducted on May 24th, 2024, with no filters related to languages, publication types, or the time frame, retrieving 444 publications. These publications were first screened to eliminate ones that were not written in English (n = 8) and not journal articles, i.e., conference papers, books, book chapters, etc. (n = 81). This means that 89 publications were eliminated from the first screening step. In the next step, the remaining 355 articles were carefully screened through their titles, abstracts, and keywords to exclude those that were not journal articles (n = 1), review articles (n = 6), irrelevant to the management of biowaste (n = 87), and not LCA for biowaste management practice (n = 31). In other words, 125 publications were eliminated after this screening. In the last round, the remaining 230 articles were screened through their full texts using the eligibility criteria: "The paper conducted LCA for biowaste management practices, i.e., regarding separation, collection, and treatment of biowaste". It should be mentioned that this study also takes papers focused on municipal solid waste management in general into consideration if they propose scenarios to deal with the organic fraction. This is to identify the best scenario regarding the practice. Due to nine articles not being accessible, the full text of 221 documents was screened to eliminate one review paper, 15 not focused on biowaste management, and 10 not LCA studies. Therefore, 195 articles were included in the final sample.

Data extraction, analysis and synthesis

To carry out this study, firstly, metadata, including abstracts, references, citation indexes, authors, institutions, countries, etc. (Carvalho et al., 2013), is extracted from the Scopus database to be used for bibliometric analysis. These data sets are then managed and analysed using tools like VOSviewer, Microsoft Excel tools, and the Biblioshiny R application. Indeed, the PivotTable function of Microsoft Excel is used to extract data from the metadata to visualise the evolution of the research topic and the source-based distribution of the collected articles. Meanwhile, the VOSviewer tool is applied to visualise bibliometric networks to illustrate the co-occurrence of keywords (Cobo et al., 2012). It should be noted that because keyword data in Scopus may not always be consistently harmonised, it is vital to prepare a thesaurus file to combine keywords with the same meaning (Van Eck and Waltman, 2021). Finally, the Biblioshiny R application is employed to develop maps to demonstrate the scientific production countries according to the authors' information.

Secondly, data regarding case studies, current approaches adopted for managing biowaste in practice, and insights from LCA studies to assess the potential environmental impacts associated with different biowaste management practices are gathered, synthesised, and managed using Microsoft Excel software through deep content analysis.

Results Reporting

This study's results are presented in two macro-categories: a) Bibliometric analysis, and b) Content analysis. Relevant subsections are hence organised to disseminate the findings accordingly.

Results and Discussion

Bibliometric analysis

Evolution of the research on life cycle assessment of biowaste management

The evolution of the research topic on life cycle assessment of biowaste management is illustrated in Figure 2. It can be seen that, before 1999, the concept of conducting LCA for biowaste management practices had not drawn much attention from scholars since no publication before that year could be found in the Scopus database. In 1999, two publications published by Björklund et al. (1999a) and Björklund et al. (1999b) were the first to document the idea of conducting LCA for biowaste management practices. From this year onwards, the number of papers gradually increased, reaching 10 in 2012 before decreasing dramatically to only two in 2014. The number of papers started to increase again, from 10 in 2015 to a peak of 22 in 2022. Generally, it can be concluded that this research topic started drawing much attention from researchers from 2015 onwards, as nearly four-fifths of the sample has been published since then.

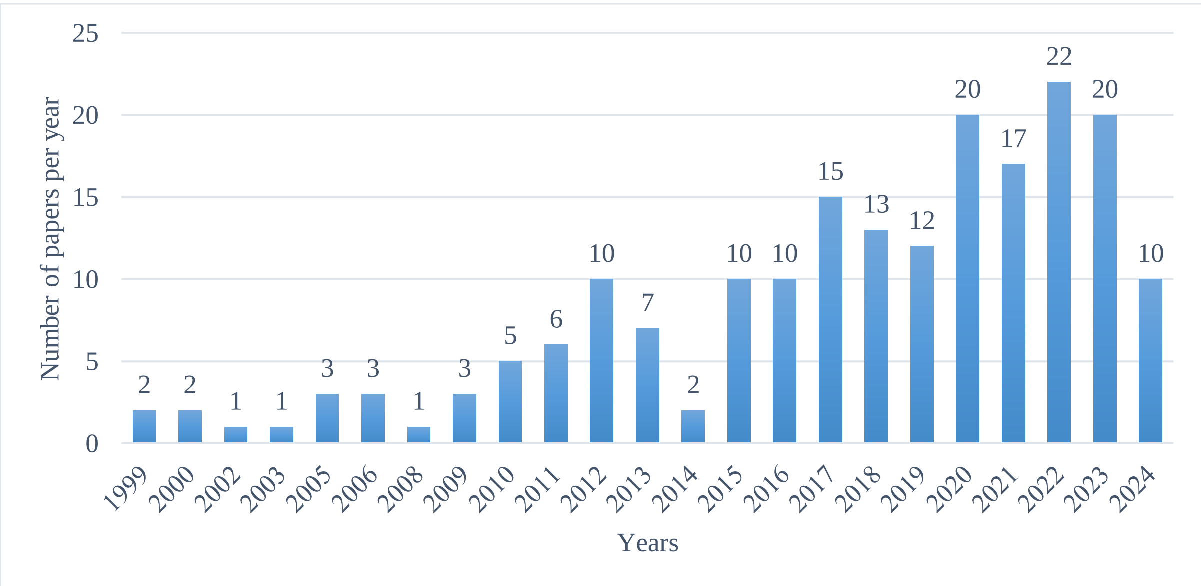


***Figure 2**. Year-base graph of literature.*

Source-based analysis

The source-based analysis of the collected sample is presented in Figure 3. Generally, a total of 195 inventoried articles have been published in 51 different journals. Among them, "Waste Management" is the most productive journal, having published 31 articles. It is closely followed by the "Journal of Cleaner Production", with 28 documents. The "Resouces, Conservation, and Recycling" journal is the third productive source with

18 papers, while "Science of the Total Environment" and "Waste Management and Research" journals are placed fourth and fifth with 11 articles for each. Only these five journals have published more than half of the collected sample (n = 99). The top ten most productive journals are visualised and presented in Figure 3.

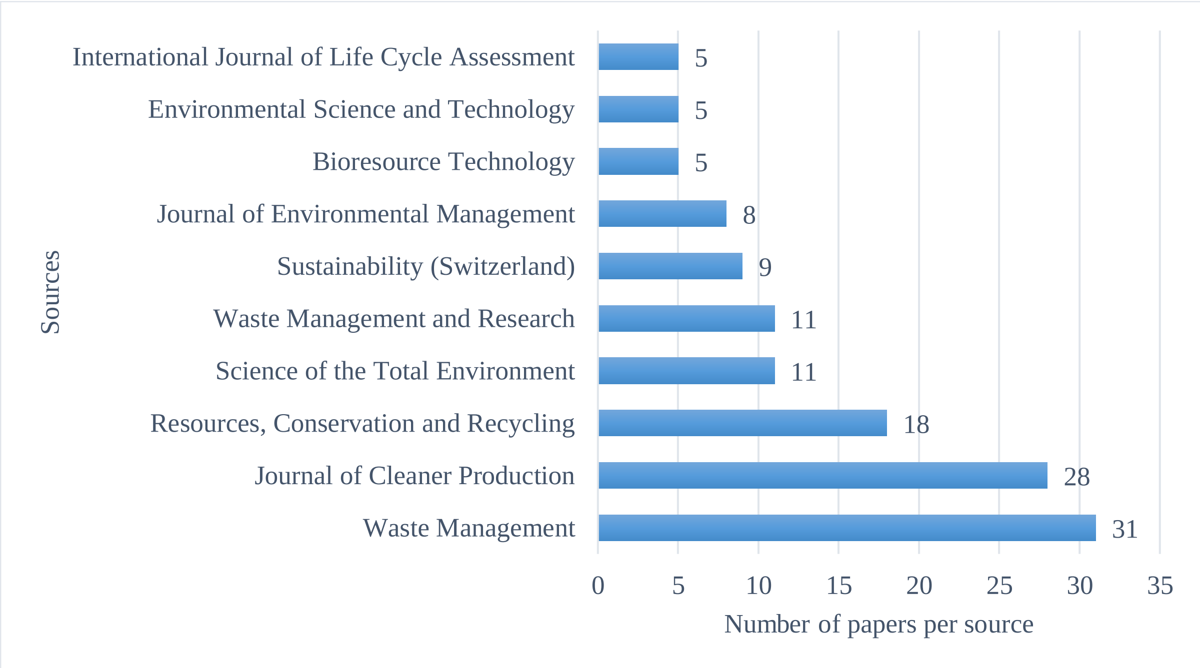


Figure 3. *Top ten most contributed sources.*

Co-occurrence network analysis

The relationship between the most frequent authors' keywords is visualised by the VOSviewer tool. In order to do that, a thesaurus file that combines keywords with the same meaning is prepared and presented in the appendix (Table A1). For instance, "global warming", "global warming potential", "greenhouse effect", "greenhouse gas", and "greenhouse gases" have been replaced by a single keyword "climate change". Likewise, "environmental assessment", "environmental impact", and "environmental performance" are replaced by "environmental impact assessment".

From the 195 collected papers, there are a total of 105 author keywords with at least two occurrences, which are then declined to 68 after applying the thesaurus file. The occurrence map of these keywords is illustrated in Figure 4. In this map, the correlation's strength among the keywords is indicated by the lines' thickness, which is determined by considering the number of papers in which the two keywords occurred together. The shorter distances between nodes imply a closer correlation between them, demonstrating their interrelationship and the similarity in their themes.

The most frequently occurring keyword is "life cycle assessment" (n = 143), which is more than triple the second most frequently occurring one, "anaerobic digestion" (n = 47). These are followed by "food waste" (n = 43), "composting" (n = 42), "biowaste" (n = 36), and "municipal waste solid waste management" (n = 35). These findings suggest that "anaerobic digestion" and "composting" are the most popular techniques that are applied in biowaste management practice. Meanwhile, "food waste" is the most popular focal point of the previous studies, closely followed by "biowaste", i.e., "organic fraction of municipal waste", which accounts for more than one-third of the municipal solid waste generated (Alves et al., 2024). This is also the reason why "municipal solid waste management" is also one of the most researched subjects in the collected sample.

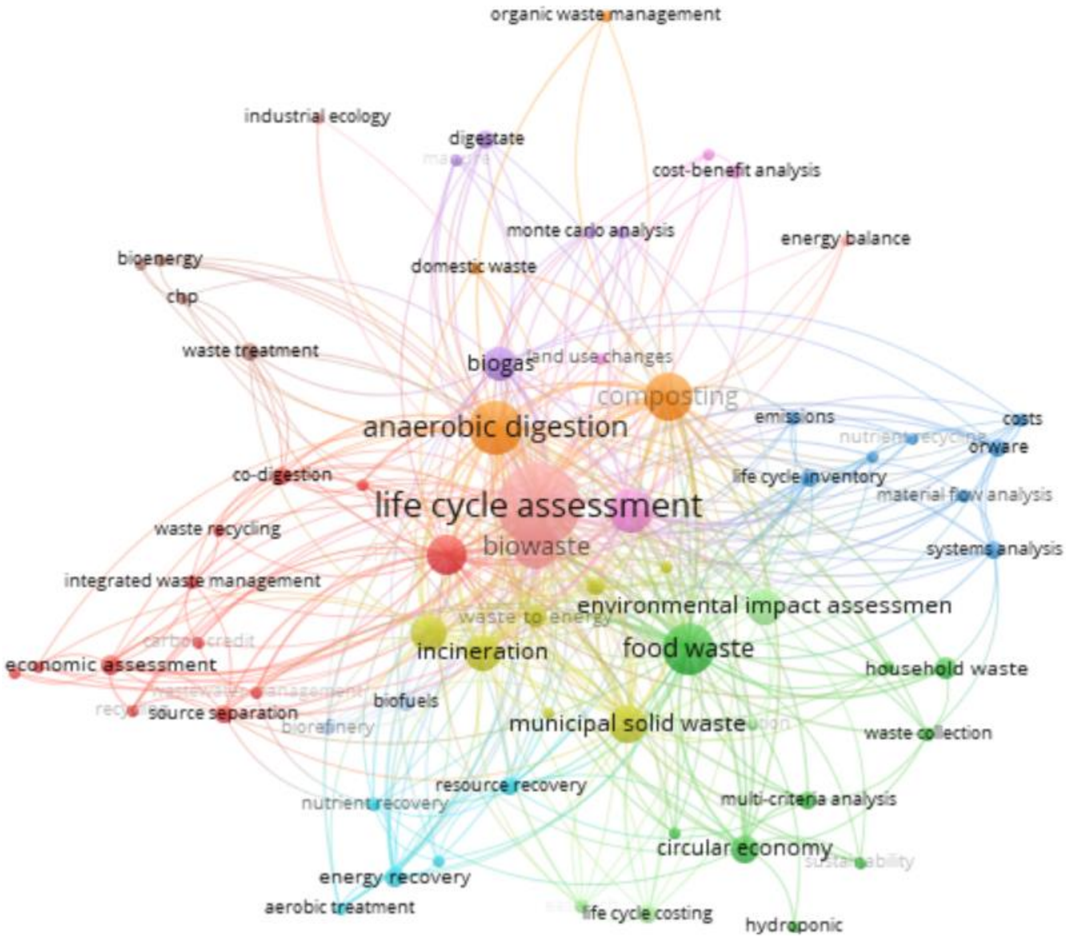


Figure 4. *The co-occurrence map of the authors' keywords.*

Geographical distribution

The geographical distribution of the collected sample is analysed and visualised by the Biblioshiny R application based on the contributing authors' affiliation information. The results are illustrated in a heat map, as shown in Figure 5. The contribution of each country is presented via a colour scale from light blue to deep blue, corresponding with the range from lowest to highest contribution. In other words, the deeper blue one country is, the higher the contribution of authors from this country is. It can be seen that China is the most productive country since Chinese authors contributed 117 papers, which is nearly one and a half times higher than the second most productive countries, Denmark and the USA, with 79 papers for each. Italy is named the fourth most scientifically productive country with 68 papers, followed by Sweden (n = 57), the UK (n = 43), Spain (n = 36), Australia (n = 35), etc. Overall, this geographical distribution highlights that the research on LCA for biowaste management practice has drawn attention from scholars worldwide. However, developed countries are more productive than countries in the Global South, except in the case of China.

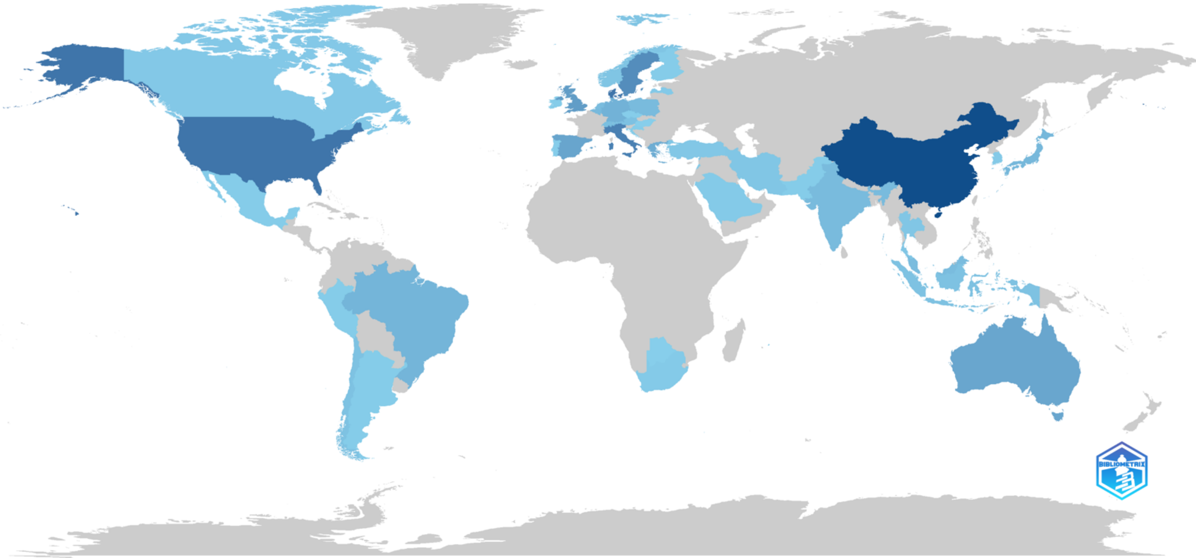


Figure 5. *Geographical distribution of the collected sample.*

Content analysis

Current biowaste management methods

Generally, biowaste management methods are diversified. However, they are grouped into 12 categories, as shown in Figure 6. It can be seen that AD and composting are the most dominant among these methods. Indeed, while AD is analysed in 119 articles, composting is reported in 87 publications. These two methods are also integrated and applied in 24 papers, such as Colón et al. (2015), Le Pera et al. (2022), etc. These findings confirm the argument in the bibliometric analysis that most of the collected studies focus on using the LCA tool to evaluate the environmental sustainability of these two methods. They are followed by mixed treatment of biowaste with municipal solid waste, like incineration (n = 80) and landfilling (n = 77) techniques. These four techniques are dominant over other methods like biorefinery-based production of materials and fuels (n = 18), mechanical-biological treatment (n = 11), bioconversion by insects (n = 6), food waste disposers (n = 6), open dumping (n = 4), hydrothermal carbonisation (n = 4), and odour control technologies (n = 1).

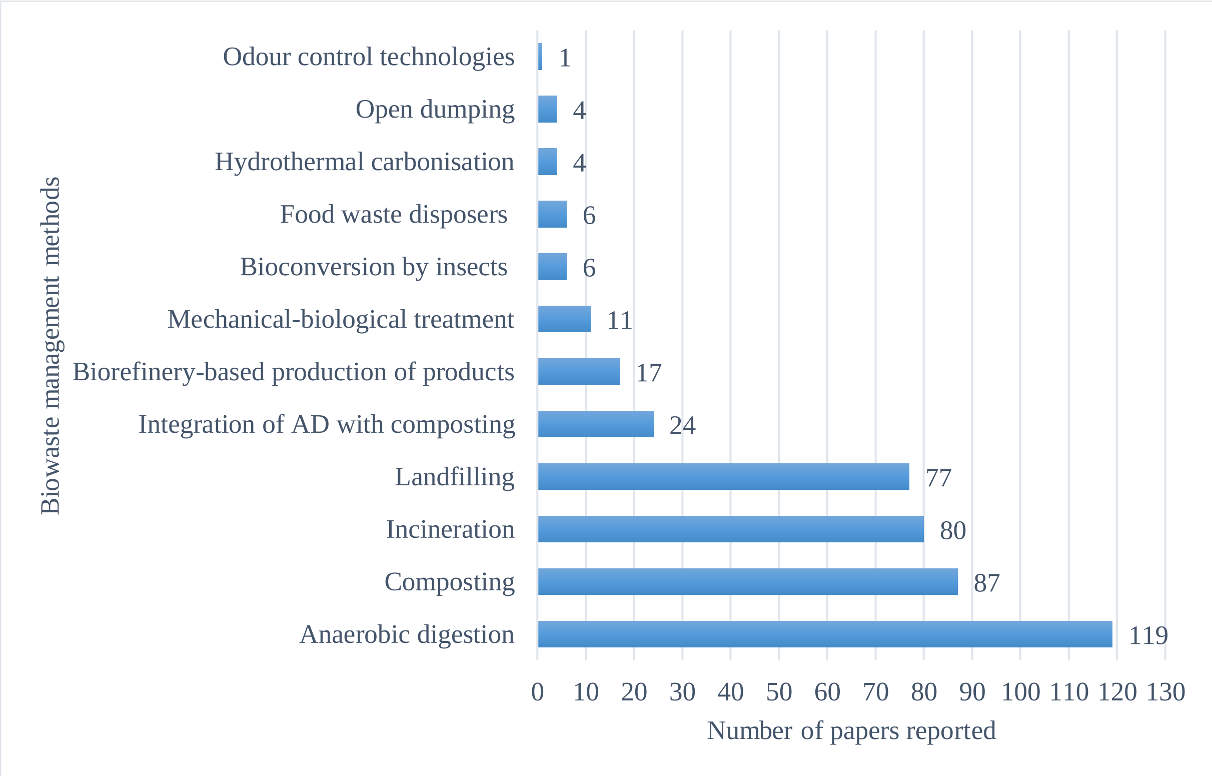


Figure 6. *Categorisation of the current applied biowaste management methods.*

a. Anearobic digestion

The anaerobic digestion and composting methods can be categorised into centralised (i.e., large and industrial scale) and decentralised (i.e., home, on-site, and local facility with short transportation distance), depending on the scales of the treatment facilities. Previous studies highlight that decentralised, i.e., smaller localised AD, should have a capacity of less than 3,000 tonnes per year (Rapport et al., 2008; Righi et al., 2013). Therefore, for the collected papers that do not specify the scale of AD, this study categorises them according to the capacity of treatment plants, as presented in the Supplementary Material (Table S1). The results indicate that the centralised approach draws more attention from scholars than decentralised approaches.

The specific techniques of AD in the collected articles are diversified. They could be wet and dry AD (Shi et al., 2024), conventional AD, i.e., a wet continuous stirred-tank reactor, or an anaerobic membrane bioreactor (Nyitrai et al., 2023). Furthermore, the AD technique could be mono-digestion (Karolinczak et al., 2024) or co-digestion of biowaste with sewage sludge (Iqbal, Ekama, et al., 2020; Karolinczak et al., 2024), one-phase, or two-phase AD (Nyitrai et al., 2023). Despite the difference in the specific techniques, the outcome products of all AD systems comprise biogas, which can be used to generate electricity and/or heat (Khoshnevisan et al., 2018) or upgraded to become biofuels (Shinde et al., 2021), and digestate, which can be used as a chemical fertiliser replacement (Nyitrai et al., 2023) or as landfill cover material (Mertenat et al., 2019).

b. Composting

Similar to AD, composting is also categorised into centralised and decentralised based on the compost capacities. According to Xiao et al. (2023), centralised compost has a capacity of at least 15, usually greater than 100 tonnes per day. Therefore, this study categorises those with a capacity of less than 15 tonnes per day as decentralised composting. The results indicate that the centralised treatment of either AD or composting draws more attention from scholars than decentralised approaches.

It is highlighted that the decentralised approach is referred to as on-site composting (Yeo et al., 2019; Zou and Zhang, 2022), on-site bio-processors (Maalouf and El-Fadel, 2018; Xiao et al., 2023), home composting (Inghels et al., 2019; Yoshida et al., 2012), bin composting (Arshad et al., 2023; Edelmann et al., 2000), local composting (Mathioudakis et al., 2022), or community composting (De Boni et al., 2022; Keng et al., 2020). Among them, community composting (De Boni et al., 2022), i.e., community-scale composting (Keng et al., 2020), is one of the emerging approaches, which can be understood as composting at the community scale and is a bottom-up, participatory process that involves community members. From the very beginning of the design process, local stakeholders and citizens are involved in a variety of activities. These include community drop-off networks, waste collection, and composting services provided by farmers and entrepreneurs within specific neighbourhoods; training and demonstration activities; system performance presentations; and discussions of the obtained outcomes. All of these initiatives involve local authorities and individuals, raising their awareness of the benefits that community composting offers (De Boni et al., 2022).

Regarding the specific techniques, composting can be carried out open, closed, partly closed, or covered with a semipermeable membrane (Lewerenz et al., 2023). This also could be windrow composting (Boldrin et al., 2011; Wang et al., 2020), aerated static piles composting (Kong et al., 2012), tunnel composting (Boldrin et al., 2011; Thyberg and Tonjes, 2017), in-vessel composting (Diggelman and Ham, 2003; Slorach et al., 2020a, 2020b), outdoor composting (Nordahl et al., 2020), faeces composting (Q. Wang et al., 2023), vertical composting (Butler and Hooper, 2010), or vermicomposting (Arfelli et al., 2023; Pandyaswargo et al., 2012; Thao et al., 2022). However, the outcome product for all of these composting techniques is compost, which can be used to offset mineral fertiliser (Abeliotis et al., 2015; Lundie and Peters, 2005; Matsuda et al., 2012; Triyono, 2022).

c. Incineration and landfilling

Incineration and landfilling are the methods for the mixed treatment of biowaste with other fractions of MSW not only in developing countries (Triyono, 2022; Q. Wang et al., 2023) but also in developed countries like the UK (Lévesque et al., 2023), Greece (Koroneos and Nanaki, 2012), etc. Both methods can be applied under a waste-to-energy umbrella, yet incineration is more favourable for this purpose than landfilling. Indeed, 85% of the 80 case studies refer to the energy recovery (e.g., electricity and/or heat) from the mixed incineration of biowaste with other fractions of MSW. On the other hand, only 40 landfilling cases refer to recovering energy, such as electricity and/or heat (Xiao et al., 2023), while up to 44 cases are landfilling without energy recovery. Regarding the approaches, landfilling can be in unsanitary or sanitary ways (Xiao et al., 2023).

d. Biorefinery-based production of materials and fuels

Regarding biorefinery-based production of materials and fuels, biowaste can be a valuable source to produce different types of products and fuels. For example, sea urchin waste can be converted into calcium supplements for laying hens with profound benefits (Zilia et al., 2023). Similarly, food waste is fed to produce poultry feed and liquid fertiliser (Sarkar et al., 2023; Siddiqui et al., 2021), etc. The type of waste and outcome products from the biorefinery-based production are shown in Table 1.

Table 1. Biorefinery-based production of materials and fuels from biowaste.

Terms used in the collected papers	Outcome products	Reference
Biowaste	Short chain carboxylic acid	Lizasoain-Arteaga et al. (2024)
Sea urchin waste	Calcium supplement for laying hens	Zilia et al. (2023)
Food waste	Chicken feed and liquid fertiliser	Siddiqui et al. (2021)
Food waste	Poultry feed and liquid fertiliser	Sarkar et al. (2023)
Food waste	n-caproic acid	Wang et al. (2024)
Food waste	Biofuels	Angili et al. (2022)
Wet waste biomass	Drop-in fuel	Lilonfe et al. (2024)
Food waste	Heterotrophic algae powder	Pahmeyer et al. (2022)
Surplus bread	Animal feed, beer, and ethanol	Brancoli et al. (2020)
Organic waste	Ethylene	Nuss et al. (2013)
Food waste	Ammonia	Ghavam et al. (2021)
Food waste	Bioplastic	Bassi et al. (2021)
Food waste	Oil/diesel, biomethane	Zhao et al. (2022)
Organic waste	Caproic Acid	Chen et al. (2017)
Biowaste	Ethanol	Papadaskalopoulou et al. (2019)
Biowaste	Butanol and ethanol	Meng et al. (2019)
Kitchen waste	Biodiesel or epoxy methyl ester	Z. Wang et al. (2023)

e. Hydrothermal carbonisation and mechanical-biological treatment

Hydrothermal carbonisation (HTC) is a technology relying on a thermo-chemical process where a reactor is used to convert biomass into a solid with a richer quantity of carbon (Perez et al., 2022). This method is applied in four studies, including Mathioudakis et al. (2022), Thao et al. (2022), Perez et al. (2022), and Owsianiak et al. (2016). Whereas, mechanical-biological treatment is an approach to refuse-derived fuel from biowaste before landfilling (Boer et al., 2021). Refuse-derived fuel can then be used to generate electricity (Kumar & Samadder, 2022) or heat in cement kilns (Guven et al., 2019). These are two of the waste-to-energy technologies with greater projections due to their operative advantages, especially hydrothermal carbonisation (Perez et al., 2022). The type of waste and outcome products from the mechanical-biological treatment and/or hydrothermal carbonisation are presented in Table 2.

Table 2. Mechanical-biological treatment and/or Hydrothermal carbonisation of biowaste.

Terms used in the collected papers	Outcome products	Reference
Biowaste	Biomass pelleting	Mathioudakis et al. (2022), Thao et al. (2022)
Biowaste	High-energy biochars	Thao et al. (2022)
Organic waste	HTC pellets	Perez et al. (2022)
Biomass waste	Hydrochar pellets	Owsianiak et al. (2016)
Organic waste	Dry char	Mayer et al. (2021)
Biowaste	Refuse-derived fuel	Boldrin et al. (2011), Grzesik and Malinowski (2016)
Food waste	Refuse-derived fuel	Edwards et al. (2018), Guven et al. (2019), Jensen et al. (2016)
Food waste	High caloric (coarse) fraction	Boer et al. (2021), Tonini et al. (2020)
Organic waste	Refuse-derived fuel	Di Maria and Micale (2015), Liikanen et al. (2018)
Organic fraction	Refuse-derived fuel	Burnley et al. (2012)

f. Bioconversion by insects and other methods

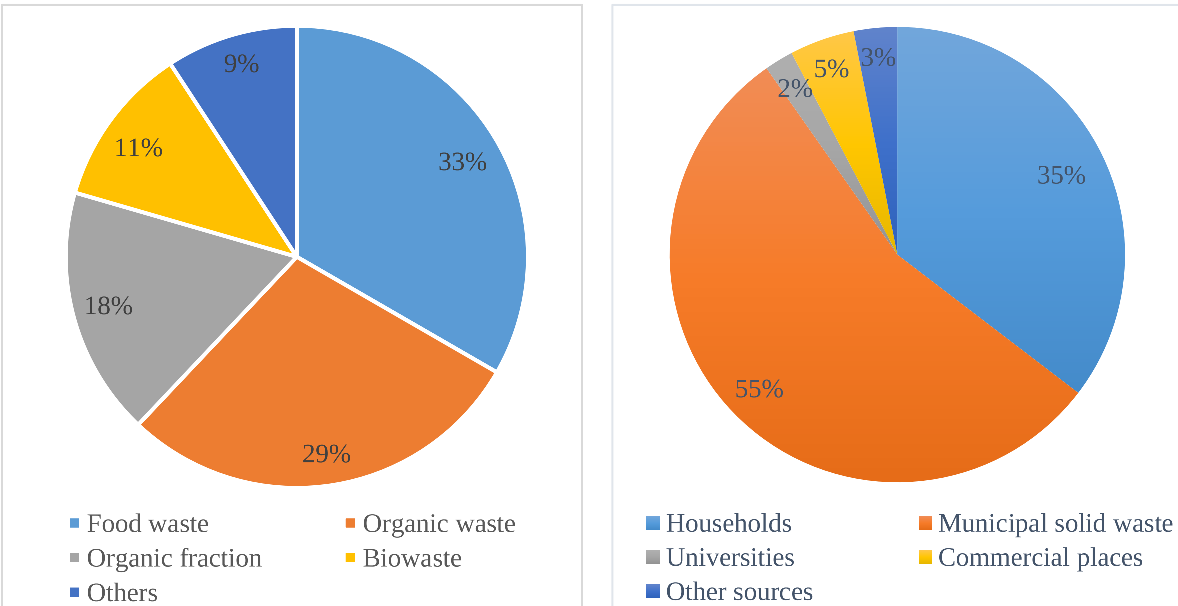
Insect-based bioconversion is a promising approach to managing biowaste, especially food waste. In the collected sample, six papers, such as Mertenat et al. (2019), Ferronato et al. (2024), etc., refer to using black soldier flies for the bioconversion of biowaste. This technique presents a promising alternative to traditional composting methods, such as vermi-, windrow, and bin composting, which are space-intensive and time-consuming (Arshad et al., 2023). Furthermore, this technique can bring profound benefits from producing high-quality compost and other by-products, such as dried larvae and black soldier flies. While larvae manure can be used as a perfect replacement for commercial fertiliser, dried larvae can be employed to produce fishmeal (Arshad et al., 2023; Mondello et al., 2017; Salomone et al., 2017). Meanwhile, black soldier flies that die during cultivation can be used as poultry feed (Kusumaningtiar et al., 2023).

Other six papers, such as Bernstad Saraiva et al. (2016), Diggelman and Ham (2003), etc., analyse the life cycle environmental impact of a system for food waste disposers in kitchen sinks. This is a technique for the separate collection of food waste from households into tanks, which are then transported to treatment facilities and commonly treated by AD. The other four papers mention open dumping as a method of managing biowaste (Cheela et al., 2021; Vázquez-Rowe et al., 2021; Wongsoonthornchai and Thitanuwat, 2024; Xiao et al., 2023). Despite its severe environmental impacts, this method is still being applied in developing countries, such as India, as it is the cheapest method (Cheela et al., 2021). Finally, only one study by Bindra et al. (2015) analyses the environmental sustainability of organic processing odour control technologies, which is one of the biggest concerns of composting facilities.

Types, composition, and sources of waste

Regarding the types of waste, as presented in Figure 7a, most of the collected papers refer to the management of food waste (n = 65, accounting for 33% of the collected sample), followed closely by organic waste (n = 56, 29% of the sample) and the organic fraction of municipal solid waste (n = 34, 17% of the collected papers). They are followed by biowaste (n = 22) and other types of waste (n = 18), such as kitchen waste (n = 5), wet waste (n = 2), etc.

It is highlighted that although different terms are used in the collected studies to refer to biowaste management, the composition of these types is quite similar. Indeed, the main compositions of either biowaste (Bernstad Saraiva et al., 2017; Lewerenz et al., 2023), organic waste (Tominac et al., 2020), or organic fraction of MSW (Mayer et al., 2021; Pandyaswargo et al., 2012; Rotthong et al., 2022; Yoshida et al., 2012) are food and garden/yard waste. Of course, there are several cases where the compositions of these types of waste are slightly different. For example, Kong et al. (2012) state that organic waste comprises food waste, green waste, textiles, and, to a much lesser extent, biosolids and other organic components, while Nhubu et al. (2019) consider biodegradable waste as kitchen and/or garden and park waste. Furthermore, it should be highlighted that although both Lilonfe et al. (2024) and Zou and Zhang (2022) focus on wet waste management, the waste compositions in these studies are different. Indeed, while the former mentions that wet waste biomass comprises food wastes, digestate, sewage sludge, landfilled biogenic municipal waste, and manure (Lilonfe et al., 2024), the latter defines wet waste as "food waste, leftovers, expired food, melon peel and fruit stone, flowers and plants, Chinese medicine residue, and other perishable household waste" (Zou and Zhang, 2022).



a. *Terms used to refer to waste types.*

b. *Sources of waste.*

Figure 7. *Types and sources of waste (percentage allocation).*

Concerning the sources of waste, as shown in Figure 7b, 55% of waste studied in the collected sample is sourced from MSW, followed by households (35%). These two sources of waste are much more popular than the third source, i.e., commercial places, such as restaurants (Lévesque et al., 2023; Soleymani Angili et al., 2022); service cafés, clubs, bakeries, supermarkets, and restaurants (Sarkar et al., 2023); supermarkets (Brancoli et al., 2017), etc.

Best biowaste management practices

In order to identify the best biowaste management practices, this study relies on results from LCA studies. Bearing in mind that it is not possible to compare results of LCA studies that do not have the same methodological choices and modelling characteristics (e.g., functional unit, system boundaries, quality of inventory data, impact assessment methods, etc.), the analysis here reported is limited to highlight the main findings emerging from the collected sample regarding the best practices on biowaste management.

Among the different waste management methods reported in the collected sample, open dumping and unsanitary landfills are the worst approaches. Indeed, these two approaches have the highest normalised environmental impacts compared to other methods like sanitary landfilling and incineration with energy recovery, composting, and AD (Cheela et al., 2021; Xiao et al., 2023). Because of this, these two approaches are banned in many countries (Colón et al., 2015), including developing ones like China (Xiao et al., 2023). The same result can be observed in the case of incineration without energy recovery since it also has high environmental impacts, especially in terms of climate change, but to a lesser extent compared to landfilling (Bilgili et al., 2022; De Boni et al., 2022). Therefore, these methods are not recommended for managing biowaste.

In comparison with the aforementioned methods, sanitary landfill- and incineration-electricity-produced approaches bring better environmental sustainability (Cherubini et al., 2009; Gunamantha & Sarto, 2012). This is because the electricity and heat produced by these technologies can offset the impact of energy consumption during the treatment process (Boldrin et al., 2011). However, can these technologies compete with other technologies like composting and AD? According to Xiao et al. (2023), these technologies have far higher impacts than centralised compost and AD in the case of Shanghai, China. Likewise, electricity-produced incineration has higher environmental impacts than AD in the case of Kyoto, Japan (Matsuda et al., 2012). The same results can be observed when comparing landfilling with energy recovery to windrow composting, aerated static pile composting, and AD in the case of California, USA (Kong et al., 2012). However, it has to be highlighted that in another case, although it has a higher climate change impact, the energy efficiency of the incineration process is slightly higher than that of anaerobic digestion (de Sadeleer et al., 2020). Despite this, landfilling and incineration with energy recovery should be less prioritised than composting and AD.

Which technology, between composting and AD, is better? Answering this question is crucial to assisting practitioners and decision-makers in selecting a suitable model. Generally, LCA results show that AD, in many cases, brings better environmental sustainability than composting. For example, Chen et al. (2020) suggest that AD should be prioritised in the treatment of food waste since its net emissions are lower than aerobic composting. The same findings are reported in other studies, such as Wang et al. (2023), Nhubu et al. (2019), Slorach et al. (2020b), etc. Likewise, Tonini et al. (2020) prove the environmental sustainability benefits of AD over either home or centralised composting. This is also consistent with findings from Björklund et al. (1999b) that AD of biowaste can reduce net environmental impact, while large-scale composting either reduces less impact or even increases environmental impact than AD. The environmental impacts of this method can even be far reduced with the application of a two-phase anaerobic digestion system since this system is reported to maximise energy recovery and reduce climate change and other environmental impacts compared to composting, anaerobic membrane bioreactors, and conventional AD, i.e., wet continuous stirred-tank reactors (Nyitrai et al., 2023). However, in another case, this technology is found to have slightly higher environmental impacts than composting, especially in terms of climate change, ecosystem quality, and fossil and nuclear energy use (Lévesque et al., 2023). This may suggest that the environmental performance of each technology differs from case to case. Despite that, AD seems to be a better solution than composting. Furthermore, it should be mentioned that the integration of these technologies, i.e., AD first and followed by composting of AD digestate, may present a promising solution to exploit the benefits from both of these methods. Indeed, this approach is reported to be better than directly composting biowaste (Le Pera et al., 2022; Mancini et al., 2019) or only AD (Mancini et al., 2019; Righi et al., 2013). This is because such integration can exploit benefits from energy savings from combined heat and power units as well as energy savings and nutrient recovery from the compost of the digested matter (Righi et al., 2013). Therefore, this solution should be recommended for use in biowaste management.

However, as reported, both composting and AD can be applied on a large or small scale, i.e., centralised or decentralised. Therefore, it is significant to clarify which scale can yield better environmental sustainability. Of course, to shed light on this, a comprehensive comparison needs to be carried out. Within this study, some insights from LCA results regarding this aspect are reported. Lu et al. (2020) find that centralised windrow composting has better environmental performance than home composting. The same results are seen in the case of centralised anaerobic co-digestion of source-separated organic waste (Yoshida et al., 2012). On the other hand, Martinez-Blanco et al. (2010) find that, compared to home composting, industrial, i.e., centralised composting, has lower impacts on acidification, eutrophication, and climate change, yet higher in other categories like abiotic depletion, ozone layer depletion, photochemical oxidation, and cumulative energy demand. This may suggest that both scales have pros and cons, and the decision should be made based on the current facility status of the study region. Furthermore, it is worth noting that the challenges of centralised treatment methods are long-distance transportation and being highly dependent on biowaste feedstock. Due to these reasons, in Singapore, a centralised AD plant was closed down after just six years of being set up (Kua et al., 2022). In this context, obviously, a decentralised treatment mode is more suitable for biowaste management. The same results are observed in Italy, where the integration of anaerobic co-digestion of organic waste with sewage sludge in decentralised plants with composting yields many environmental benefits in small communities (Righi et al., 2013). Therefore, this approach should be highlighted to apply to managing biowaste, especially on a community scale.

Conclusions

Efficient biowaste management can not only mitigate environmental impacts, especially climate change but also yield benefits from valorising this waste. Given that biowaste is renewable, proper management of this waste can be a great contribution to achieving a CE. There is a growing interest among scholars and practitioners in conducting LCA for biowaste management practices to identify the best scenario. Due to the diversification of treatment methods and LCA scenarios, practitioners and decision-makers may be challenged to select a suitable model for biowaste management in practice, highlighting a need for research to analyse and identify case studies and best practices. Although there have been review studies done previously, they either focus on MSW or food waste management rather than biowaste, or the sample selection has limitations.

This study applies a systematic approach to review the state-of-the-art of LCA studies for biowaste management practice. A total of 195 journal articles have been identified from the Scopus database and analysed using a combination of bibliometric, systematic, and content analyses. From that thorough review, the bibliometric analysis results, case studies, and best practices are identified and discussed. Firstly, the bibliometric analysis results show that the topic related to LCA for biowaste management has drawn attention from scholars around the world, especially in China and developed countries, in recent years, and Waste Management is the most productive journal. Secondly, regarding case studies, AD and composting are the two most applied technologies to handle biowaste around the world because of the environmental benefits they offer. It is noted that the centralised treatment of either AD or composting draws more attention from scholars than decentralised approaches. Incineration and landfilling are the third and fourth most popular case studies in the collected sample, respectively. Regarding these two technologies, incineration to generate electricity and/or heat is more favourable than landfilling with energy recovery. Thirdly, considering the best practices, the integration of AD and composting should be considered in biowaste management because of their benefits. Technically, this combination first starts with the AD of biowaste, followed by the composting of AD digestate matter. Particularly when this combination is conducted in decentralised facilities, it can yield benefits from the reduction of long-distance transportation, the low energy needed for the treatment process, the potential to offset energy consumption by energy produced from the AD process, as well as energy and nutrient savings or recovery from the compost. Of course, to decide the scale of facilities, it is recommended that practitioners and decision-makers take into consideration the socio-economic and infrastructure conditions of the case areas. Additionally, the feedstock for the treatment facilities should be thoroughly investigated to ensure exploiting their maximum wattage, especially when considering setting up centralised plants.

Generally, the outcomes of this study can contribute to the body of knowledge in research on biowaste management. However, this study also has some limitations. Firstly, the collected papers focus only on journal articles written in English that are identified from only the Scopus database, which may limit the sample size. Future studies should consider articles from other scientific databases, such as the Web of Science and ScienceDirect. Secondly, the methodological issues and implications of the collected LCA studies have not been identified, analysed, and discussed in this study. Future research should take this limitation into account to support scholars and practitioners in conducting LCA for biowaste management.

Acknowledgement

This paper has been conducted with the support of the project "Reducing Emissions through WAste pRactices and new business moDels – Measuring Effects - REWARD-ME", code PE0000018, CUP J43C24000270002.

Appendix

Table A1. Thesaurus file.

label	**replace by**
article	
biofuel	biofuels
carbon dioxide	carbon
carbon footprint	climate change
environmental assessment	environmental impact assessment
environmental impact	environmental impact assessment
environmental performance	environmental impact assessment
food	food waste
gas emissions	climate change
global warming	climate change
global warming potential	climate change
greenhouse effect	climate change
greenhouse gas	climate change
greenhouse gases	climate change
land fill	landfilling
landfill	landfilling
lca	life cycle assessment
life cycle	life cycle assessment
life cycle analysis	life cycle assessment
life cycle assessment (lca)	life cycle assessment
methane	biogas
organic fraction of municipal solid wastes	organic waste
organic wastes	organic waste
priority journal	
solid waste	municipal solid waste
solid wastes	municipal solid waste
waste management	solid waste management

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Environmental impacts of soilless and in-soil strawberry cultivation: a comparative Life Cycle Assessment

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Abstract

The surging demand for strawberries necessitates sustainable cultivation practices that prioritize both yield and environmental stewardship. Soilless systems, offering an alternative to conventional in-soil methods, utilize inert or organic substrates (liquid or solid) to grow crops and deliver nutrients through dedicated solutions. However, concerns linger regarding their environmental sustainability due to potentially high energy demands and additional infrastructure requirements. Hence, this study proposes a comparative Life Cycle Assessment (LCA) to evaluate the environmental impacts of two cultivation systems: in-soil tunnels and greenhouse soilless. Primary data were collected from a Sicilian strawberry farm, located in Maletto (Italy). Secondary data were retrieved from scientific literature and databases. The CML I-A baseline method was chosen to assess the environmental burden associated with producing 1 kg of strawberries from each system. By pinpointing environmental hotspots within each system, the study aims to identify potential areas for improvement. This knowledge can empower strawberry growers and policymakers to make informed decisions regarding environmentally responsible cultivation practices, considering the unique advantages and disadvantages of both in-soil and soilless production methods.

Keywords: soilless, hydroponics, strawberries, environmental impact, LCA

Introduction

The global population is projected to reach 8.5 billion by 2050, placing pressure on the already strained agricultural systems. To meet the growing demand for food, agricultural production needs to be intensified (Economou et al., 2024) exacerbating its environmental impacts. Indeed, conventional agricultural practices are often associated with a range of environmental concerns, such as greenhouse gas emissions, deforestation and land degradation (Searchinger et al., 2018; Wimmerova et al., 2022). Among the many small fruits, strawberries are considered a leading fruit (Valiante et al., 2019), providing both economic and health benefits (Ilari et al., 2021). For example, strawberries production accounts up to €360 million, in Italy, and the demand for such fruits is expected to increase (Pergola et al., 2023). Nonetheless, strawberries are fragile, and their quality largely depends on many environmental factors (Warner et al., 2021), such as temperature (Khammayom et al., 2022), artificial light (Nadalini et al., 2017), fungi, viruses and bacteria (Abbas et al., 2021). However, a potential solution to these issues lies in Controlled Environment Agriculture (CEA), where crops' vital parameters are artificially monitored and optimized with minimum use of agrochemicals, water, and fertilizers (Casey et al., 2022). Soilless systems are one of the most prevalent forms of CEA. These systems replace soil with alternative growing mediums such as rock wool, coconut fibre, or perlite, but also immerging roots directly into water, while essential nutrients are delivered through a specifically designed nutrient solution (Fussy and Papenbrock, 2022). However, these systems, depending on the level of technology employed, can become complex and sophisticated (Payen et al., 2022), raising concerns about their environmental sustainability when compared to conventional farming (Rothwell et al., 2016). These shortcomings prompt the need for suitable methods to assess comprehensively their environmental sustainability (Armanda et al., 2019). Life Cycle Assessment (LCA) is widely used to assess the environmental impacts associated with all life cycle stages of a product or system. Its principles and framework are standardized in ISO 14040-14044:2006 (ISO,2006a; ISO 2006b). While the environmental impacts of conventional in-soil strawberry cultivation have been extensively studied across the globe (Galafton et al., 2023; Delahaye et al., 2023; Pergola et al., 2023; Valiante et al., 2019), while LCA studies on soilless strawberry production remains limited (Ilari et al., 2021; Romero-Gámez and Suárez-Rey, 2020). Existing studies often compare a narrow scope, such as tunnel in-soil vs. tunnel soilless (Ilari et al., 2021) or analyse a broader range of systems where only a few are soilless (Romero-Gámez and Suárez-Rey, 2020). While these studies provide valuable results, they highlight the need for further investigation into the environmental performance of soilless strawberry production compared to traditional in-soil methods. This research gap is particularly relevant because previous findings from scientific literature suggest contrasting environmental impacts, depending on the type of soilless system employed. For example, Romero-Gámez and Suárez-Rey (2020) found macro-tunnel soilless systems to have a lower environmental footprint per t of strawberries produced, compared to in-soil systems, attributing this to higher productivity and reduced resource use. However, Ilari et al. (2021) reported higher environmental impacts for tunnel soilless systems compared to in-soil tunnels, highlighting potential contributions from substrates, pesticides, and reliance on fossil fuels. These contrasting results likely stem from methodological differences, geographical variations (Southern Spain vs. Central Italy), and the specific research objectives of each study. In this regard, the study here presented aims to carry out a comparative LCA of two strawberry cultivation systems in unheated greenhouses, located in Maletto, in the province of Catania, Southern Italy. In particular, the first system is a multi-tunnel greenhouse (four tunnel in total) with mulched soil, while the second system employs a soilless growing medium in a double-span greenhouse. This comparison aims to shed light on the potential environmental benefits and drawbacks of each system, allowing growers and policymakers to make informed decisions regarding sustainable and environmentally friendly cultivation practices. After this introduction, the next section delves into the methodological choices employed for this comparative LCA. Subsequent sections present the results and discussions, followed by conclusive remarks.

Methods

The comparative analysis is performed using the LCA method (ISO, 2006a; ISO 2006b). In particular, two main goals are defined: i) to identify the most impactful processes among the two systems; and ii) to evaluate which system has the lower environmental loads. In this regard, a cradle-to-farm gate approach was chosen, encompassing all material and energy inputs and outputs associated with the strawberry production within the two cultivation systems. Hence, greenhouses' structure and irrigation system were not included, as well as the strawberries packaging processes and the post-harvest activities, such as transportation to market, but not transportation to the farm. A recent review by Licastro et al. (2024) on LCA studies of soilless systems indicated that the predominant functional unit is based on mass. Hence, the selected functional unit is represented by 1 kg of strawberries. Concerning the methods and models used to calculate the emissions to air, water, and soil, it should be noted that there is a lack of appropriate models fit to calculate the emissions caused using fertilizers and agrochemicals products in soilless crops (Llorach-Massana et al., 2017). This is due to the substantial difference in chemical and physical properties between soil and substrates. Nonetheless, in this study established methods and models for the computation of emission were used. For the soilless system, emissions to soil were excluded given the very nature of soilless cultivation. Emissions to air from synthetic fertilizers were calculated using methods outlined by IPCC (2006) and Zampori & Pant (2019). Similarly, emissions to air from active ingredients in agrochemicals were estimated using Zampori & Pant (2019) under the assumption that 9% of the applied compounds volatilize. Diesel use emissions were calculated following Nemecek & Kägi (2007). Water emissions from fertilizers were determined using IPCC (2006), Zampori & Pant (2019), and Prasuhn (2006). For emissions to water from agrochemicals, Zampori & Pant (2019) was adopted, under the assumption that 1% of the applied compound is emitted to water. In contrast, the in-soil system retains the potential for soil emissions from applied agrochemicals. Here, Zampori & Pant (2019) was used, assuming 90% of the applied compounds reach the soil. Emissions from heavy metals were not considered in this analysis. The inventory data were obtained through foreground and background sources. In particular, primary data were collected via direct interviews and questionnaires submitted to the company, and relevant data were then collected in Excel data sheets. The reference year of the reported data was 2023. Secondary data were obtained from Ecoinvent 3.8 database (Ecoinvent, 2024). Furthermore, whenever a particular process could not be found within the database, an 'unspecified' process in Ecoinvent was used. This pertained to certain active ingredients in agrochemicals and fertilizers. Alternatively, the substances were modelled based on a similar compound. Due to missing information regarding the end-of-life processes related to the plastics utilized in input packaging and mulch sheets, it was assumed that these waste plastics undergo recycling. In this regard, environmental impacts related to the recycling process are assumed to be attributed to the newly created products derived from this recycled plastic, following the "cut-off" approach (Shen et al., 2010). Moreover, wood crates used to transport plantings in both systems were included only as inputs in the transport to the farm. SimaPro software 9.3.0.3 (PRé Sustainability, 2024) was used to evaluate the environmental impacts of the systems and the impact assessment is calculated through CML-IA Baseline method (Guinée, 2002).

System Description

The two types of systems under analysis are implemented by a firm located in Maletto, Italy (37° 49.4974' N, 14° 50.6408' E). The first is an in-soil system, where crops are cultivated directly in the ground and covered with polyethylene (PE) mulch (120 x 1.5 m). This system comprises four tunnel greenhouses, each housing four rows of crops with walkways for workers in between, covering a total of 1920 m² with an effective cultivated area of 1096.32 m². Conversely, the second system is soilless, placed within a double-span greenhouse that accommodates fourteen rows in total, covers a lesser area of 1200 m² and an even smaller cultivated area of 210 m². Here, strawberries grow in polyethylene bags filled with coconut fibre, placed atop a channel gutter. The effective cultivated area should be considered as the area covered by the channel gutter where the growing bags are placed, excluding the walkways. Both greenhouses share commonalities in construction, utilizing Ethylene-vinyl acetate (EVA) for the roofing and walls, and galvanized steel for the structural framework, negating the need for heating. Despite the double-span greenhouse's smaller cultivated area and a lower plant count of 8400 versus 17300, it presents a superior yield of 1 kg per plant, doubling the 0.50 kg per plant of the in-soil system. Such efficiency is in line with previous literature (Romero-Gámez and Suárez-Rey 2020). Ground water is pumped from the local well and collected in tanks in a dedicated room, where there were also placed the fertilizers' tanks. In this room fertirrigators mixed water with all nutrients to compose the fertirrigated water, which is then delivered in both systems via drip irrigation. The channel gutter, upon which the substrate bags were placed, was composed by a polyvinyl chloride (PVC) semi-tubes and galvanized steel stakes. The fertirrigated water runs through the substrate bags and then it drains into the PVC gutter. Then the drained fertirrigated water is collected into buckets and then carried into groundwater.

Results and Discussion

This section firstly reports the analysis of the potential environmental impacts of soilless and in-soil strawberries cultivation, respectively. Then, the results of the comparative analysis between the two systems are provided. Finally, a discussion and conclusion paragraphs are provided as well.

Environmental Impacts of Soilless Strawberries

Figure 1 shows the characterization results of the soilless system under analysis. Impacts deriving from insecticides were relevant only in abiotic depletion category, accounting for 79.32%, followed by fertilizers (18.55%). Fertilizers, indeed, presented a broader influence, being a significant factor in various environmental impact categories. They contributed as little as 5.13% to Eutrophication and as much as 64.03% to Terrestrial Ecotoxicity, averaging 30.60% across all categories examined. Such impacts had to be attributed NPK (Nitrogen, Phosphorus, and Potassium) fertilizers production. It should be noted that due to the impossibility to find the correspondent process, specific for the fertilizers, a generic process was chosen. Given that the impact of fertilizers is significant across various categories and considering that agriculture is significantly vulnerable to global warming (Malhi et al., 2021), a closer look at emissions associated with this category is warranted. Producing 1 kg of soilless strawberries emits around 0,0947 kg CO_2eq, with fertilizers production being responsible for 37% of these emissions. While emissions from the use of synthetic fertilizers and agrochemicals were responsible for 15.85% of impacts in Global Warming, due to ammonia release. Second major hotspot was transport to farm, in particular transportation of coconut fibre substrate, with an average amount of 18.98%, across all impact categories. Transport of the substrate to the farm accounted ranged from a minimum of 0.8% in Abiotic Depletion to a maximum of 49.54% in human Toxicity. Such impact derived from the long distance between the farm and the substrate supplier. Indeed, it should be noted that the farmer supplier is located in the northern region of Italy, while the farm is located in Sicily, southern Italy. In addition, such impacts are mostly ascribed to EURO3 lorry, emissions from treatment of tire and brake wear, respectively. Third major hotspot was packaging, in particular the polyethylene growing bag used for the substrates. The substrate growing bag was responsible for an average amount of 17.46%, stemming from a minimum of 1.07% in Eutrophication to a maximum of 53.70% in Photochemical Oxidation. Highest percentage of electricity consumption was found in Marine Aquatic Ecotoxicity (28.30%); however, it was preceded by fertilizers (29.43%) and packaging (33.58%) in the same impact category. Emissions to air attributed to the use of fertilizers were the highest in Acidification (59.25%), while emissions to water were prominent in Eutrophication (69.50%).

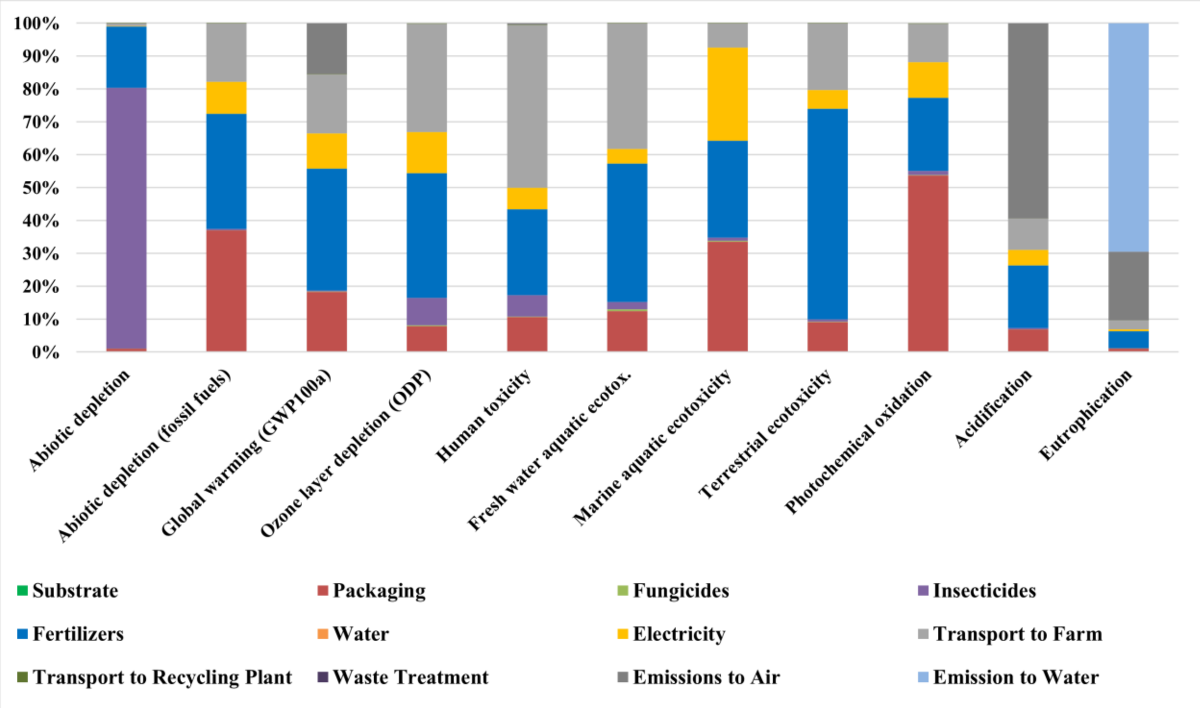

Figure 1. *Characterization results of the soilless system.*

Environmental Impacts of Soil Strawberries

Figure 2 presents characterization results of a strawberries in-soil system. Similar to the soilless system, although higher in percentages, insecticides impacted most in Abiotic Depletion (96.66%), but also in Ozone Layer Depletion (22.58%), although it is followed by fertilizers (57.03%). Field operation included the diesel used by the tractor to prepare the field, as well as the plastic mulch sheet. The latter was responsible for the most impacts across 7 impact categories, with an average of 51.54%. It ranged from a minimum of 1.18% in Abiotic Depletion to a maximum of 87% in Abiotic Depletion (fossil fuels). These impacts are attributed to the extrusion process to make the mulch sheet. Contrary to the soilless system, fertilizers were second most impactful inputs, ranging from 1.89% in Abiotic Depletion to 77.79% in Human Toxicity with an average of 23.32%. Concerning the impacts on Global Warming, producing conventionally 1 kg of strawberries released 0.196 kg CO_2eq, most of these impacts are to be attributed to the mulch sheet (76.99%) and fertilizer (12.31%) production. Just like the soilless system, emissions to water (mostly potassium and nitrates) are found relevant in Eutrophication, but with a lesser percentage (58.36%). Emissions to air registered the highest percentage in Acidification (18.11%), nonetheless it was preceded by fertilizers (19.51%) and field operations (55.47%). Differently from the soilless system, in the conventional in-soil one electricity, transport to farm and packaging played no significant role in terms of environmental impacts.

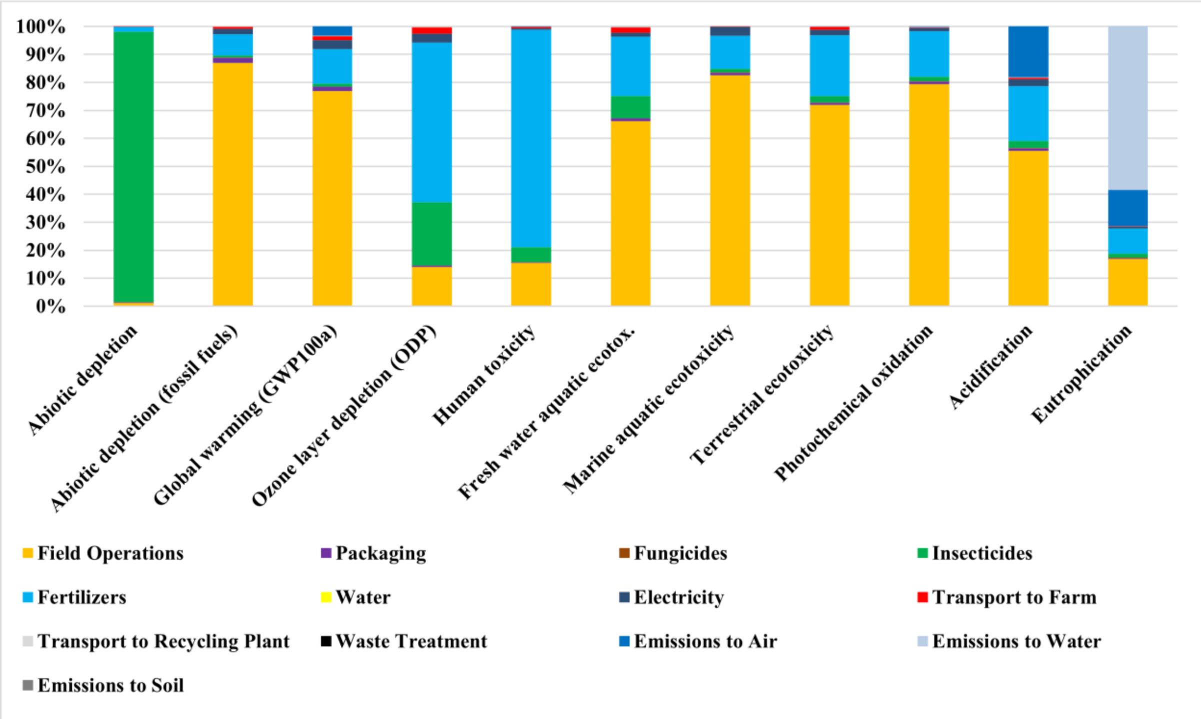

Figure 2. *Characterization results of the soil system.*

Comparative Analysis

Figure 3 provides a comparison analysis of the two systems. A bar at a lower percentage indicates a proportionally lower impact. For example, if the soilless system has a bar at 70% in the global warming category, it means its impact is 30% less than the in-soil one. Overall, the soilless system causes far less potential environmental impacts than the in-soil one in all but one of the investigated impact categories. Indeed, only in Eutrophication, the impacts stemming from the conventional system are 44% less than the soilless one. This is due to the lesser amount of fertilizer used in the in-soil system compared to the other one. The least difference was found in Acidification were, instead, the soilless system is 12% less impactful than the in-soil system. Whereas the highest difference was found for Human Toxicity, in favour of the soilless system (88%). Considering the Global Warming impact category, soilless system appeared to have 52% less impacts than the in-soil one.

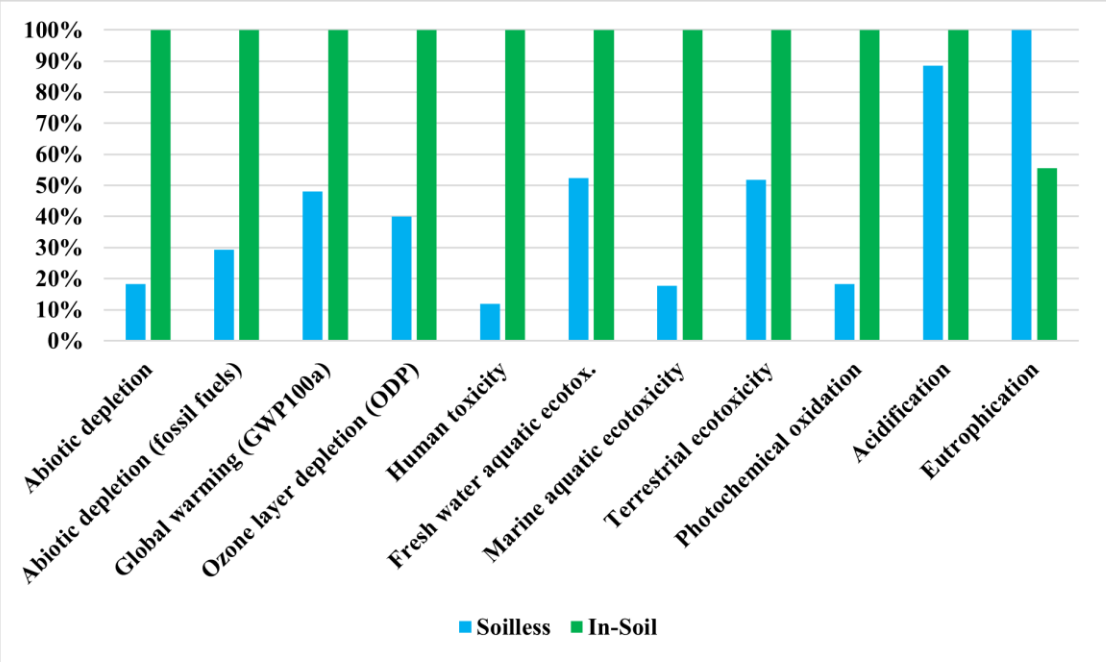

Figure 3. *Comparison between conventional system and soilless system*

Discussion

Soilless strawberries managed to meet the expectation it initially promised. Despite the one under analysis has as lower plant density and cultivated area (compared to the in-soil one), it appeared more environmentally friendly than conventional farming system for most of the considered impact categories. These findings are in line with those of other authors (Romero-Gámez and Suárez-Rey, 2020), where similar systems were compared. Nonetheless, such disparity in environmental performance might be due to the difference in yield between the two systems. Indeed, higher yields lead to reduced environmental impacts per unit of food produced (Sanyé-Mengual et al., 2015). Another positive aspect that emerges from the comparative analysis is that the soilless system scored better in abiotic depletion (elements), as the soilless system minimized the use of pesticides, reducing the impacts from agrochemicals. Indeed, the controlled conditions typical of the soilless system can mitigate the prevalence of plant diseases and pests, further reducing the dependency on harmful pesticides (Fussy and Papenbrock, 2022). In contrast with aforementioned authors (Romero-Gámez and Suárez-Rey, 2020), these findings contradict those of earlier studies (Ilari et al., 2021), where strawberries grown in soil exhibited better results in abiotic depletion (elements) and other impact categories. This discrepancy in results could potentially be ascribed to the differences in the volume of inputs employed in the systems examined by Ilari et al., (2021), where it was noted that the soilless system required a larger quantity of nutrient solution and pesticides. Another advantage lies in the environmental impacts avoided by the lack of field operations, such as field preparation and mulching, which translates into a significant reduction in emissions associated with fossil fuel combustion and mulch plastic production. Indeed, the necessity for mulching is effectively eliminated by the adoption of substrate bags, which recreates the proper environment for plant growth, taking less space and using less plastic. On the other side the amounts of fertilizers used to supply nutrients to the plants is the major concern, specifically in Eutrophication. These results are in line with those of other authors (Boneta et al., 2019; Corcelli et al., 2019; D'Amico et al., 2023; Romero-Gámez and Suárez-Rey, 2020). However, these results, in this instance, can be explained by several factors. Firstly, the fertirrigation cycle for soilless strawberries is considerably longer than that of traditional soil-based methods, which in turn demands more frequent nutrient replenishment and water use. Secondly, the growing medium itself, coconut coir, is inert (Munib, 2021), meaning it does not naturally supply nutrients to the plants. As a result, there is an increased need for added fertilization to sustain the strawberries. An additional factor is the lack of a closed-loop system that could recycle waste fertirrigated water, thereby potentially diminishing the consumption of water and nutrients. In contrast, the current system is an open-loop one, which directly discharges leachates into the environment. This practice has been identified as a cause of considerable ecological impact (Rufí-Salís et al., 2020). However, the choice of an open-loop system is economically advantageous, offering cost savings due to its straightforward installation and reduced expenses (Licastro et al., 2024). On the other side, while closed-loop systems incur higher initial investments, they are beneficial for the sustainable management of water and nutrients, despite their increased material and energy demands (Sanjuan-Delmás et al. 2018). Indeed, impacts from fertilizers can be mitigated by the implementation of several practices. Fertilizers doses can be optimized without incurring to yield loss (Muñoz et al., 2008), or could be replaced by bio-fertilizers (Martin-Gorriz et al., 2021). Additionally, inert substrates can be replaced by nutrient-rich composts (Romero-Gámez et al., 2017). Farmers can consider opting for more innovative systems, like aeroponics (Schmidt Rivera et al., 2023). Transport of inputs to farm was another impactful process in the soilless system. This might be explained by the higher distances between suppliers and the farm. This is relevant for delivery of plantlings, which need to be shipped via refrigerated transport, and coconut coir substrate. This aspect should not be underestimated, as delivering supplies and materials to farms can be much more impactful than delivering final products to the consumer (Dorr et al., 2023). According to some authors, energy is one of the most frequent environmental hotspots in soilless systems across various impact categories, especially if the system is placed in colder regions, where energy is required also for heating (Maynard et al., 2023; Rothwell et al., 2016). However, in the systems under analysis, electricity consumption was not particularly relevant. Indeed, it should be noted that these agricultural systems were situated in the Mediterranean region, which is naturally conducive to farming due to its climate, eliminating the need for heating. However, the increased electricity usage for the extended fertirrigation cycles in soilless strawberry cultivation could contribute to environmental impacts. Even if energy does not appear as so relevant as in other studies, soilless systems can still benefit from renewable energy sources, as recommended by various authors (Goldstein et al. 2016; Schmidt Rivera et al. 2023).

Conclusions

Strawberries are an important part of the Mediterranean diet and hold relevant economic value, further increasing the demand for such fruits and prompting environmental concerns. Soilless strawberries performed environmentally better than the in-soil one, having as main hotspots fertilizers, polyethylene substrate bags and transport of inputs to farm. In contrast, the amount of mulching film used for covering a greater cultivated area, fertilizers and pesticides were the major hotspots for the in-soil system. The in-soil system performed better only in Eutrophication, probably mainly because the soilless one lacked a closed-loop recirculation system. Overall, soilless cultivation displayed potential environmental benefits in terms of resource efficiency and reduced chemical usage. These systems indeed have potential, but further efforts might be needed to make them more input-optimizing and environmentally sustainable. Despite the soilless system appeared to be more environmentally friendly than conventional farming methods, such results do not lead to a definitive conclusion, as the current study is not exempt from limitations. First, as it was explained in the methodology section, models and methods for emission calculations adapted for soilless crops are yet to be researched and their application might lead to different results. Indeed, it should be noted that substrates (whether organic or inert) display different physical and chemical characteristics, compared to the soil. Hence, methods and models used for calculating emissions may vary significantly due to the distinct properties of substrates. Future research can involve the development and application of models and methods for calculating emissions specifically tailored for soilless crops. Second, greenhouse structure and irrigation system have been excluded from the analysis, and their inclusion can change the outcome. Third, different impact assessment methods can be used and lead to different results. Indeed, sensitivity analysis on several parameters can improve the current understanding of these systems, for example, focusing on yield and different models and methods for emissions calculation could be conducted to enhance the overall understating of soilless systems. Fourth, as this study adopted but one functional unit, future studies aiming to provide a deeper understanding of such system should adopt more than one functional unit. In conclusion, soilless systems, while offering certain environmental benefits, also present challenges that must be addressed. Future studies should be focused on whole life cycle strawberry, also including the assessment of greenhouse structures and irrigation systems. Other areas for further research include life cycle cost analysis (LCC), to assess not only environmental impact but also their economic cost, as well as Social Life Cycle Assessment (S-LCA), to assess their social impacts. In addition, further exploration of land use and inclusion of soil quality indicators could shed new light on the environmental impacts of these systems. In essence, soilless systems hold promise for environmentally friendly agriculture, but require further development to overcome resource inefficiencies and environmental burdens. With continued research and innovation, soilless agriculture can become a key player in sustainable food production for the future.

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A preliminary Life Cycle Assessment of electromagnetic energy harvesting devices. A focus on Magnetic Tunnel Junctions

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Abstract

The Internet of Things (IoT) encompasses a vast network of diverse interconnected smart devices, and their number is expected to rise rapidly. In this context, a critical challenge to face is finding solutions for the supply of adequate quantity of electricity necessary to power these devices. In particular, this means the development of miniature energy-efficient power supplies to ensure sustained autonomous operation. Charging these devices with energy from the environment could offer a valid alternative to reduce environmental concerns. Electromagnetic waves in the microwave spectrum, typically used for wireless data transmission, offer a valuable yet underutilised resource. Emerging electromagnetic energy harvesting technologies, like spin-torque devices, show promise in converting unused electromagnetic energy into electricity for IoT devices. However, their reliance on materials categorised as critical and rare could pose potential environmental challenges. This paper aims to preliminarily assess the environmental impacts of Magnetic Tunnel Junctions (MTJs), which are pivotal components in spintronic devices. Through a systematic literature review, key materials used in MTJs are identified, facilitating hotspot mapping. Then, the Life Cycle Assessment (LCA) method is used to evaluate the potential environmental impacts associated with different sizes and efficiency parameters. The results are useful for identifying critical materials within devices and suggesting solutions for reduction or substitution without compromising energy efficiency. This preliminary analysis also aims to guide LCA application to electromagnetic energy harvesters, identifying gaps, limitations, and methodological considerations. Funded by the EU Next Generation initiative through the MUR-PNRR project, this research contributes to the "Innovation Ecosystem - Sicilian MicronanoTech Research and Innovation Center" (SAMOTHRACE - ECS00000022) project.

Keywords: Spin-torque; MTJ; Life Cycle Assessment (LCA); Electromagnetic energy harvester; microwaves detector

Introduction

The Internet of Things (IoT) comprises billions of interconnected smart devices that require much energy to be powered. However, in this context, a critical challenge is the development of miniature, energy-efficient power chargers to ensure sustained autonomous operation (Demin et al., 2020). This challenge underscores the crucial need for energy harvesters, especially at the level of nanodevices.

Electromagnetic energy harvesting technologies, such as spintronic devices, offer promising solutions for harvesting and converting unused electromagnetic energy into electricity for IoT devices (Cutugno et al., 2023; Tu et al., 2020). Within spintronic devices, Magnetic Tunnel Junctions (MTJs) play a pivotal role in radiofrequency and microwave detection, serving as core components.

An MTJ primarily comprises three main layers: the free layer, the insulating layer (or tunnel barrier), and the fixed layer (or pinned layer), along with two electrodes (top and bottom), as schematically represented in Figure 1. Generally, MTJs are produced through the consecutive deposition of materials via sputtering processes on a base layer, followed by annealing (Gupta et al., 2023; Tomasello et al., 2013; Zhang et al., 2020). The literature also indicates that the fabrication method of MTJs can influence the device's efficiency (Gribelyuk et al., 2024).

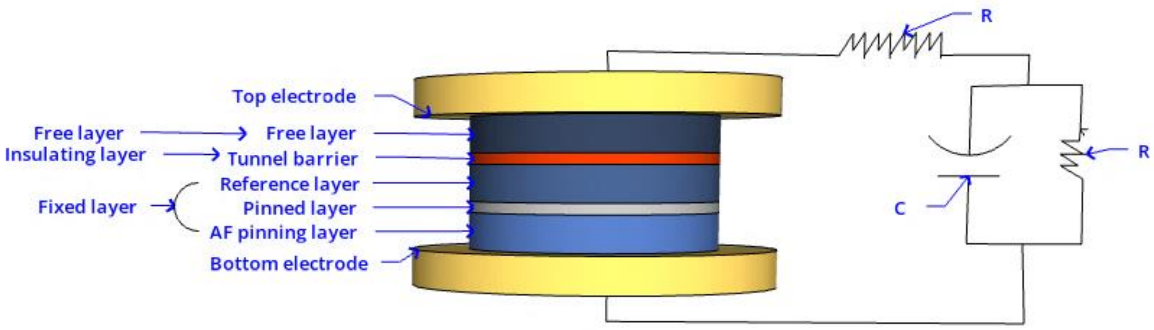

***Figure 10.** Example of a Magnetic Tunnel Junction and a schematic representation of a matching circuit.*

This technology has gained attention due to its high efficiency, scalability, and integrability in electronic circuits for various applications, ranging from memory storage to energy harvesting (Ikeda et al., 2007). However, some materials used in these devices are classified as critical (Palomino et al., 2020), necessitating a thorough examination of their environmental sustainability that could affect the benefits reached.

To the authors' knowledge, no environmental impact assessment has been conducted on spintronic energy harvesting technologies. This study aims to preliminarily evaluate the potential environmental impacts of key components in spintronic devices, with a specific focus on MTJs. The study excludes additional components such as receiving antennas and impedance-matching networks (circuits). A systematic approach is used to identify the main components and material compositions in spintronic devices for energy harvesting. The materials are then evaluated using the Life Cycle Assessment (LCA) method to assess the potential environmental impacts associated with different sizes and efficiencies of MTJs, normalised to 1V/W of sensitivity. The results help to identify critical materials within devices and suggest solutions for reduction or substitution without compromising energy efficiency. In addition, the approach implemented following in part a prospective LCA allows for identifying the critical aspects in modelling nano energy harvesters and identifying the potential uncertainty in data analysis.

This study is part of the "Innovation Ecosystem - Sicilian MicronanoTech Research And Innovation Center" (SAMOTHRACE) project (ECS00000022), funded by the EU Next Generation initiative, which aims to develop sustainable micro and nano technologies and systems for various applications, including energy, environment, smart agriculture, smart mobility, health, and cultural heritage.

Methods

To achieve the objective of this paper, a preliminary LCA study is conducted following the guidelines outlined for the preliminary phase of prospective LCA as detailed in the articles from Sander-Titgemeyer et al. (2023) and Arvidsson et al. (2018), as well as the ISO 14040-44 standards (ISO, 2006a, 2006b, 2020a, 2020b). The methodological approach of a prospective LCA differs from traditional attributional LCAs by emphasising additional considerations for uncertainty and variability in results. A systematic literature review is typically conducted to map the device's materials, components, and production processes (Arvidsson et al., 2015). The same steps have been followed in this study to gather data. Subsequently, the LCA method is applied from the initial goal and scope definition to the interpretation of results, identifying critical aspects and hotspots of selected components and materials as well as uncertainty in the characterisation results generated by data variability.

Preliminary goal and scope of study

The study aims to assess the cradle-to-grave life cycle impacts of MTJs used in spintronic devices for harvesting energy, including data from raw material extraction to the production of MTJs and one potential end-of-life scenario. It is important to note that transport and infrastructure and the installation, maintenance and use phases are excluded in this preliminary study.

The functional unit is 1 V of potential voltage produced for 1 W of microwaves harvested. This information is collected using the sensitivity parameter, which quantifies the device's ability to detect radiofrequency and microwave signals and convert them into voltage (Vdc) (Fang et al., 2016; Li et al., 2016; Wang et al., 2009). This, along with the Tunnel Magnetic Resistance (TMR), represents the main parameters for evaluating the efficiency of MTJs as energy harvesters.

Preliminary inventory analysis

To evaluate the life cycle of MTJ devices, two steps are conducted: first, the collection of data on material compositions and assumption on metalworking, and second, the estimation of the recycling rate of different materials to close the loop partially, quantifying the reduction of impacts due to the reemployment of materials into the same system.

To identify the materials used in MTJ devices (employed as energy harvesters or microwave detectors), a literature search is conducted on Scopus using keywords related to "magnetic tunnel junctions" and "energy harvesting" or "microwave detectors”[3]. This search is limited to English peer-reviewed articles, resulting in the identification of 45 articles.

During the screening process, 37 articles are excluded for not focusing on using MTJ devices as energy harvesters or for not providing a comprehensive description of layer composition. Additionally, two articles are excluded due to the unavailability of the full text. Finally, 12 articles are considered eligible for the study, as they effectively reported the sensitivity value and the geometric size of the device’s layers. Two articles (Sidi et al., 2022; Zhang et al., 2020) also propose two variants of MTJs that are included in the sample, resulting in 14 prototypes.

However, not all the analysed papers specify the materials used for the top and bottom electrodes, and even fewer for the base layer (excluded from the analysis). Therefore, only the prototypes in which both top and bottom electrode materials are reported, in addition to the core layers, are included in this study, reducing the sample to 9. Additional details about the characteristics of the selected devices are reported in Table 1.

Table 9. *Main technical characteristics of selected prototypes.*

ID	References	Sensitivity	Volume [μm^3]	Weight [ng]
1	Goto et al. (2021)	106 V/W	1.48E-03	1.26E-05
2	Gupta et al. (2023)	5 mV/mW	3.73E-02	2.74E-04
3	Hemour et al. (2014)	128 μV/μW	7.51E-03	7.43E-05
4	Li et al. (2016)	151 mV/mW	1.44E-03	1.08E-05
5	Sidi El Valli et al. (2022)	300 mV/mW	7.43E-05	5.01E-07
6		7 mV/mW	4.91E-04	3.31E-06
7	Wang et al. (2009)	16.67 mV/mW	5.58E-04	4.52E-06
8	Zhang et al. (2020)	10.5 mV/mW	7.09E-03	5.60E-05
9		42.5 mV/mW	3.99E-03	3.15E-05

As shown in Table 1, the prototypes exhibit significant variability in sensitivity parameters and geometric dimensions. To harmonise the results, the data collected from the studies are first broken down into individual materials, with composite materials considered using an average density among the weight percentage generally indicated for composite materials (e.g. $Co_{20}Fe_{60}B_{20}$, $Pt_{38}Mn_{62}$). Thus, the geometric size is then converted into weight. Next, the weight is normalised to 1V/W of sensitivity by dividing the weight of each material by the sensitivity reported in the literature case studies (see Table 1). A benchmark prototype is then developed for the study, and average arithmetic values for each material in each layer are calculated independently from the original material composition. Then, a descriptive analysis is conducted to identify the data variability along the sample.

[3] TITLE-ABS-KEY (("magnetic tunnel junction*" OR MTJ*) AND ("energy harvest*" OR "microwave detect*")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) (Accessed by 25/04/2023)

The production phase includes consideration of the use of metalworking processes accounting for all the mass of nanodevice core layers and top and bottom electrodes.

For the quantification of the recycling rate of different materials, similar to the study proposed by Abokersh et al. (2021), the End-of-life Recycling Input Rate (EOL-RIR) proposed by the European Commission (2023) is used to estimate the potential benefits derived from the recycling of different materials. Instead, the other parts of materials that are not reused are accounted as waste in landfills, while the treatment process is assumed to be equal to the electric and electronic waste treatment (FitzGerald and Sonderegger, 2022).

For all the life cycle phases, the background processes associated with the extraction, production and final treatment of materials are estimated using the Ecoinvent v3.8 database (FitzGerald and Sonderegger, 2022). In addition, another assumption related to Platinum Group Metals (PGM) is made for which representative datasets are identified, such as iridium and ruthenium. In this case, the extraction processes are assumed equal to that of Platinum (Gulotta et al., 2022) assumed to be equal to metals that are generally mined with them as part of the PGMs group (Snowden-Swan et al., 2016). All the results of this phase are discussed in section 3.1.

Impact assessment

Considering that no other LCA studies have been found on this kind of device, the CML-IA baseline method has been selected, consistent with other LCA studies on energy technology (Masoni and Zamagni, 2011). This method includes characterisation factors for various categories such as Abiotic depletion (elements) (ADE), Abiotic depletion (fossil fuels) (ADF), Global warming potential (GWP), Ozone layer depletion (ODP), Human toxicity (HT), Freshwater aquatic ecotoxicity (FAE), Marine aquatic ecotoxicity (MAE), Terrestrial ecotoxicity (TE), Photochemical oxidation (PCO), Acidification (AC), Eutrophication (NP).

Interpretation

The data are first interpreted by presenting the absolute inventory values and LCA characterisation results. Then, a contribution analysis is performed to identify the main hotspots throughout the life cycle. However, since MTJ is a yet commercialised device, the technical system used for energy harvesting is still under development and in the early assessment and design stage, presenting changes in materials employed to reach the highest efficiency possible in converting harvested energy. Therefore, the challenges in assessing emerging products include data unavailability, scale-up effects, choosing a relevant functional unit, and comparing existing products. As for a prospective LCA (Thonemann et al., 2020), this study would like to address the uncertainties of applying LCA methods to this emerging device. This is evaluated by applying a Monte Carlo analysis using the Simapro software and comparing two different uncertainty modelling approaches: i) uniform distribution of data between maximum and minimum values and ii) normal distribution using the calculated standard deviation. This allows for identifying which layer has the highest uncertainty and what effects this might have on the final characterisation results.

Results and Discussion

Inventory data description

In Table 2 the mean data for the benchmark prototype, along with the statistical variation for each material in each layer of the prototypes, are reported.

The analysis reveals that copper and ruthenium are the prevalent materials in the nanodevice, accounting for 51% and 18% of the composition, respectively. These are followed by aluminium and tellurium, constituting 13% and 7%, respectively. All other materials, including platinum, are less than 5% of the total weight.

As highlighted by the Coefficient of Variation (CV) in Table 2, the materials used in MTJ devices can exhibit significant variability, sometimes exceeding 200%. This high variability is strongly influenced by the different design choices researchers make, because, as mentioned earlier, this technology is still in the experimental and design stages. Thus, identifying a benchmark prototype could be difficult. Therefore, accounting for the effects generated by the statistical variability on results is essential, especially in the preliminary stages, as yet identified by different LCA studies on emerging technologies at low Technology Readiness Levels (TRLs) (Arvidsson et al., 2018; Sander-Titgemeyer et al., 2023).

Table 10 *Inventory data and statistical variability of main materials included in the benchmark prototype functional unit and EOL-RIR*

Layer	Material	Mean [ng]	Min [ng]	Max [ng]	Std [ng]	CV	EOL-RIR*
Bottom layer	Aluminum	8.53E-07	-	7.68E-06	2.41E-06	283%	32%
	Cobalt	1.39E-08	-	1.24E-07	3.91E-08	282%	22%
	Copper	5.89E-07	-	3.52E-06	1.13E-06	191%	55%
	Platinum	1.57E-08	-	1.40E-07	4.41E-08	282%	12%
	Ruthenium	4.97E-08	-	3.73E-07	1.15E-07	232%	12%
	Tantalum	4.03E-07	-	2.57E-06	8.02E-07	199%	1%
Free layer	Boron	2.89E-09	1.20E-11	1.33E-08	4.31E-09	149%	1%
	Cobalt	1.68E-08	-	5.32E-08	2.11E-08	126%	22%
	Iron	2.20E-08	3.84E-11	1.27E-07	3.98E-08	181%	31%
	Tungsten	2.34E-09	-	2.10E-08	6.60E-09	282%	42%
Insulating layer	Magnesium	1.49E-09	-	1.04E-08	3.29E-09	221%	13%
	Magnesium oxide	6.51E-09	-	3.35E-08	1.16E-08	178%	13%
Fixed layer	Boron	6.72E-09	6.31E-12	4.92E-08	1.52E-08	226%	1%
	Cobalt	9.18E-08	1.51E-10	5.95E-07	1.83E-07	200%	22%
	Iron	5.72E-08	2.02E-11	4.06E-07	1.26E-07	220%	31%
	Iridium	7.10E-08	-	5.42E-07	1.68E-07	237%	12%
	Manganese	1.95E-07	-	1.51E-06	4.67E-07	239%	9%
	Platinum	3.04E-07	-	2.67E-06	8.35E-07	275%	12%
	Ruthenium	3.56E-08	-	2.04E-07	6.28E-08	177%	12%
	Tantalum	1.35E-09	-	1.21E-08	3.81E-09	282%	1%
	Tungsten	1.95E-09	-	1.75E-08	5.50E-09	282%	42%
Top layer	Aluminum	3.41E-08	-	3.07E-07	9.65E-08	283%	32%
	Copper	2.93E-06	-	2.57E-05	8.07E-06	276%	55%
	Magnesium	1.09E-09	-	9.76E-09	3.07E-09	282%	13%
	Ruthenium	1.14E-06	-	9.58E-06	2.99E-06	263%	12%
	Tantalum	8.59E-08	-	4.99E-07	1.54E-07	179%	1%
Metalworking for all mass device		6.93E-06	1.67E-09	5.47E-05	1.70E-05	245%	

*Data from European Commission et al. (2023)

Environmental impacts and contribution analysis

Table 3 reports the potential environmental impacts calculated for the prototype.

The results show that the highest impacts in all categories are linked to the raw materials used in the devices, with the production phase contributing less than 0.05% of the impacts. During the disposal phase, using current EOL-RIR parameters for each material, a reduction of about 12% is observed in each impact category. This indicates that improving recycling processes, particularly for electronic and electrical equipment, could enhance the potential environmental benefits of these devices.

Table 11 *Potential environmental impacts of the benchmark prototype functional unit (ε =1V/W)(characterization results)*

Categories	Units	Phases			Total
		Raw materials	Production	Disposal	
Abiotic depletion	kg Sb eq	5.54E-18	2.60E-21	-6.97E-19	4.85E-18
Abiotic depletion (fossil fuels)	MJ	1.56E-12	1.41E-16	-1.87E-13	1.37E-12
Global warming (GWP100a)	kg CO_2 eq	1.07E-13	1.34E-17	-1.28E-14	9.40E-14
Ozone layer depletion (ODP)	kg CFC-11 eq	4.81E-21	9.65E-25	-5.78E-22	4.23E-21
Human toxicity	kg 1,4-DB eq	3.55E-13	1.10E-16	-4.33E-14	3.12E-13
Fresh water aquatic ecotox.	kg 1,4-DB eq	4.39E-13	1.08E-16	-5.31E-14	3.86E-13
Marine aquatic ecotoxicity	kg 1,4-DB eq	6.15E-10	3.25E-13	-7.42E-11	5.41E-10
Terrestrial ecotoxicity	kg 1,4-DB eq	3.23E-16	7.74E-20	-3.93E-17	2.83E-16
Photochemical oxidation	kg C_2H_4 eq	2.32E-16	6.20E-21	-2.79E-17	2.04E-16
Acidification	kg SO_2 eq	6.64E-15	1.30E-19	-7.98E-16	5.84E-15
Eutrophication	kg PO_4^{3-} eq	7.10E-16	5.37E-20	-8.54E-17	6.24E-16

Although each nanodevice uses only small amounts of materials, their future widespread use in IoT devices could significantly impact supply risk[4]. Almost all materials used in this device have been identified as critical raw materials by the European Commission (2023), except for cobalt, boron, manganese, magnesium, and tungsten, which are considered strategic for different industrial sectors. Copper is also accounted as a strategic material, although it did not meet the CRM criteria, but it is employed in various technologies and industrial processes.

The effects of the recycling option can be better understood through the network graphical representation developed using Simapro. Figure 2 shows an example of the GWP impact category. The top electrode, followed by the fixed layer, achieves the highest benefits from the reuse of recycled materials.

[4] Supply risk indicates that the supply is associated with a high risk of not being adequate to meet EU industry demand and depends on the recyclability rate, taking into consideration the implementation of circular economy actions during the end-of-life of technologies (European Commission et al., 2023).

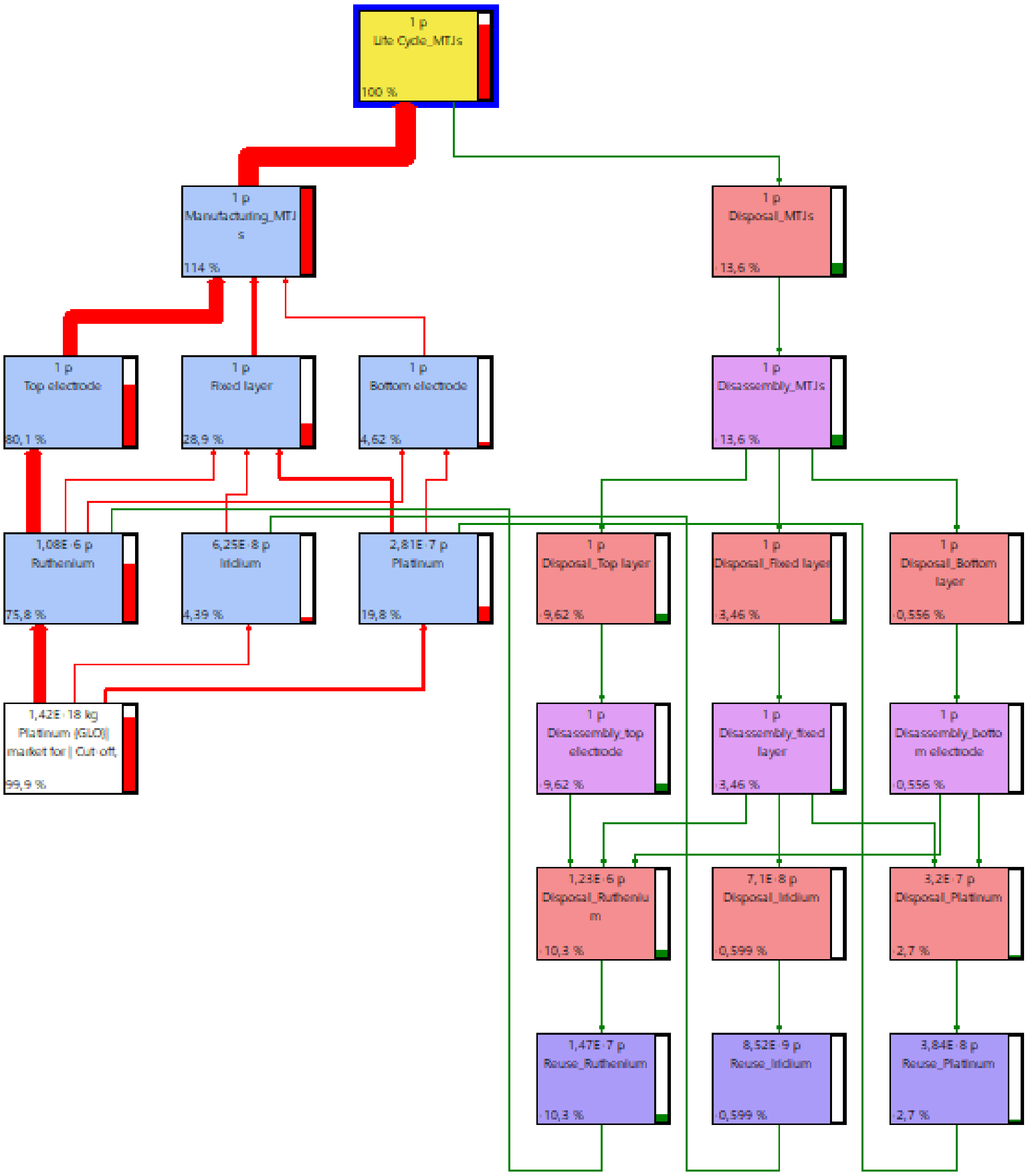

Figure 11. *GWP network contribution of the life cycle of MTJ device (cut-off 0.5%) (characterization results)*

Their environmental performance is strongly influenced by the significant, although small, amounts of PGMs, as shown in Figure 2. Even though they represent less than 5% of the nanodevice's weight and their recycling rate is only 12%, they impact both the manufacturing and disposal phases in terms of impacts and benefits. Instead, copper, which represents about 51% of the weight of MTJ and is characterised by a recycling rate of 55%, does not influence the environmental performance of the device. A similar distribution of environmental hotspots has been obtained across all impact categories.

This result highlights the need to identify alternative design solutions that, while maintaining the highest possible energy performance, reduce the presence of PGM materials, confirming what was identified by Palomino et al. (2021) for memory spintronic devices. It is also true that missing reliable data on ruthenium and iridium, assumed as platinum in this model, could generate the highest uncertainty in environmental impacts. Considering that these kinds of materials have the highest impacts in all impact categories, a consistent distribution is recorded among the different categories for each layer. Different datasets will be chosen in future studies to determine how the selection of different datasets in case of missing data could be reflected in results, such as conducting a sensitivity analysis.

Uncertainty analysis

As mentioned above, the study refers to a benchmark prototype, where the highest variability is identified along with the different materials employed (see Table 2). Therefore, conducting an uncertainty analysis is essential in LCA studies, especially for low TRLs technologies and prospective LCA studies. Thus, this study presents the results of the Monte Carlo simulation using two approaches: first accounting for a uniform distribution of data from minimum to maximum values (Figure 3) and then using a normal distribution with standard deviation values (Figure 4).

The first approach (Figure 3) shows that the CV of uncertainty on characterisation results could range from 43% (ADE) to 86% (TE). In some impact categories, from the characterisation results reported in Table 3, average values could also differ by an order of magnitude with a variation of about 300% among them.

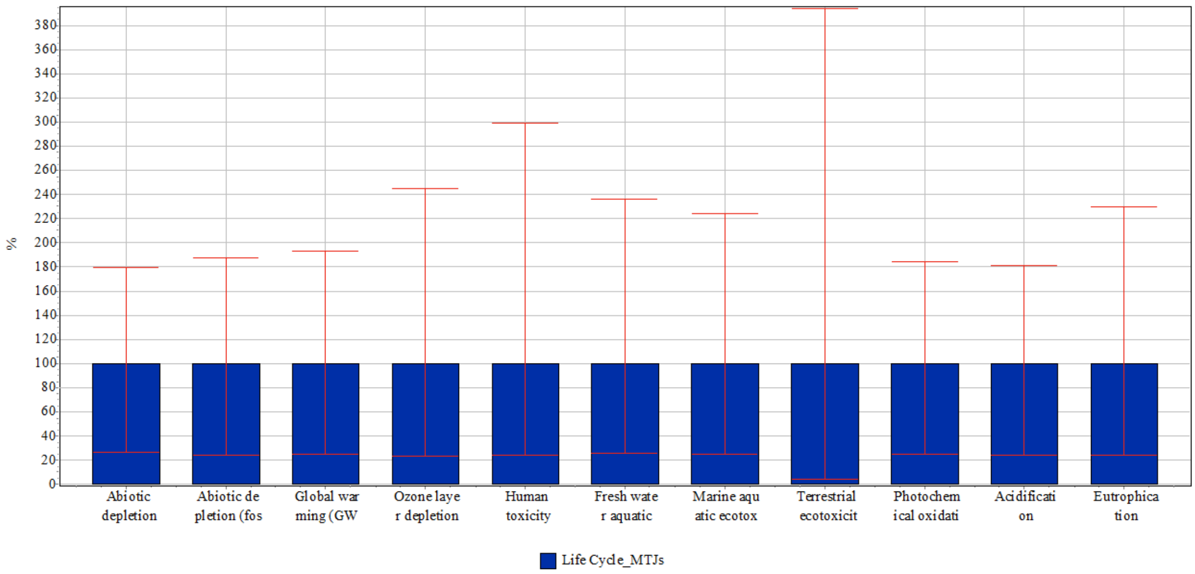

Figure 12 *Monte Carlo simulation using the minimum and maximum values with uniform distribution*

The second approach (Figure 4) shows that the CV of uncertainty on characterisation results could range from 198% (ADE) to 251% (TE). These results are notably higher than those reported by the first approach, indicating a higher uncertainty in characterisation results. However, calculating the differences between the results reported in Table 3 and the average calculated from the Monte Carlo simulation, only a variability between ±2% (FAE, ODP, TE) and 8% (NP) is noticeable among impact categories.

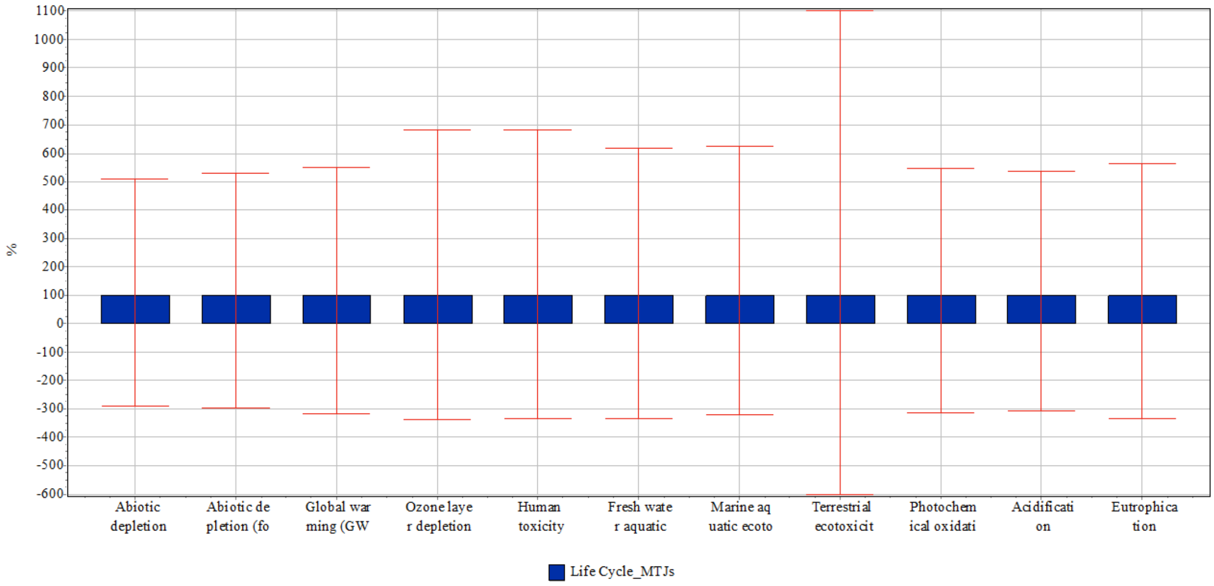

Figure 13 *Monte Carlo simulation using the standard deviation values with normal distribution*

Although the second approach reports average values closer to those calculated for the benchmark prototype, it estimates negative values for some inventory data, altering the scope of the analysis conducted. Therefore, these results indicate the need to identify and select more appropriate methodological approaches in uncertainty calculation to select the most appropriate case-by-case. Although conducting an uncertainty analysis is widely suggested in the preliminary stage of prospective LCA studies, this information is generally omitted in the literature, representing a challenge in the transparency and reproducibility of studies, especially for emerging technologies (Moni et al., 2020).

Conclusions

This study conducted a preliminary LCA of MTJ benchmark prototypes using a systematic approach to identify the average quantity of materials employed in the different layers. This study identified improvement options, uncertainties in characterisation results, and critical issues for conducting this kind of study.

The resulting inventory data shows high variability in the materials employed for the functional unit, resulting in a coefficient of variation close to 300%. Focusing on potential environmental impacts, the study shows that the highest impacts are linked to the raw materials phase, particularly using PGMs in almost all layers from the bottom to the top electrodes. Accounting for EOL-RIR, the impacts could be reduced by about 12% in all impact categories. This means that implementing circular practices to reuse materials could strongly reduce impacts and increase the benefits associated with energy technologies. However, different end-of-life scenarios must be implemented to account for the effective efficiency of the recycling process on nanodevices.

Given the emerging nature of this device, no other LCA studies have been identified to validate the results. However, following the initial steps proposed for conducting prospective LCA, an uncertainty analysis using Monte Carlo simulations was conducted. The analysis identified several magnitudes of variability in results, obtaining different interpretations based on the chosen method. This indicates the need for more guidelines for developing LCA studies on emerging technology, suggesting the most relevant approach to calculate uncertainty in characterisation results. Indeed, communicating uncertainty interpretation represents one of the critical issues associated with emerging technologies and the implementation of prospective LCA.

Future studies will be conducted to identify the best practices in modelling nanodevices, accounting for selecting representative datasets for background processes. In the case of nanodevices, this could strongly affect the characterisation results and the uncertainty estimation.

Acknowledgement

This work has been funded by the European Union (NextGeneration EU) through the MUR-PNRR project SAMOTHRACE (ECS00000022). However, the views and opinions expressed are those of the authors only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

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Students’ Intentions After Graduation: The Influence of University Students' Satisfaction

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Abstract

The purpose of this study is to examine the influence of service quality on student satisfaction in the higher education environment. It also investigates the students’ intentions after graduation to go on to postgraduate study or begin a career. A total of 440 valid questionnaires were collected from business undergraduate students enrolled in public universities in Greece. The data were collected in a self-administered questionnaire. A performance-based measuring scale that was exclusively designed for the higher education sector was used to measure service quality. The relationships between service quality dimensions (non-academic aspects, academic aspects, reputation, access, and programme issues) and student satisfaction were examined by structural equation modeling. In addition, a one-way ANOVA test was used to check how average institutional satisfaction influences students’ attitude towards continuing studying at the same university. It was found that the more satisfied students are with the university where they are enrolled, the more likely they are to continue their studies there. A lower degree of satisfaction leads students to look for another university in their country or abroad. A quite alarming result concerns the large percentage of students who want to migrate after graduation in order to study or work abroad. It was also found that students’ intentions vary according to their gender and their year of study.

Keywords: Higher education, Service quality, Behavioral intentions

Relevant Topic: service quality

Introduction

The first purpose of this study is to examine the influence of service quality on student satisfaction in the higher education environment. Despite the fact that service quality in Higher Education Institutes (HEIs) and its antecedents have been studied over decades, it remains a crucial area of research mainly due to its dynamic and contextual nature (Alfy and Abukari, 2020). Thus, researchers highlight the need for more studies in this field (Arrieta and Avolio, 2020; Rafik and Priyono, 2018). The second aim of this empirical research is to investigate the students' intentions after graduation. Nikou and Luukkonen (2024) pointed out that only a few studies have focused on the mobility intention of post-graduates. They also noticed a gap in the literature when it comes to examining students' attitude towards staying in the host country and how their intentions are influenced by their surroundings. Thus, it is essential to understand students' overall satisfaction and their behavioral intention after graduation (Shafiq et al., 2018). Specifically, this study tries to discover if the intention of domestic students' to study in their country is positively correlated with their satisfaction with their university.

The study examines the students' attitudes toward their university using the Cognitive-Affective-Behavioral (CAB) model. According to the CAB model, human attitudes have three components: a cognitive (belief and knowledge), an affective (feelings) and a behavioral component (the effect of the attitude on behavior) (Tan et al., 2021). In this case, the cognitive component is related to service quality evaluation, the affective represents student satisfaction, and the behavioral refers to student behavioral intentions. The causal progression of these three factors is examined in many sectors, even in higher education (Lee and Seong, 2020; Tan et al., 2021). The cognitive Theory of Planned Behavior (TPB) proposed by Azjen (1985) can also support the explanation of students behavioral intention. According to this theory, an individual's decision to engage in a specific behavior, such as study or work in his country or overseas, can be predicated by their intention to engage in that behavior (action). Indeed, it was found that the correlation between intention and actual behavior is very high ranging from 0.9 to 0.96 (Ajzen et al., 2009).

In addition, the theory of push-pull factors was used as it provides the most frequently cited framework for explaining the intention of young, highly qualified personnel to migrate (Bijak, 2011). Abbas et al. (2021) found that students' decision to move abroad is mainly based on poor education quality and low career prospects in the home country. The high rate of unemployment in the country combined with extremely low rates of economic growth, low wages, bad working conditions or low job satisfaction influence the emigrants' decisions (Chatziprodromidou et al., 2017; Ullah, 2018). Another impactful factor affecting student intention to stay or leave the home country after graduation is the lack of institutions for specialized postgraduate or doctoral studies and research, a fact which leads them to search for better educational opportunities in other countries (Kattel and Sapkota, 2018). Conversely, students plan to stay if they are satisfied with their current university (Nikou and Luukkonen, 2024).

The research was conducted in Greece. In this country, a significant migration flow has occurred in recent years due to the economic crisis of 2009, which resulted in a reduction in the salaries of executives and an increase in unemployment. The value of the human flight and brain drain indicator for Greece in 2023 was

4 index points, while the world average based on 177 countries was 5.17 index points. Data also indicated that in 2017 25.8% of Greeks obtained a master's degree in another country compared to 5% which is the average for EU countries (European Commission, 2019).

In the next section, the basic concepts of this research are briefly discussed and the research hypotheses are put forth. The two sections that follow provide a description of the methodological analysis and findings. The discussion of the results, and the limitations of the research are covered in the last section of the paper.

Literature review

Service quality dimensions

Educational quality is difficult to define (Dicker et al., 2018), as it is a complex concept with many facets (Zulkefli and Uden, 2013). Numerous multidimensional instruments have been created to capture students' evaluations. Some general instruments, which appear to be applicable to a wide range of service sectors, are also used in the HE sector, for instance, SERVQUAL (Parasuraman et al., 1988), SERVPERF (Cronin and Taylor, 1992) or the technical and functional quality model (Grönroos, 1984). Some others were exclusively designed for the higher education sector based on the idea that generic service quality scales cannot adequately assess the quality of higher education in all its dimensions (Arrieta and Avolio, 2020; Khalid et al., 2021; Bouranta et al., 2024). For example, Khan et al. (2023), gathering data from Australian online undergraduate and postgraduate students, proposed the OLQUAL scale. Their instrument comprises five dimensions: system quality, administrative quality, educational quality, transformative quality and social quality. Similarly, Annamdevula and Bellamkonda (2016) postulated the HiEduQual scale with six main dimensions, namely teaching, administrative services, academic facilities, campus infrastructure, support services and internationalization. Sultan and Wong (2010) assessed service quality in HE based on an extended scale (PHed) consisting of eight dimensions (dependability, effectiveness, capability, efficiency, competencies, assurance, unusual situation management, semester and syllabus) and 67 items. Many other attempts, focusing on introducing instruments constructed solely for higher education services, have been found in literature such as HEdPERF (Abdullah 2005), i-HESQUAL (Asnawi and Setyaningsih, 2020), HESQUAL (Teeroovengadum et al., 2016), MEQUAL (Verma and Prasad, 2017), PAKSERV (Kashif et al., 2016), CUL-HEdPERF scale (Randheer, 2015; Ramzi et al., 2022), HEDQUAL (Icli and Anil, 2014), INSTAQUAL (Kumar and Dash, 2014), SQM-HEI (Senthilkumar and Arulraj, 2011), ARCHSECRET (Vaughan and Woodruffe-Burton, 2011), PESPERF (Yildiz and Kara, 2009), EduQUAL (Mahapatra and Khan, 2007), etc.

Among them HEdPERF (Higher Education PERFormance) appears to be one of the most used (Silva et al., 2017). This performance-based measuring scale was proposed by Abdullah (2005). The original version consists of 41 items, while the modified structure consists of 38 items indicating five distinct dimensions (Abdullah, 2006a): non-academic aspects, academic aspects, reputation, access and programme issues. This instrument has been tested in different countries and HE contexts (Võ, 2021; Wan Mustafa et al., 2019). In some, measurement dimensionality, applicability and validity are supported (Muhammad et al., 2018;

Mohammed et al., 2023; Khalid et al., 2021), whereas in others the five-factor structure was not confirmed (Yavuz and Gülmez, 2016; Mang'unyi and Govender, 2014; Võ, 2021). This context-specific instrument seems to perform better than SERVQUAL, but mixed results appear when it is compared with SERVPERF (Brochado, 2009; Law, 2013; Abdullah, 2005; 2006a,b).

Service quality and customer satisfaction

The evaluation of students' experience with the educational service determines the level of their satisfaction (Elliot and Healy, 2001). Student satisfaction takes into account the whole student experience rather than just one particular aspect of it. Thus, the service quality dimensions are considered as an antecedent to satisfaction (Culiberg, and Rojšek, 2010). This relationship has been supported in the HE context in a variety of country and institutional settings (Chaudhary and Dey, 2021; Hwang and Choi, 2019; Mutum et al., 2023; Subrahmanyam, 2017). Particularly, Oliso et al. (2024) proved that the facets of service quality accounted for 71.2% of the variations in students' satisfaction in the Ethiopian public universities. Nguyen et al. (2024) using a set of five service quality dimensions (academic aspect, nonacademic aspect, programme issues, facilities and industry interaction) revealed that most of them have a positive influence on student satisfaction. In the same line, Tandilashvili et al. (2023) indicated that student satisfaction is influenced by programme quality and reputation, study environment, and quality of academic and administrative staff. Ali et al. (2016) gathering data from international students at three public Malaysian university campuses examined the relationship between service quality and student satisfaction. They found that the five dimensions of the HEdPERF instrument influence student satisfaction. Based on the previous findings, the relationship of the five dimensions of the HEdPERF instrument with student satisfaction was examined.

H1. Non-academic aspects positively affect student satisfaction
H2. Academic aspects positively affect student satisfaction
H3. Reputation positively affects student satisfaction
H4. Access positively affects student satisfaction
H5. Programme issues positively affect student satisfaction

Students' Intentions After Graduation and satisfaction

Behavioral intention in HE refers to the willingness of students to remain at the same university, choosing a postgraduate course there, as well as offering a positive word-of-mouth recommendation (Ammigan, 2019). Satisfied students are prompted to enroll in a higher level of studies within the same institution, to recommend the institution to other potential students or to say positive things about the university (Sultan and Wong, 2014; Clemes et al., 2013). On the other hand, dissatisfied students may complain, spread negative word-of-mouth opinions or drop out (Khoo et al., 2017). Previous studies have supported that satisfied students are more likely to remain loyal to their institute (Ali et al., 2021; Rehman et al., 2020). Luque-Martínez et al. (2023) maintained that satisfaction is a necessary condition for loyalty, but it is not always converted into loyalty; especially for university studies in which both personal and social factors are at work which means that following studies at different universities can add extra stars to a curriculum vitae.

Indeed, the students face many alternative educational options after completing their studies. They may choose to pursue education at the same university, at another domestic university or to pursue study overseas. Lee (2017) found that a strong push factor in students choosing to study abroad is the low level of their satisfaction with the educational quality of the home country. Similarly, Ahmed and Ilahi (2020) showed the propensity of Saudi male undergraduate students towards the foreign environment especially because of the oportinity it provided to get a better education. Low student perception of institutional infrastructure also results in a significant increase in their switching intention (Agu, 2022). Following the previously presented contentions, it is logical to assume that:

H6. Student satisfaction positively affects student intention to study at the same university

Sample and procedure

Sample

The target respondents for this study were undergraduate students from public universities who were enrolled in a four-year full-time business administration program. With the assistance of the professors, students were informed during lectures about the current survey. Professors provided the online click-through survey link and asked students to voluntarily fill out the anonymous online questionnaire.

Among the 467 completed questionnaires, 27 were discarded. This resulted in 440 usable responses. Out of these respondents, 169 were male (38.4%) and 271 were female (61.6%). The majority of the respondents (56.8%) had finished at least one year of education in their program, which means that they have had contact with the institution for a long period of time and probably they have developed realistic service quality perceptions.

Measures

A structured questionnaire was used to collect data. The first section of the questionnaire contained que

stions about the main concepts of this research (service quality, student satisfaction, behavioral intention) and the second one contained questions about the demographic profile of the respondents.

The HEdPERF instrument was utilized to evaluate service quality (Abdullah, 2006c). As regards overall student satisfaction, the measurement scale includes five items extracted from previously developed instruments (Ali et al., 2016; Wilkins and Balakrishnan, 2013). The items of these instruments were presented as statements, measuring students' agreement on a seven-point, Likert-type scale that varied from 1=strongly disagree to 7=strongly agree. Students were also invited to respond to questions about their intentions after graduation indicating their choice among the possible career options.

The questionnaire also included a series of questions related to the demographic characteristics of the respondents, such as gender, year of studies and university. The draft questionnaire was subjected to face validation by 24 students. Three experts (an academician, a PhD researcher and a practitioner) also received the questionnaire and were asked to evaluate it. Based on their feedback, minor changes were made to improve the clarity of the questions.

Data analysis and results

Preliminary analyses

Table 1 shows career choice intentions of students right after finishing their current study program. Half of the business students chose further study (50%), while in the five students (21.3%) who responded intend to look for a job. A significant number of students have not yet decided what they want to do after graduation (22.3%). A small amount of students have plans, other than study or work (6.4%). Specifically, they want to travel and/or take a gap year/break from academic study, while some male students want to fulfill their military obligations. It should be noted that a large percentage of students (29.8%) want to migrate after graduating in order to study (25.5%) or work (4.3%).

Table 1 Intentions After Graduation

Intentions after graduation	**frequency**	**%**
Stay		***41.5%***
studying at the same university	66	15
studying at another domestic university	42	9.5
looking for a job in my country	75	17
Go		***29.8%***
studying at a university abroad	112	25.5
looking for a job overseas	19	4.3
other	28	6.4
I do not know / I do not answer	98	22.3
Total	**440**	**100**

The results of the crosstabulation analysis indicate the existence of statistically significant differences in students' intentions after their graduation among students' from different years of studies (Pearson Chi-square χ^2= 98.711, df=24, p<.000). 49% of the first-year students don't know or don't answer the question about their intentions after graduation. This uncertainty decreases over the years of study. Only 18% of the 3rd and 4th year students remain undecided as to what they will do next. Moreover, the students' preferences change over time. For example, 61.1% of young students are more likely to continue theirs studies abroad straight after graduation, compared to 11.6% of those in the 4th year. In addition, the majority of the 1st year students intend to continue their education after graduation, but this intention changes over time as during the last years of their studies they prefer to start working and getting professional work experience.

Moreover, the results suggest that gender plays a significant role in students' immediate career intentions (Pearson Chi-square χ^2= 21.160, df=6, p<.002). Female students are more likely to intend to look for a job in their country (11.6%) than their male co-students (5.5%). Male students have plans after graduation other than working or studying (4.1%) as many of them intend to immediately perform their military service which is obligatory for Greek males by Greek law.

Testing of hypotheses

Before any data processing took place, it was verified that the assumptions of normality (kurtosis and skewness) were upheld. Based on the Mahalanobis d-squared distance index, eight observations were removed from the analysis because their values were greater than the threshold of 3. Thus 440 useful questionaries remain. The skewness values of the observables fell within -1 to +1 which is an acceptable range. Furthermore, the kurtosis values showed that the data distribution was normal (Hair et al., 2010).

After checking the suitability of the data, Confirmatory Factor Analysis is performed to validate the measures considered in this study. The results provided strong evidence that the model is reasonably reliable and valid. More specifically, the basics of goodness of fit (χ^2=522.549, p<0.000), the absolute fit indices (χ^2/df=1.730, RMSEA=0.041, GFI=0.918), the incremental fit indices (NFI=0.936, IF1=0.972, TLI=0.967, CFI=0.972) and the parsimony fit indices (PCFI=0.836, PNFI=0.806) indicate an acceptable fit of the proposed model.

Table 2 Confirmatory Factor Analysis

Construct / Items	**Mean**	**S.D**	**Standardized regression weights**
Non-academic aspects			
secure dealings	4.605	1.582	0.794
good knowledge of the systems/procedures	4.857	1.422	0.694
good communication	4.309	1.626	0.819
positive work attitude	4.584	1.581	0.799
keep promise	4.493	1.486	0.687
respond to student requests	4.059	1.566	0.735
efficiently dealt with complaints	4.073	1.581	0.824
interest in solving problems	4.186	1.604	0.805
individual attention	4.084	1.614	0.817
Academic aspects			
good communication	5.377	1.166	0.676
positive attitude	5.452	1.120	0.840
sincere interest	5.014	1.393	0.723
courteous manner	5.459	1.246	0.761
Program			
programmes with flexible syllabus	5.157	1.367	0.819
wide range of programmes	5.602	1.214	0.688
Reputation			
ideal location	4.330	1.718	0.731
adequate and necessary academic facilities	4.052	1.789	0.701
adequate facilities and equipment of hostel	4.670	1.671	0.794
professional appearance/ image	4.757	1.592	0.789

Access			
setting up of Student's Union	4.555	1.468	0.677
feedback from students	4.416	1.560	0.778
simple service delivery procedures	4.689	1.250	0.739
Student satisfaction			
satisfied with this university	5.502	1.307	0.974
enjoyable experience	5.600	1.248	0.874
wise choice	5.584	1.410	0.848
good decision to register	5.707	1.410	0.840
met my expectations	4.964	1.593	0.786

The standardized regression weights are above 0.60 and the squared multiple correlations are satisfactorily high (Table 2). As far as the service quality scale is concerned, 16 of the 38 items of the HEdPERF scale showed a negative effect (items with factor loading values of lower than 0.5) were removed. The five-dimension structure of HEdPERF was confirmed. Concerning the student satisfaction scale, a one-dimensional structure was revealed ensuring the unidimensionality of the construct.

Tests concerning multicollinearity are also performed using two measures: the tolerance value of each item and the variance inflation factor (VIF). In this case, all the tolerance values are above the minimum acceptable cut-off value of 0.1 (tolerance values situated between 0.272 and 0.698), while all the VIFs are well below the maximum acceptable cut-off value of 5.0 (VIF situated between 1.329 and 3.720). All of the above indicate the absence of a multicollinearity problem in the data.

In addition, reliability analysis is applied by the internal consistency method calculating the Cronbach's α coefficient and the construct reliability index. The reliability both of the service quality scale (α=0.932) and of the student satisfaction scale (0.934) was higher than the evaluation standard criterion of 0.70 (Table 3). Moreover, the construct reliability (CR) values surpassed the acceptable level of 0.70 indicating that the selected items reliably estimate the latent factors (Table 3). Construct validity is confirmed by evaluating convergent validity (AVE>0.50) and discriminant validity (AVE>Corr^2) (Sadeh et al., 2013). The Average Variance Extracted (AVE) values for the two constructs were above the 0.50 threshold, supporting the convergent validity of the construct. Discriminant validity is evidenced by the fact that the Corr^2 is less than the AVE for each construct (Table 3).

Table 3 Reliability and validity of the constructs

	Reliability Cronbach's α	Construct Reliability (CR)	Average variance extracted (AVE)	(Corr)^2
Non-academic aspects	0.935	0.796	0.603	0.522
Program	0.717	0.779	0.572	0.316
Academic aspects	0.831	0.776	0.566	0.376
Reputation	0.827	0.777	0.570	0.361
Access	0.775	0.759	0.537	0.522
Student satisfaction	0.934	0.868	0.740	0.432

The research hypotheses were tested by a Structural Equation Modeling (SEM) analysis. The model showed a good fit; thus it is considered applicable for estimating the relationships among the variables (χ^2/df=1.730; RMSEA=0.041; GFI=0.918, CFI=0.972, TLI=0.967, NFI=0.936, IF1=0.972, PCFI=0.836, PNFI=0.806). Their regression standardized coefficient values were positive and significant ($p<0.01$) supporting H2, H4 and H5. In practical terms this means that students who have a positive opinion of the university's academic aspects, access and program issues are more satisfied (Table 4). H1 and H3 were not supported by the findings.

Table 4 Testing of research hypotheses

Hypotheses	**Estimate**	**S.E**	**Critical Ratio**	**p**	**Results**
Student Satisfaction←Non-Academic aspects	-0.099	0.073	-1.352	0.438	Reject H1
Student Satisfaction←Academic aspects	0.187	0.080	2.337	*	Accept H2
Student Satisfaction←Reputation	0.048	0.061	0.776	0.438	Reject H3
Student Satisfaction←Access	0.490	0.098	5.015	***	Accept H4
Student Satisfaction←Program issues	0.382	0.097	3.939	***	Accept H5

Note: *** Significant at p < 0.001, * Significant at p < 0.05

The analysis of variance (ANOVA) was applied to check how the average level of student satisfaction within the institution positively influences their attitude towards staying and continuing studying at the same university (Table 5). After applying the Tukey post hoc test, it is possible to determine that a statistically significant difference in the mean student satisfaction value exists among students' intentions (abroad, at the same university, at another domestic university). The more satisfied students are with the university at which they enroll, the more likely they are to continue their studies there. A lower degree of satisfaction leads students to look for another university in their country or abroad. This result supports H6.

Table 5 Results of Tukey post hoc comparison tests

Attributes	**studying at …**	**Mean (S.D.)**	**Sig. diff. in means**	**F-value**	**Tukey post hoc comparison tests**
Student satisfaction	the same	6.14 (1.01)	0.023	3.833	the same- domestic the same- abroad
	domestic	5.52 (1.2)			
	abroad	5.55 (1.5)			

Discussion and conclusions

The first purpose of this study is to examine the influence of service quality on student satisfaction based on primary data collected by Greek public universities. It is a response to academic calls for further research in the field of service quality in HEIs (Arrieta and Avolio, 2020; Rafik and Priyono, 2018).The results reveal that some sub-scales of the HEdPERF scale have a significant impact on student satisfaction. So, academic aspects, access and program issues are the influential dimensions of student satisfaction in the Greek higher education industry. Thus, managers of Greek universities should focus for predictive purposes on these dimensions to achieve their student satisfaction.

A negative or nonsignificant relationship between non-academic aspect and student satisfaction was also found. In recent years students have been using platforms to gain quick access to information, to log into the their portal, select courses, or find out their grades. Thus, they don't have regular personal contact with administrative staff and the chance to evaluate it (Bouranta et al., 2024). Maybe this is the reason that non-academic aspects have no significant impact on student satisfaction. Previous research has also found an insignificant relationship between reputation and student satisfaction (Damaris et al., 2019; Qazi et al., 2022; Bouranta et al., 2024).

As far as students' intentions after graduation are concerned, it was found that only 21.3% of the respondents plan to get a job after graduation, while the majority (50%) consider a master degree as essential in order to be hired employed and be successful. 41.5% of the students opt to stay in their own country. Most of them incline towards studying (24.5%), while the rest of them want to embark on their career (17%). However, it is a source of concern that 30% of the local respondents have the intention of leaving the country in order to study (25.5%) or work (4.3%) after graduating. The attraction of foreign study and work pointed out a serious student inclination towards the foreign environment. The ability of a country to retain students and skilled workers is critical as this source of highly skilled labour can contribute to domestic economic growth by increasing productivity and spreading know-how and innovation. Consequently, the loss of educated workers, who are an important asset and driver of development, is a serious issue for the home country, both economically and socially. Several countries are experiencing a shortage of skilled workers (Farivar et al., 2019) because a great many graduates depart from their country after completing their education to work or study abroad. The brain drain phenomenon is particularly pronounced in countries of Eastern Europe, the Western Balkans, the South Caucasus and Central Asia (World Bank, 2019). The flight of scientists affected the country's human resources both quantitatively and qualitatively. Recent governments have taken initiatives to retain competent students and workers. In order to promote higher student retention rates, it is important to understand the factors that determine their intention to leave. Students' low level of institutional satisfaction is likely to trigger their intention to switch to other universities for graduate studies.

The findings of the current study support the positive impact of students' satisfaction on their behavioral intentions, as the satisfied students are prompted to enroll in a higher level of studies within the same institution. It was found that the more satisfied students are with the university where they are enrolled, the more likely they are to continue their studies there. A lower degree of satisfaction leads students to look for another university in their own country or abroad. The students who choose to study abroad are likely to remain there and get a permanent job after finishing their post-graduate studies.

The improvement of service quality will increase satisfaction of students who will consider re-enrolling for post-graduate studies after the successful completion of their undergraduate studies. Thus, student satisfaction will also work as a potential determinant of students' decision to remain in their country. According to the human capital theory (Becker, 1964) people considered education as an investment in future earnings. The quality of education may affect students' expected returns when they compare the present value of future earnings obtained from studying in their home countries with the present value of future earnings obtained from studying abroad (Cao, 2022). The universities enhancing their quality may change the perception amongst students that studying abroad is better than studying locally. In addition, education quality may not only encourage local student to stay in their country but also attract international students. Thus university administrators and policy makers who desire to retain their students through to their graduate studies should focus of the service quality dimensions which the students considered important.

There are some limitations to this research. First, a drawback of this research concerns sampling. The data come from one country and the respondents were selected only from public universities enrolled in business administration programs. Students from other countries, private universities or different study fields may have different needs and intentions. Second, there is a need for research investigating the students intention over time, from the time of studying until some years after graduation. This is beacause several factors can affect and alter students plans after graduation, such as tuition fees, market opportunities, family recommendations, intervening events or new information. Further study is also required to explore other reasons that may influence students behavioral intention.

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Track 15: Sustainability and Service Innovation

Uncovering the Impacts of Food Safety Culture: A Systematic Literature Review

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Abstract

The present study focuses on Food Safety Culture (FS-culture), which has been recognized as a major factor in the context of food safety and aims at identifying its multifaceted impacts and grouping them into logical themes. A Systematic Literature Review (SLR) of peer reviewed journal articles was carried out based on four major academic publishers, namely, Emerald Online, Science Direct, Springer Link and Taylor & Francis. In total, 36 articles published in 12 journals during 2010–2024 were methodically selected and analysed, which revealed FS-culture impacts. A simple affinity diagram was applied to group the large number of FS-culture impacts into logical themes. The main themes of FS-culture impacts concern employee participation in food safety activities, food safety management, business performance, public health and regulatory compliance. The synthesis of the literature underscores the importance of prioritizing FS-culture as a strategic imperative for achieving prevention of food borne outbreaks, organizational excellence and societal well-being within the food sector. The limited number of the publishers and keywords used to search for the articles of interest, as well as the subjectivity of grouping the large number of the FS-culture effects into themes are the main limitations of the present study upon which future SLR studies can be designed. This SLR contributes to advancing our understanding of the complex interplay between FS-culture and its impacts, and provides valuable insights for practitioners, policymakers, and researchers striving to strengthen food safety practices and standards while promoting sustainable development within the food industry. No previous SLR studies focusing on analyzing the impacts of FS-culture have been published so far.

Keywords: Food safety culture, Impacts, Systematic literature review

Relevant Topic: Literature review

Introduction

Food safety remains a significant challenge, highlighted by recurring outbreaks despite extensive investments in food safety management systems (FSMS), regulations, training, and auditing (European Food Safety Authority and European Centre for Disease Prevention and Control (EFSA and ECDC), 2018). Annually, the United States faces 47.8 million foodborne illnesses, resulting in 127,839 hospitalizations and 3,037 deaths (Scallan et al., 2011). These outbreaks often come from failures in food safety programs due to improper human behavior or inadequate food safety culture (Griffith, 2010; Griffith et al., 2010a, 2010b; Jespersen & Huffman, 2014).

While FSMS design and implementation are crucial, the human element, e.g. perceptions, decision- making, and adherence to food safety protocols, significantly impacts food safety performance (De Boeck et al., 2015; Jespersen et al., 2017a; Nyarugwe et al., 2018; Ungku Fatimah et al., 2014). Recent research underscores the importance of a positive food safety culture in enhancing food safety outcomes (De Boeck et al., 2018; Jespersen et al., 2017a; Manning, 2018; Nayak & Taylor, 2018).

Incidents such as the 2008 listeriosis outbreak in Canada and the 2007 Melamine poisoning in China have spotlighted the critical role of food safety culture (Gossner et al., 2009; Hatt & Hatt, 2012). Furthermore, the Global Food Safety Initiative (GFSI) has adopted food safety culture as a GFSI benchmark criterion in the new private standards versions (BRCGS, IFS FOOD, FSSC 22000). Meanwhile, on September 2020, Codex Alimentarius Commission revised the General Principles of Food Hygiene CXC 1-1969 and introduced the concept of food safety culture as a general principle. The extension of food hygiene requirements in Regulation (EC) No. 852/2004 through Regulation (EU) 2021/382 introduced the term of food safety culture in the European Union’s legislation and made it obligatory in food industry companies in the European Union (Cavelius et al., 2023).

Although the effectiveness of Hazard Analysis and Critical Control Point (HACCP) plans in managing food safety, breaches still occur, highlighting the need for a robust food safety culture (Powell et al., 2011a, Duong et al., 2023; Jespersen et al., 2019a). A positive food safety culture, alongside a well- implemented FSMS, is essential for optimal food safety performance (De Boeck et al., 2015; Powell et al., 2011a).

GFSI (2018) asserted that a positive food safety culture is integral to organizational culture. The concept of organizational culture was first defined by Jaques (1952) and elaborated by Schein (2004), who defines it as a set of shared basic assumptions learned by a group while solving problems of external adaptation and internal integration. These assumptions, having proven successful, are taught to new members as the correct way to perceive, think, and feel about these issues (Schein, 2004). Jespersen et al. (2016) used this definition to develop a food safety maturity model.

Various definitions of food safety culture highlight its complexity and multifaceted nature. Griffith et al. and Yiannas were the first people to propose definitions for food safety culture (Griffith, 2010; Griffith et al., 2010b, 2010a; Yiannas, 2009), while lastly Sharman et al. (2020) define it as the collective beliefs and behaviors impacting an organization's food safety performance. Effective food safety culture management requires clear identification and understanding of its influencing factors (Nyarugwe et al., 2018; Wiśniewska et al., 2019). Mixed-method assessment approaches are recommended to capture the full depth of food safety culture (De Boeck et al., 2019; Zanin, Luning, et al., 2021).

Research has shown that food safety culture significantly impacts public health, organizational performance, and individual behavior. Enhancing food safety culture can notably reduce the incidence of foodborne illnesses, as it addresses a critical risk factor in disease outbreaks (Griffith et al., 2010b; Nayak & Taylor, 2018; Powell et al., 2011a; Reynolds & Rajagopal, 2018; Wiśniewska, 2023). Moreover, fostering a robust food safety culture not only mitigates risks but also offers economic benefits to companies, highlighting its dual role in improving safety and achieving financial gains (Duong et al., 2023; Jespersen et al., 2019b).

This systematic literature review explores these multifaceted impacts of food safety culture, aiming to offer a thorough understanding of its significance. Given this context, it is evident that there is a pressing need to review existing literature in order to identify and analyze the impacts of food safety culture. Thus, the main objective of this paper is to add value by reviewing a large body of studies and to synthesize the review findings into a comprehensive multi-dimensional framework offering a guidance to policymakers, food industry professionals, and regulators on the effect of assessing, improving and sustaining a strong food safety culture within organizations, and for academics seeking future research topics of high interest. Each systematic literature review (SLR) is driven by a clearly defined and well- justified research question (Kuckertz & Block, 2021). Accordingly, this study seeks to answer the following research questions through an SLR of articles on food safety culture published over an extended period.

RQ1. What are the impacts of food safety culture?

RQ2. What are the main themes of the impacts of food safety culture?

The paper is structured as follows: it begins with an overview of food safety culture evolution and then the SLR and the respective stages are presented. Subsequently, the results of the literature review are presented in detail, outlining the profiles of the reviewed articles, the identified impacts of food safety culture in the literature, and the emerging themes. Lastly, the discussion of the findings and the conclusions are presented.

Methods

To accomplish the objective of this study, a systematic literature review (SLR) on food safety culture was undertaken. This approach offers distinct benefits compared to traditional narrative reviews (Halim Lim et al., 2017; Hu et al., 2015). Numerous articles in reputable scientific journals have discussed 48 impacts of food safety culture (Hu et al., 2015). The study followed the SLR methodology outlined by (Lettieri et al., 2009; Tranfield et al., 2003), which includes the planning, conducting, and reporting/dissemination stages.

Stage I – planning the review

The main phase of this stage includes the preparation and development of the review protocol (Tranfield et al., 2003). The protocol should include the different sources that are going to be used for identifying relevant articles, the intended search strategy, the specific criteria for including and excluding articles, the criteria for assessing the quality of the studies selected, and any other information that would allow someone else to reproduce the review (Lettieri et al., 2009; Tranfield et al., 2003). The literature search starts with the database selection in accordance with the research protocol (Thomé et al., 2016). A variety of online databases of academic publishers was used to increase the accuracy of the analysis and minimize bias. Following the approach of the most recent systematic literature review study in the food safety culture field conducted by Zanin, Stedefeldt, et al. (2021) and also most recognized publishers, the publishers selected for this study were the following: Emerald Insight, Elsevier/ ScienceDirect, SpringerLink and Taylor & Francis. It is worth noting that Emerald Insight, Taylor & Francis and Wiley include the largest repositories of business research (Sawyerr & Harrison, 2019), while Elsevier/ScienceDirect and SpringerLink publish high-quality scientific articles with generally low overlap in terms of duplications (Hrabovská et al., 2019). Furthermore, the search strategy should be reported sufficiently to ensure that the search could be replicated (Tranfield et al., 2003). In this study, the search strategy was developed to identify peer-reviewed articles published by the abovementioned publishers between 2010 and 2024. The selection of the year 2010 as the starting point for this literature review study was based on the fact that the year 2010 was taken as the beginning of the present SLR, given that the beginning of 2010 decade was the starting point of publishing food safety culture research articles (Ball et al., 2010; Griffith et al., 2010b, 2010a; Yiannas, 2009). It is worth noting that since Griffith's first published articles in 2010 (Griffith, 2010; Griffith et al., 2010a, 2010b), the literature on food safety culture has grown rapidly with increasing knowledge and expertise in the fields of organizational and safety culture (Nyarugwe et al., 2016). As a complex phenomenon, authors have proposed several determinants for conducting food safety culture research, such as a systems approach, defining measurable indicators, using a classification system, and applying triangulation methodology (Jespersen et al., 2017b; Nyarugwe et al., 2016). However, there is a lack of recent literature review articles with lastly were the mixed methods SLR on food safety culture assessment evolution by Zanin, Stedefeldt, et al. (2021) and the literature review about legal and normative requirements for food safety culture by Cavelius et al. (2023), while there isn't any SLR about food safety culture impacts in bibliography. According to Hanim Md Pazil & Che Razak (2019), a period of 10 years is considered adequate to determine the evolution of existing studies and related publications. This also justifies the selection of the year 2010 as the starting point for the present SLR. Inclusion and exclusion criteria were then formulated (Table 1) to identify relevant articles. According to Booth et al. (2016), inclusion and exclusion criteria are formulated to make clear to the reader why some articles have been excluded from the review. Finally, a quality assessment of the articles selected should be undertaken to refine the literature selection (Tranfield et al., 2003). More specifically, the quality of the selected articles was evaluated based on criteria such as the clarity and accuracy of the purpose of the respective study, the study specificity and utility (Gough, 2007; Mubayrik, 2018), and the methodological design and quality including the reliability and validity of the latent constructs of the theoretical framework formulated in each study (Alcivar et al., 2017; Lee, 2017). The quality assessment was undertaken simultaneously by the authors of the present study, and any disagreements and doubts were resolved through discussion, to reduce subjective bias and enhance the reliability of the selection.

Stage II – conducting the review

Based on the search terms identified during the planning stage, search strings were formulated and entered consistently into the bibliographic databases. All articles retrieved

Table 1. *Inclusion and exclusion criteria for literature review*

Inclusion criteria	Exclusion criteria
Articles published between 2010 and 2024	Any publication before 2010 and after 2024
Well-known publishers: Emerald Insight, Elsevier/ ScienceDirect, SpringerLink, Taylor & Francis	Non-academic publishers
Fully accessed articles	Non fully accessed article
Academic journals	Books, online sites and grey literature (conferences, master's theses, doctoral dissertations, textbooks, working papers, technical reports, project deliverables, editorial notes, newsletters, magazines, PowerPoint presentations, etc.)
Only peer-reviewed articles	Articles that were not peer-reviewed
Articles in which FS-culture was of primary research interest	Articles in which FS-culture was not the main focus
Articles highlighting FS-culture impacts	Articles not highlighting FS-culture impacts
Articles written in the English language	Articles written in any language other than English

from these databases were screened and assessed for their relevance to the study's focus, considering the title, abstract, and keywords of each article, and when necessary, the full paper was read for clarity. The application of inclusion and exclusion criteria narrowed the selection to a final sample of 36 articles published across 14 journals (Table 2). Information such as the title, publication year, journal, authors, paper type, geographic research area, industry sub-sectors, and the number of companies involved in the research, along with statements regarding food safety culture impacts, was extracted and compiled into an Excel spreadsheet (Hu et al., 2015; Tranfield et al., 2003;). It is worth noting that the FS-culture impacts were reported by the authors in the reviewed articles using statements such as "The impact of […] led to […].", "Following […], […] was observed.", "Consequently, […] was a direct outcome of […]." the influence of […] led to […].", "There is a clear link between […] and […].", The positive impacts of […] include [...].", "As a beneficial result of […], […] was achieved" and so on. In order to deal with the chaotic and unorganized qualitative data of FS-culture impacts, the "affinity diagram" was applied (Lagrosen, 2019), which is one of the "new seven quality tools" (McDermott et al., 2023; Sousa et al., 2023) and commonly used (Tarí & Sabater, 2004). By organizing the FS-culture impacts into natural and logical groups, according to some form of natural affinity (Moura E Sá & Martins, 2016), a meaningful structure of themes of FS-culture impacts was created (Chan et al., 2009; Lagrosen, 2019).

Stage III – reporting and dissemination

Building on the Excel spreadsheet created in Stage II, a comprehensive overview of the sample articles is given and critically examined. Additionally, the identified research gaps and the significant themes discovered are presented analytically, offering a detailed examination of the current research gaps. This stage also includes the clustering and ranking of FS-culture impacts themes.

Results

Publisher and journal

A rate of 83.2% (41.6% - 15 articles per each publisher) of the sample articles were published by both of Elsevier/ScienceDirect and Emerald Insight, 13.8% (5 articles) by SpringerLink and 0.02% by Taylor & Francis (Table 1, Figure 1). In all, the 36 articles considered for this SLR were published in 14 different academic journals. However, some journals published more FS-culture articles than others. A rate of 52.7% of the sample articles were published in the following two journals: the Food Control (11 articles, 30.5%) and British Food Journal (8 articles, 22.2%).

Table 2. *The list of journals considered in the present study*

Publishers - Journals	Number of Articles	Percent
Science Direct	15	0,416
Food Control	11	0,305
Trends in Food Science & Technology	2	0,055
Journal of Food Protection	1	0,027
International Journal of Hospitality Management	1	0,027
Emerald Insight	15	0,416
British Food Journal	8	0,222
Worldwide Tourism and Hospitality Themes	5	0,138
International Journal of Contemporary Hospitality Management	1	0,027

Journal of Agribusiness in Developing and Emerging Economies	1	0,027
SpringerLink	5	0,138
Agriculture and Human Values	1	0,027
Early Childhood Education Journal	1	0,027
Operational Management Research	1	0,027
International Journal of Environmental Health Research	1	0,027
Food Security	1	0,027
Taylor & Francis	1	0,027
Journal of Marketing Channels	1	0,027

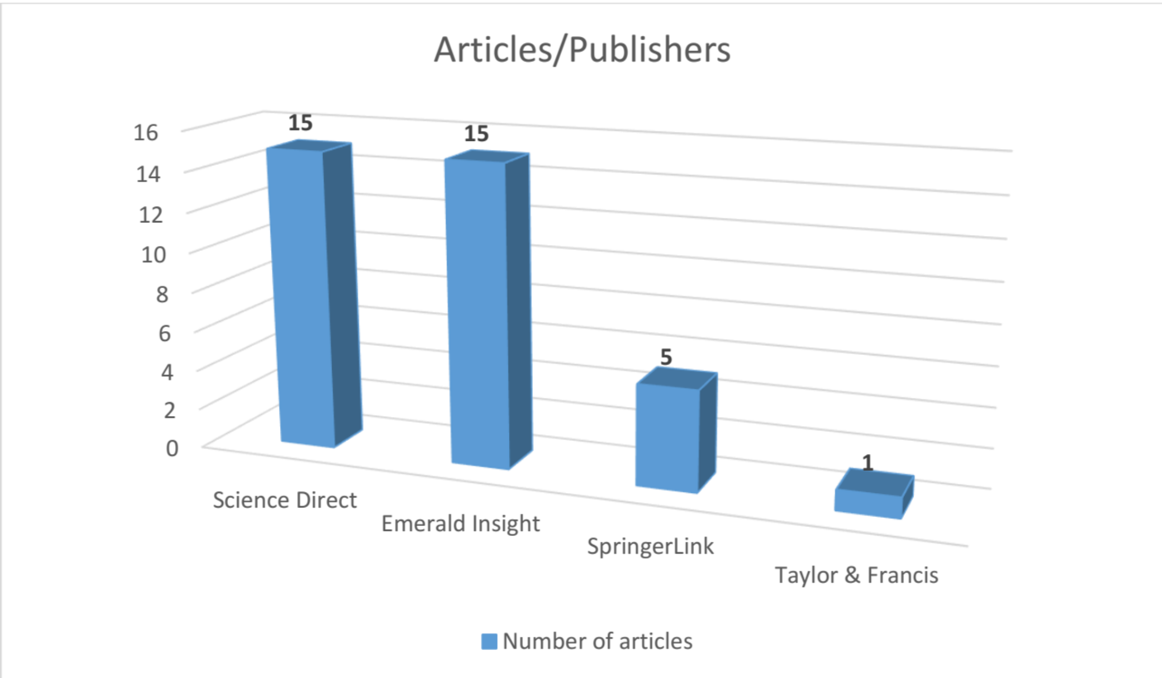

Figure 1. *Distribution of the articles based on the publishers*

Article type

Based on the article type, the sample articles were categorized as empirical, conceptual and literature review articles, following the approach of the previous SLR studies conducted by (Aquilani et al., 2017; Bakır, 2017; Gatti et al., 2019). The majority of the sample articles were empirical in nature (27 case studies and 27 surveys, 80.6%), followed by articles which used a conceptual approach (11 articles, 16.4%). The literature review articles represented the smallest share (two articles, 3.0%) (Figure 2). It is worth noting that among the empirical sample articles, 66.7% (36 articles) used cross-sectional data and only 33.3% (18 articles) applied a longitudinal research approach.

Figure 2. *Distribution of articles based on the research method*

Year of publication

The reviewed articles were screened based on the year of publication to determine how academic interest in the FS-culture subject has evolved over time. As shown in Figure 3, the number of the sample articles remained consistently low from 2010 to 2016, with the mean number of publications per year (in the period 2010–2016) at 1.3. However, a steep rise in the number of publications was observed in 2017 with the publication of 6 articles. The number of the sample articles had two ups and downs from 2018 to 2023 but remained at rising levels compared to the first half of the decade (2010 to 2016), since 8 articles were published from 2010 to 2016 and 28 articles were published from 2017 until 2023. In 2017 and 2020, the number of the sample articles reached a peak at 6 per year. Based on above, it is obvious that a significant pool of articles are available revealing the FS-culture impacts.

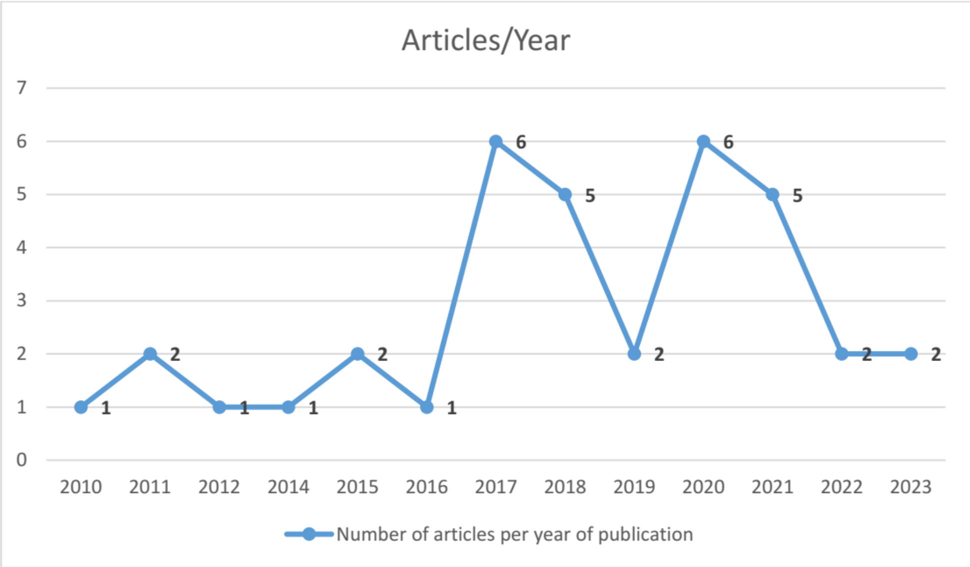

***Figure 3**. Distribution of articles based on the year of publication*

Data collection method

The empirical articles were further analyzed in terms of the data collection method used. These articles used various data collection methods, including archives, interviews, questionnaires and mixed methods. It is evident from Figure 4 that the questionnaire was the most frequently used data collection method (16 articles, 44.4%). In addition, a significant number of researchers relied on archives and mixed methods to collect data (9 articles, 25% each). Both of mixed method and interview were not so popular methods for data collection, since mixed method was used in 6 articles (16%) and interview in 5 articles (13.8%).

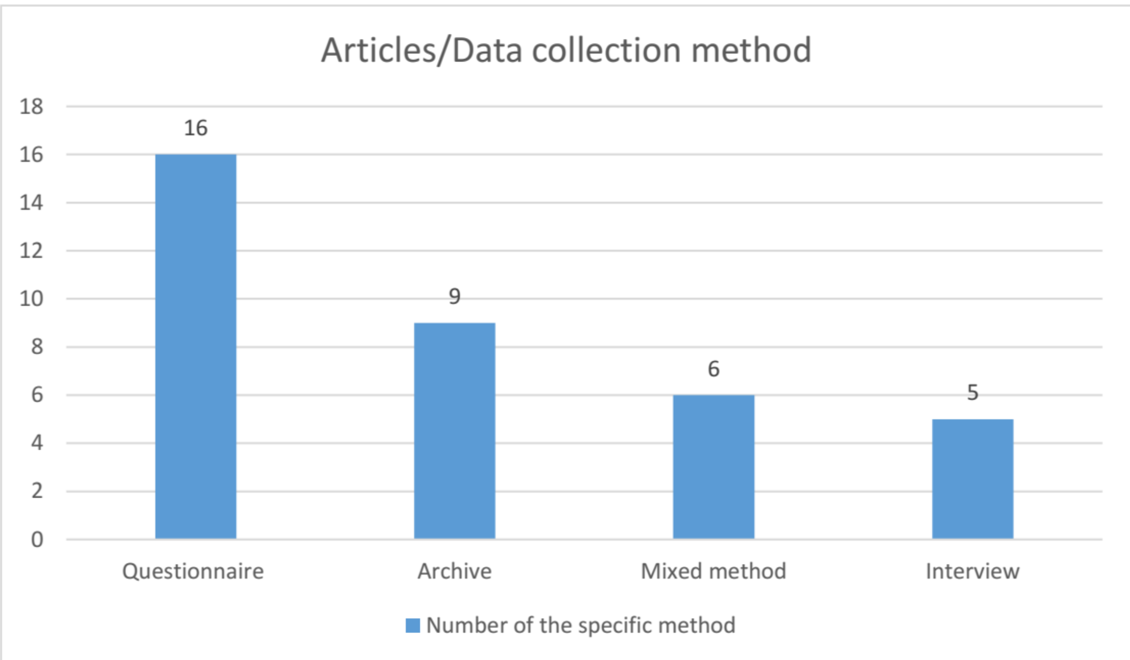

***Figure 4.** Distribution of articles based on the data collection method*

Geographic research area

The empirical articles were also classified according to the continent and country where the research was carried out. Most of these FS-culture studies were conducted in Multiple continents (10 articles, 27.7%) and Asia (10 articles, 27.7%), followed by North America (6 articles, 16.6%) and Europe (5 articles, 13.8%). Africa, Ocean and South America had a lower concentration of studies (3 articles, 0.08% for Africa and 1 article, 0.02% for the last two continents) (Figure 5). In terms of the countries where the empirical studies were conducted, there were 15 cross-national studies conducted (e.g. Greece, Zambia, China and Tanzania etc.), while the rest of these studies were conducted in 10 different countries (Figure 6). The countries with the highest number of empirical studies are the USA (5 articles) and United Arab Emirates (4 articles), while in UK, Madagascar and Zimbabwe were placed 2 studies in each country (Figure 6).

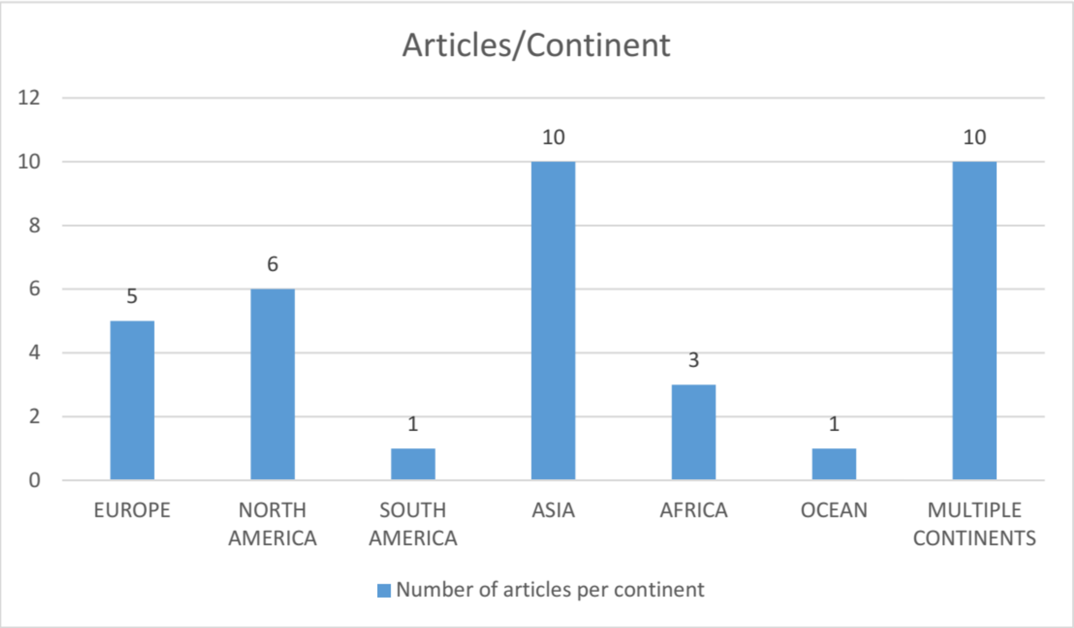

Figure 4. *Distribution of articles based on continent*

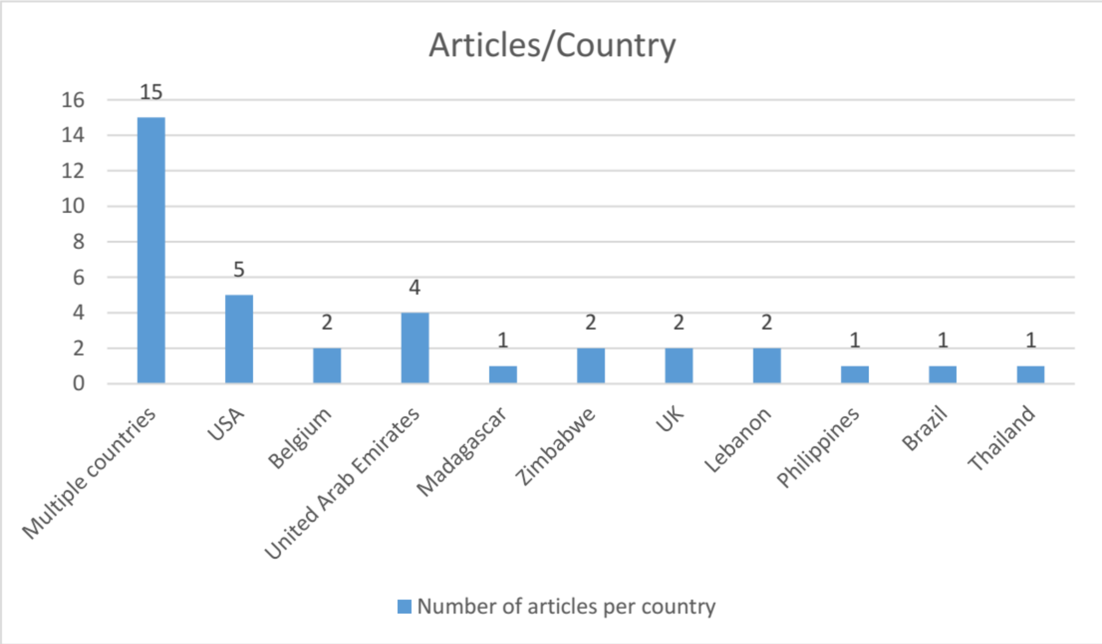

Figure 5. *Distribution of articles based on the countries where the studies were conducted*

Industry sector

The FS-culture studies were conducted mainly in both of the food manufacturing sector (12 articles, 33.3%) and food service sector (12 articles, 33.3%), followed by little studies in multiple sectors (2 articles, 0.05%) and the public organization sector (2 articles, 0.05%). Retail, packaging and farm sector did not attract much attention from researchers, by conducting just one study per sector (1 article, 0.02%) (Figure 7).

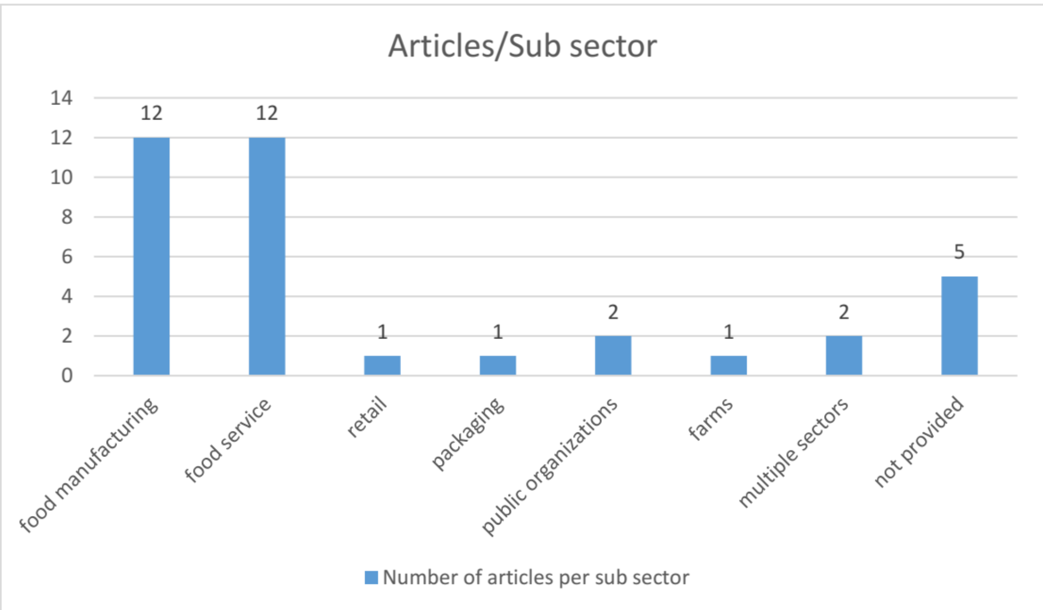

Figure 6. *Distribution of articles based on sub sectors*

Impacts of food safety culture

The FS-culture impacts presented by several authors in the reviewed articles were classified, through the "affinity diagram", into 5 meaningful themes (Table 3). The FS-culture impacts classified in a respective theme are highly inter-related. This makes each theme unidimensional and substantially discriminating from the others. The themes of the FS-culture impacts are the following (in descending order based on the number of the literature references): impact on business performance (18 references), impact on food safety management (18 references), impact on public health (15 references), impact on employee participation in food safety activities (14 references) and impact on regulatory compliance (9 references).

Table 1. *The FS-culture impacts and the respective themes*

Themes	Impacts
Impact on business performance	The impacts of FS-culture on business performance are the following: economic gain (Duong et al., 2023; Jespersen et al., 2019), reduced cost of poor quality and increased savings gain (Jespersen et al., 2019), improved operational performance and business sustainability (Duong et al., 2023; Emond & Taylor, 2018; Frankish et al., 2021; Manta et al., 2022), driving changes and continual improvement throughout the company (Caccamo et al., 2018; Nouaimeh et al., 2018; Taylor et al., 2015), gaining recognition (Emond & Taylor, 2018), setting good food safety and hygiene practices over generating profits (Nayak & Taylor, 2018), improved reputation (Jespersen et al., 2019), enhancing market recovery in the event of a food

Continued

	safety incident (Frankish et al., 2021; Harris et al., 2018), progressing towards company's certification and accreditation (Evans & Taylor, 2021), market recovered in case of foodborne disease incident (Harris et al., 2018).
Impact on food safety management	The impacts of FS-culture on food safety management are the following: improved food safety performance (Abebe, 2020; Jespersen et al., 2019b; Nyarugwe et al., 2020; Taha et al., 2020; De Andrade et al., 2020), enhanced microbiological safety effectiveness of organization (De Boeck et al., 2016; Nyarugwe et al., 2018), reduced vulnerability to microbial contamination throughout the food production system (Nyarugwe et al., 2020), improved implementation, effectiveness and efficacy of a food safety management system (Faour-Klingbeil et al., 2015; Griffith et al., 2017; Maiberger & Sunmola, 2023; Manning, 2017; Nayak & Taylor, 2018; Nayak & Waterson, 2017), critical factor for implementation food safety interventions (Grace, 2023), prevention of bad standard practices in farms (Thongpalad et al., 2022).
Impact on public health	The impact of FS-culture on public health are the following: improved food safety and hygiene (Frankish et al., 2021; Griffith et al., 2017; Nayak & Waterson, 2017), improving food safety (Frankish et al., 2021; Griffith et al., 2017), improved health and safety (Nayak & Waterson, 2017), reduced incidence of disease and foodborne illness (Griffith et al., 2010b; Nayak & Taylor, 2018; Powell et al., 2011a; Reynolds & Rajagopal, 2018; Wiśniewska, 2023), reduced injuries (Jespersen et al., 2018), prevent a food safety incident (Manning, 2017), associated with lower L. monocytogenes contamination risk (Wu et al., 2020).
Impact on employee participation in food safety activities	The impacts of FS-culture on employee participation in food safety activities are the following: Employees have a positive behavior towards food safety management and fully engage in it (De Boeck et al., 2017; Faour-Klingbeil et al., 2015; Powell et al., 2011a), adhere to hand washing according to the level of food safety culture (Clark et al., 2019), stay up- to-date on emerging food safety issues (Powell et al., 2011a), communicate compelling and relevant messages regarding risk-reduction activities and empower others to put them into practice (Powell et al., 2011a), foster a value system within the organization that focuses on avoiding illnesses

	(Powell et al., 2011a), promote effective implementation of a food safety system before an incident occurs (Powell et al., 2011a), do not blame customers (including commercial buyers and end consumers) when illnesses are linked to their products (Powell et al., 2011a), prepare well organized and safe food as street food vendors (Sarter & Sarter, 2012), help management team gain valuable feedback, which is useful in establishing baseline and benchmark data points (Ungku Fatimah et al., 2014), always behave the right way (Emond & Taylor, 2018), are "audit-ready" at all times (Emond & Taylor, 2018), improve their productivity (Jespersen et al., 2019).
Impact on regulatory compliance	The impacts of FS-culture on regulatory compliance are the following: reduced the number of legal notices (Nayak & Waterson, 2017), reduced time of the inspection by Environmental Health Officers (Nayak & Waterson, 2017), improved compliance with food safety practices (Griffith et al., 2010a; Wiśniewska, 2023), improved compliance with third-party hygiene standards (Griffith et al., 2010a), reduced number of food safety violations (De Andrade et al., 2020), reduced number of inspections the company has to carry out (Nayak & Waterson, 2017), reduced customer complaints (Jespersen et al., 2019), prevent an associated recall (Manning, 2017).

Discussion

The profile of the reviewed articles

Significant insights have been derived from the descriptive analysis of the sample articles. Over a 13- year review period, 36 articles were published in 14 journals, highlighting the impacts of food safety culture. The body of research on food safety culture is likely to grow substantially in the coming years. Between 2010 and 2016, only 8 articles were published, whereas from 2017 onwards, 28 articles have been published. Key sources of literature for those interested in food safety culture include databases like Science Direct and Emerald Insight, as well as journals such as Food Control and the British Food Journal. The impacts of food safety culture span various sub-sectors within the manufacturing and services industries. Focusing on a specific sub-sector can provide deep insights into food safety culture issues within that business environment. Additionally, comparing different sub-sectors can help identify how specific conditions within each sub-sector influence the impact of food safety culture in an organization. Researchers have shown significant interest in food safety culture studies that cover multiple continents, as well as Asia, with notable focus on countries like the United Arab Emirates and the USA. This suggests that multinational studies should continue to attract researchers, enabling comparative empirical studies on food safety culture across businesses in different countries with diverse food safety governance and national values. Furthermore, expanding research to other industrialized Asian countries could provide valuable insights into food safety culture. Interest in food safety culture research is also growing in North America, but this trend needs further enhancement. These regions present fertile ground for future research. Conversely, in Africa, Oceania, and South America, research on food safety culture remains limited and should be increased.

Discussing the themes of food safety culture impacts

In order to gain significant insights from the plethora of the impacts of food safety culture identified in the reviewed articles, the affinity diagram was used allowing thus to exploit the similarities among the suggestions. Through this quality tool, it became possible to minimize the large volume of information collected and to create a more manageable data set consisting of 5 meaningful and unidimensional themes of the food safety culture impacts. The variety of the statements attributed to each theme implies that there are many aspects of managing FS-culture issues that need to be further researched. The themes revealed are the following: impacts on descending order based on the number of the supporting literature references of the food safety culture impacts (Table 3): impact on business performance, impact on food safety management, impact on public health, impact on employee participation in food safety activities and impact on regulatory compliance. Based on the aforementioned, it is clear that addressing specific issues related to food safety performance, such as consumer death, illness, and injury (Havelaar et al., 2015), as well as the effect on brand and economic factors (Hussain & Dawson, 2013) across the food supply chain, now widely acknowledges the crucial role of food safety culture (Ball et al., n.d.; Griffith, 2010b; Griffith et al., 2017; Nayak & Waterson, 2017; Powell et al., 2011b; Taylor, 2011).

Conclusions, limitations and agenda for future studies

The limited number of literature review articles of food safety culture published so far focus on various subjects excluding the impacts of food safety culture. For example, Cavelius et al. (2023) presented the legal and normative requirements applying to food safety culture by identifying and condensing the applicable requirements, Spagnoli et al., (2023) proposed a food safety culture diagnosis and gap analysis methodology as the first two steps in the food safety culture improvement roadmap, Zanin, Stedefeldt, et al. (2021) conducted a mixed-methods systematic review to analyse the evolvement of scientific FS-culture assessment tools, while Nayak & Waterson (2017) investigated the current challenges, barriers and future opportunities of the assessment of FS-culture. This has strongly motivated the author of the present study to systematically review the literature focusing exclusively on the impacts of FS-culture. The contribution of the present SLR is attributed, firstly, to the fact that the subject that is analyzed has not been previously reviewed; secondly, to the analytical way that the impacts statements are presented; and finally, to the summarized picture of the FS-impacts statements that is revealed though formulating the respective themes. Portraying the food safety culture impacts of the existing FS-culture studies would help researchers better highlight the literature and research gap, as well as practitioners understand the significant benefits FS-culture and formulate their improvement plans. However, the present SLR suffers from some limitations that should be considered in future. For example, only four academic databases, to which the researchers had free access from their home institution, were used to search for FS-culture articles. It is therefore recommended that future literature review studies should incorporate additional databases to the ones searched in this study to lower the risk of missing documents. In addition, the literature search was limited to articles published in the English language, which implies that some relevant articles written in other languages may have been excluded. For this reason, it is suggested that future studies extend the breadth of the literature review by incorporating articles written in languages other than English. Moreover, although a significant number of keywords was carefully selected for this literature review, completeness is not assured. Thus, expanding the keywords to identify as many articles as possible represents a promising avenue for future literature review studies. Finally, another limitation of this SLR is related to the subjectivity in applying the "affinity diagram" quality tool. So, the subjectivity of grouping the large number of the practical implications into themes should be taken into consideration while interpreting the present study findings. To address this shortcoming, the evaluation process of the FS-culture impacts should be conducted by a larger panel of experts and external reviewers.

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Service Ethics for the Complexity of Modern Service Interactions by Including Non-Customers

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Abstract

The emergence of digital service platforms enabled numerous interaction effects that remain largely unexplored, especially when it comes to the intended or unintended impacts on non-customers. A conceptualization of service ethics for modern interactions enabled by digital service platforms is introduced in this paper. The conceptual framework is illustrated through two narratives of non-customers being intentionally and unintentionally exploited by customer interactions enabled by digital service platforms. By integrating theoretical insights with illustrative narratives, the paper demonstrates the potential impact of digital service platforms on non-customers' well-being, highlighting instances of exploitation and unintended consequences. The study advances service research by focusing on non-customers that might experience intentional or unintentional exploitation. Furthermore, the paper outlines a future research agenda for exploring and advancing the understanding of service ethics, along with the implications for fostering ethical business practices and shaping ethical societal norms.

Keywords: service ethics, service interaction, digital platforms, non-customers, enabling, well-being, well-becoming, service systems

Introduction

Modern service interactions are enabled by digital service system platforms that can be activated using digital devices (phones, tablets, computers, and watches) (Letaifa et al., 2016; Tan et al., 2022). These new digital platforms have created a wide range of interaction effects, which have not yet been studied. Thus, a conceptualisation of service ethics that encompasses service systems and a broader service ecosystem is needed (Edvardsson & Tronvoll, 2020; Letaifa et al., 2016). This study conceptualises service ethics beginning with typical service interactions, including the intended or unintended effects of these interactions on non-customers.

The simplest form of service interaction involves a dyadic exchange between a service provider and customer (Bitner et al., 2000), which forms the focal point of many discussions in the business ethics literature (Freeman, 1994). However, service interactions extend beyond this dyadic relationship to encompass interactions with other individuals, nature, and physical environment. In the 21st century, ethical decisions in services have complex social impacts owing to the integration of digital service system platforms into service systems (Letaifa et al., 2016; Tan et al., 2022). These platforms have improved service delivery by enhancing efficiency, accessibility, and personalisation (Latupeirissa et al., 2024). However, they also enable digital service interactions to have a negative impact on non-customers. These changes have raised new ethical considerations that have not been explored in the service, business, or marketing ethics literature.

While the normative approach of S-D logic provides excellent perspectives on how service systems should operate in a mutual fashion, it does not explain how to create and maintain such systems or how to transform service systems that are not mutually beneficial. In their comprehensive book on S-D logic, (Lusch & Vargo, 2014, p. 117) state, “Forced or involuntary exchange is an interesting area of inquiry, but one that S-D logic does not address”. Addressing involuntary exchange requires recognising the humane or ethical ethos of the S-D logic (Laczniak & Murphy, 2019). Furthermore, Transformative Service Research (TSR) provides the much-needed improvement logic necessary for enhancing human well-being (Anderson et al., 2013). Recently, ServCollab, a human services non-profit based on TSR, expanded its mission "to serve humanity through research collaborations that catalyse reducing suffering, improving well-being, and enabling well-becoming.” www.servcollab.org

With more than eight billion humans sharing the precious resources of our planet, we urgently need to enable each other’s well-becoming by respecting and celebrating human diversity including non-service customers (Russell-Bennett et al., 2023). Developing service ethics is necessary to transform fragile and contentious service ecosystems to resilient, harmonious, and regenerative service ecosystems. Our research builds upon prior conceptualisations of service and ethics to create a conceptual framework for exploring the intended or unintended societal impacts of modern service interactions enabled by digital service platforms on the well-being and well-becoming of non-customers.

This study makes three major contributions to the literature. First, it contributes a conceptual framework for the impact of modern service interactions on non-customers. The explanatory power of our conceptual framework is demonstrated through an illustration of two thought-provoking narratives of non-customers intentionally or unintentionally exploited by customers of services provided on digital service platforms. In the first narrative, housemaids are traded via various digital service platforms such as mobile trading applications and social media. The narrative examines a contemporary form of labour exchange that features indentured servitude. The second narrative concerns the obstacles faced by a visually impaired Paralympian who experiences difficulties that prevent him from fulfilling his basic mobility needs because people dump e-scooters on sidewalks. These illustrative narratives enable the exploration of service interactions as life experiences (Connelly & Clandinin, 1990; Czarniawska, 2004). These narratives exemplify the potential problems caused by modern service platforms. Our second contribution is the development of service ethics to protect non-customers from intentional and unintentional service exploitations that significantly influence their well-being. Our framework fosters social inclusion by recognizing suffering of non-customers and promoting their well-being. The third contribution outlines an agenda for future research in service ethics, along with implications for fostering ethical business practices and shaping ethical societal norms.

This study begins by introducing essential service ethics in modern service interactions and the essential concepts for building service ethics, followed by a theoretical and conceptual framework. The impact of modern service interactions on non-customers is then illustrated. Subsequently, the conceptual framework is discussed, followed by implications and a future research agenda.

Service ethics in modern service interactions

As the conceptualisation of service has expanded in the 21st century, the understanding of service interactions has also expanded. Today, service interactions include all the social and economic interactions between and among humans. They also include all technology-mediated interactions (Bitner et al., 2000), which may occur via digital platforms or any other technology that provides intermediary interactions (Edvardsson & Tronvoll, 2020; Letaifa et al., 2016; Tan et al., 2022). Furthermore, the role of ethics in decision-making should expand, as ethical decisions impact the benefits and suffering of individuals and/or groups. At the actualisation layer (societal level), ethical decisions "relate to the social ramifications of organizational decisions and affect everyone in society" (Bridges, 2018, p. 577). We argue that ethical decisions in services should include societal impacts on both customers and non-customers.

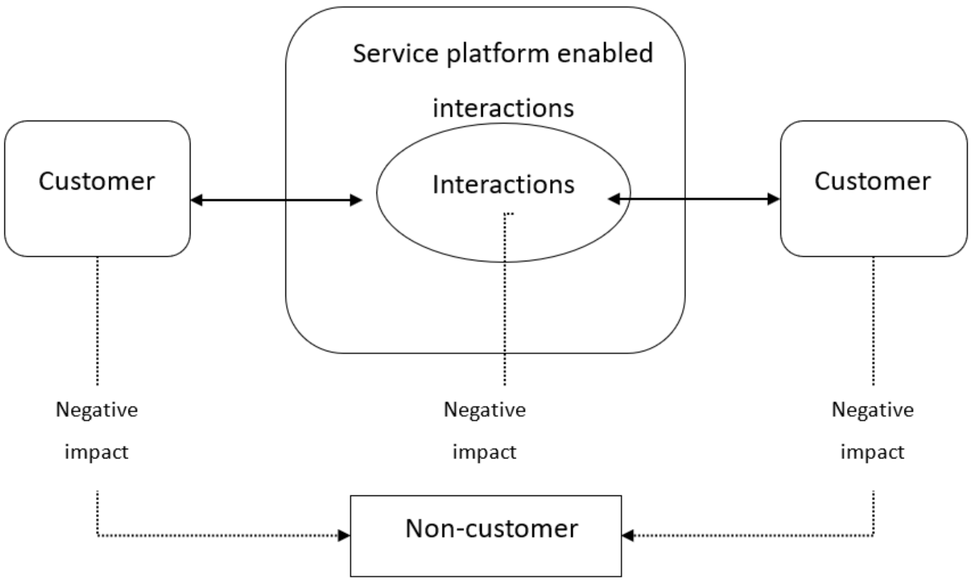

Figure 1. *Modern service interactions impact on non-customers*

As service systems are the basic abstraction of service science (Maglio et al., 2009), we conceptualise service ethics from a system flow perspective. Hence, we argue that service ethics should include the purpose of the service, the process of the service, and the outcome of the service. Further, it is necessary to consider the intended or unintended societal effects of these service interactions on others in the service ecosystem. The simplest service interaction is a dyadic interaction between a service provider and a service customer (Bitner et al., 2000). This is where most discussions on business ethics are centred (Freeman, 1994). The purpose, process, and outcomes of service interactions are explored further in the Theoretical Framing section.

Concepts for building service ethics

This section provides foundational conceptual framing for building service ethics, based on the relationships between key concepts (Jaakkola, 2020). Conceptual framing focuses on introducing essential service ethics concepts from philosophical and service perspectives.

Philosophical perspectives on ethics

In this section, ethics are discussed from different philosophical perspectives and forms. Winkler (2022, p. 65) defines ethics as "a system of moral principles and norms that guide the relationships between humans and between humans and their natural and artificial environment." Ethics, as a set of principles guiding moral values, directs human behaviour based on considerations such as rights, fairness, societal benefits, and virtues. The inherent characteristics of culture and social history shape the necessity of good behaviours and define well-established values, traditions, religious beliefs, and other factors that influence the morality of communities and individuals (Walker & Hennig, 2004). This captures the essence of the deontological aspect of ethics, which literally translates to the "study of duty," emphasizing the focus on duties and rules (Immanuel Kant, 1724–1804). This perspective prioritises individual principles over the consequences of actions (Bridges, 2018; Cervantes et al., 2016; Van Staveren, 2007).

Over the past two centuries, ethical discourse has been characterised by a dichotomy between two broad frameworks: the deontological view and the teleological view, which focus on goals and outcomes (Yazdani & Murad, 2015). The Hunt-Vitell model suggests that the processes or guidelines individuals employ in ethical decision-making can be mapped onto these two frameworks (Hunt & Vitell, 1986; Hunt & Vitell, 2006). Various interdisciplinary scholars argue that deontological and teleological evaluations are mutually exclusive, examining how individuals adopt favourable deontological or teleological outcomes. (Friesdorf et al., 2015).

In recent decades, axiological perspectives have been incorporated into ethical discourse to evaluate the value of outcomes (Yazdani & Murad, 2015). For example, consider the value of booking an "Airbnb" for the service customer without acknowledging the moral obligations regarding the unintended consequences, such as the potential increase in housing costs and homelessness for locals in major cities and tourist destinations. Similarly, the use of Uber may contribute to local taxi owners' joblessness. The axiology of ethics contemplates questions such as ‘What should one value?’ Axiological change remains a constant feature of human history as human values appear to fluctuate across time and space (Danaher, 2021). Axiology serves as a bridge between the dichotomy of values, whether seen as objective or subjective entities, and holds implications for comprehending and modifying behaviour (Danaher, 2021).

Additionally, ethical thinking, valuing, and reasoning exist along a continuum between two opposing views: ethical relativism and ethical objectivism. Relativism pertains to the acceptance of ethics and morality, which vary among individuals or societies, whereas objectivism concerns the existence of universal or objective morals (Brannigan & Boss, 2001). The ethical issues of decision making addressed in this paper are inspired by normative ethics, which render judgments about what constitutes "duty," "goal," or "moral" behaviour, its outcome and value for individuals and societies, see Figure 2 below. Based on moral actions, the ethical reasoning continuum reflects two opposing views: ethical relativism and objectivism. Service ethics, as discussed in this study, describes how people make decisions and the impact of customers’ ethical judgments.

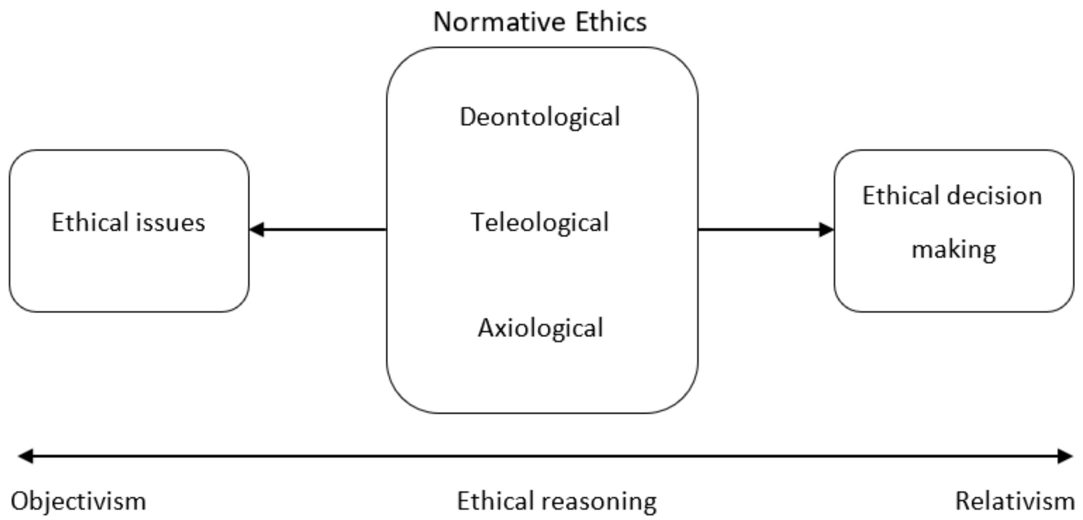

***Figure 2**: Ethical perspectives and reasoning for decision making*

Personal values and ethical decision-making tend to be interrelated (Bridges, 2018) as both are learned through socialisation and exhibit the same dynamic tendency to change over time in response to life experiences (Feather, 1988). Additionally, ethical behaviours are often motivated by different values (Hunt & Vitell, 2006; Laczniak & Murphy, 2019), and individuals' value systems can offer valuable insights into the motivational aspects associated with both ethical and unethical behaviours (Bridges, 2018; Doran, 2009).
Some research suggests that not all service interactions necessitate ethical choices, ethical frameworks, or ethical systems (e.g., Bridges, 2018; Friesdorf et al., 2015). However, service interactions have ethical implications as they can lead to intended or unintended negative impacts on the well-being of non-customers who did not choose to participate. The Hunt-Vitell model of deontological and teleological evaluation processes informs discussions on ethics surrounding impact, but not on service interactions and their intended or unintended impact on non-customers. The focus of this paper is to present ethical perspectives and discuss

the moral issue of where a person's actions, when freely performed, may impact the benefits and suffering of individuals and/or groups (Bridges, 2018; Velasquez & Rostankowski, 1985). We seek to explicitly identify the values and implicit ethical systems that guide service customers in modern service interactions enabled by digital service platforms to promote disciplined and informed ethical decision making.

Service perspective

This section presents essential concepts for conceptualising and introducing service ethics (also illustrated in Table 1). We initiated an ethics discussion for the service research community, with the aim of designing responsible service systems. These systems require ethical considerations for modern service interactions facilitated by digital service systems. The influence of digitalisation on service experiences demands new capabilities from customers. These capabilities pertain to the style of interaction or code of conduct as practiced, rather than merely as espoused (Normann, 2001). The value of human interaction hinges on customers' expected abilities to fulfil their roles in the service process (Bitner et al., 2000), thereby influencing their preference for human interaction (Immonen et al., 2018).

Recent studies have assessed ethics in service from organizational and societal perspectives, focusing on ethical decision-making (Bridges, 2018), corporate digital responsibility (CDR) (Wirtz et al., 2023), and ethical issues in AI practice (Belk, 2021). Business ethics, marketing ethics, and public service ethics (Bowman & West, 2021) represent related areas of study from an organizational perspective that has been extensively studied and discussed. However, service ethics encompasses more than just organizational ethics, including a broader perspective of service interactions of the purpose, process, and outcomes.

Service inclusion, as introduced by Fisk et al. (2018), becomes a key element, advocating for service inclusion, the consideration of the "full diversity of the human species." This paper stresses the urgency of enabling well-becoming by respecting and celebrating human diversity. Based on the two illustrative narratives of real-life experience, this paper expands the scope of service ethics beyond dyadic service interaction, delving into matters of morality and right and wrong. It distinguishes ethical considerations from socio-psychological aspects and the well-being of non-service customers, enriching the discourse on service ethics. This conceptual framework proposes aligning actions with mutual benefits, inclusion, well-being, and responsibility.

Additionally, Laczniak and Murphy (2019) argue that research should be directed toward the societal, ethical, and normative aspects, concerning Vargo and Lusch (2017) perspective on the more humane or ethical ethos of S-D logic. Transformative service research also assesses the well-being of people in service interactions; even non-service users deserve to reduce their suffering and improve their well-being (Anderson et al., 2013). “Well-being is a composite contextual state of business stakeholders that constitutes psychological, job-related, materialistic, social, physical, financial, environmental, spiritual, and educational aspects with variable weightings, depending on the micro, meso, and/or macro levels they are positioned on and is shaped by the interactions with other stakeholders” (Hamdan, 2023, p. 60). In recent years, research on service innovation has broadened to include the exploration of service ecosystems, particularly focusing on the role of platforms in emphasising the importance of new combinations of existing resources. These platforms also facilitate collaborations that provide access to new resources and capabilities, ultimately aiding in the co-creation of services and enhancing well-being (Edvardsson & Tronvoll, 2020). Well-becoming is ServCollab's concept for service system innovations that expand human potential at any service system level, from micro to macro. Over time, these innovations have enabled new levels of human well-being. The label "enabling" was inspired by (Normann, 2001). It addresses that acting as an 'enabler' is central in value-creation processes, including also value-creation communication, and also moves the focus to "the capabilities of the customer as a value creator" (Normann, 2001, p. 36). Therefore, in this study, service ethics refers to a system of moral principles, virtues, norms, values, and actions that underlie what we ought to do in relation to human interactions, and human interactions with life and planet Earth. These ethical values and actions form the basis of what ought to be done in relation to rights, fairness principles, societal benefits, and virtues (Bridges, 2018). In Table 1, we define the key concepts used to build our conceptualisation of service ethics.

***Table 1**: Definitions of key terms*

Term	Definition
Enabling	Enabling addresses acting as an 'enabler' is central in value-creation processes and focuses on the capabilities of the customer as a value creator.
Ethics	"… a system of moral principles and norms that guide the relationships between humans and between humans and their natural and artificial environment" (Winkler, 2022, p. 65).
Service Ethics	Service ethics refers to a system of moral principles, virtues, norms, values, and actions that underlies what we ought to do in relation to human interactions, and human interactions with life and planet Earth.
Service Inclusion	"… an egalitarian system that provides customers with fair access to a service, fair treatment during a service and fair opportunity to exit a service" (Fisk et al., 2018, p. 842).
Well-being	"… refers to the multidimensional concept that constitutes psychological, job-related, materialistic, social, physical, financial, environmental, spiritual, and educational aspects" (Hamdan, 2023, p. 60).
Well-becoming	Well-becoming is ServCollab's concept for service system innovations that expand human potential at any service system level from micro to macro to establish new levels of human well-being over time.

Normative ethics concern the articulation and justification of the fundamental values and principles of how people should live and what they morally ought to do (Laczniak & Murphy, 2006; Schroeder, 2019). We built on normative ethics to understand the ethical perspectives of deontology, teleology, and axiology to discuss three specific questions in relation to modern service interactions: 1. How should customers act?; 2. What do customers think is right?; and 3. What do customers value? This is related to the purpose, process, and outcomes of the service interactions which are explained in the next section.

Systems of Exploitation & Service

As mentioned earlier, our exploration of service ethics is grounded in S-D logic and TSR. These two major service research topics facilitated our efforts to transform service ethics. S-D logic has always emphasised mutually beneficial service systems (Lusch & Vargo, 2014). This normative approach offers valuable insights into the operations of service systems. However, it fails to explain how to create and maintain such systems, or how to transform service systems that are not mutually beneficial. According to Lusch and Vargo's (2014, p. 117) comprehensive book on S-D logic, "Forced or involuntary exchange is an interesting area of inquiry but one that S-D logic does not address."

When ServCollab was introduced (Fisk et al., 2020), it offered a framework of four categories of human interaction: conflict, competition, cooperation, and collaboration. Any of these four categories of interaction can occur in service systems. Based on the roles of the people involved, collaboration was presented as the highest form of human interaction. The roles of dominance and submission are possible in conflict, competition, and cooperation. Collaboration requires mutual benefit. Another ServCollab article (Fisk et al., 2024) presented these four interactions as a hierarchy with conflict at the bottom, rising to competition, rising to cooperation, and finally rising to collaboration. Their hierarchy also overlays the biological concepts of parasitism and mutualism, with parasitism at the bottom of the hierarchy next to conflict, and mutualism at the top of the hierarchy next to collaboration. To elaborate further, they state that service systems have evolved toward collaboration, and describe the systems of exploitation that are possible with conflict, competition, and cooperation. Based on our service ethics framework, we summarise unethical exploitations as follows:

Exploitation

Exploitation of others can be described using three concepts: purpose, process, and outcome.

Purpose – Exploiting other humans or nature is the purpose of conflict, but competitive systems can become exploitative over time. Like conflict, competitive systems are intended to have winners. Therefore, there is always a temptation to cheat. Cooperative systems can be exploited by deceiving people into supporting systems that are exploit them. This is particularly true if the people being exploited have little or no power in a cooperative system.

Process – Exploitative systems are designed to extract resources quickly or slowly from exploited humans or nature. Legal and moral systems of law and ethics have been created to control these processes. Examples include laws of war, antitrust laws, and civil rights laws. Although these laws can slow down aggressive exploiters, they rarely stop them. Of course, the worst processes of exploitation can occur when those holding legal power can easily subjugate those they exploit.

Outcome – If exploitative actors succeed, resources are extracted and transferred to the exploiters (s). If this exploitation is easily repeated, the cycle becomes vicious and oppressive.

Methods

Modern service interaction impacts on non-customers

To illustrate the practical application of the conceptual framework, a contextualisation featuring narratives of housemaids traded via various digital service platforms and the obstacles faced by a visually impaired Paralympian is presented. These narratives leverage the explanatory power of our conceptual framework of service interaction by illustrating that non-customers are intentionally and unintentionally exploited by customers of the services provided on digital platforms. These illustrative narratives represent the common customer interactions that begin with typical service interactions but also include the intended or unintended effects of these interactions on non-service customers.

Understanding modern service interactions extends beyond this dyadic relationship to encompass interactions enabled by innovative digital service system platforms (Edvardsson & Tronvoll, 2020). Ethics in the service context are conceptualised in a dialectic between theory and narratives (practice). The narrative approach is used as a method of enquiry (Carter, 1993; Connelly & Clandinin, 1990; Gudmundsdóttir, 1997). Narratives permit lifelike accounts of individual experiences (Pepper & Wildy, 2009) and illustrate the impact of ethical judgements and decisions on non-service customers (Conle, 2003).

Illustrative narratives contextualise the deontological and teleological discourse of ethics in service. This study also focuses on the axiological perspectives of the moral implications of individual actions that may harm or benefit others when performed freely (Velasquez & Rostankowski, 1985). Personal values and ethical judgments tend to be interrelated because they are learned through socialisation (Feather, 1988). Furthermore, ethical behaviours tend to be motivated by different values (Hunt & Vitell, 2006; Laczniak & Murphy, 2019). In this way, the analysis of the value system of an individual provides insights into the motivational aspects of ethical and unethical behaviours (Doran, 2009).

We applied narrative as a research approach to understand how engaged actors experience the world (Huttunen et al., 2001), to represent the social reality of individual lived experiences (Czarniawska, 2004; Hyvärinen, 2008), and to recognize narratives as both creators and conveyors of reality (Huttunen et al., 2001). Using a thematic analysis approach, the team identified patterns, trends, and underlying themes within the narratives to gain valuable insights into the dynamics of the life experiences of non-customers (Glaser, 1999). The explanatory power of our conceptual framework is demonstrated in two narratives: the housemaids and a

Paralympian which illustrate the need for service responsibility to enable well-becoming by transforming service ethics.

The narratives of the housemaids

These narratives illustrate the societal influence of service customer interactions enabled by digital service platforms on a special category of non-customers, which are domestic workers. The narratives focus on migrant domestic workers caught within a sponsorship system, in which their visas are tethered to employers who function as sponsors. Sponsors, typically citizens of the host nation, hold legal responsibility for the sponsored migrants throughout their employment and oversee their repatriation once their employment period ends. Under this system, millions of migrant workers are required to obtain permission from their sponsors to leave their job or exit the country. In recent years, legislation has been strengthened to prevent sponsors from exploiting the system and the act of transferring sponsorships has become illegal. However, the digital platforms available on the Apple Store, Google Play, and Instagram enable sponsors to transfer worker sponsorship, and enabling a black market that exploits vulnerability. Domestic workers, such as maids, are deprived of fundamental human rights, such as vacation time, the ability to communicate with their families, and keeping their passports, which are confiscated by sponsors. The narratives delve into a modern-day labour arrangement that features characteristics reminiscent of indentured servitude.

The persistence of indentured servitude casts a dark shadow on the lives of domestic workers, whose fates are intricately intertwined with those of their sponsors. This study explores a world in which the transfer of sponsorship, both in the form of offers and requests, paints a heart-wrenching picture of exploitation, discrimination, and a system skirting on the edge of legality. In 2023, we collected public data from various announcements on digital platforms where sponsors either sought or requested the transfer of housemaid sponsorships. The authors collected data and translated it into English for thematic analysis. The following sections illustrate the prejudices of indentured servitude using the examples from Appendix 1.

1. The dilemma of dehumanizing labour

Several announcements underscore a dehumanising trend: the disposability of domestic workers within the sponsorship transfer system. When the service is no longer needed, the housemaids are offered in the market for a fee, without their consent, instead of terminating their contracts and setting them free. This might include transferring or renting them to sponsors from different regions or cities. Economic considerations and the return of previous maids often dictate the fate of these individuals. This reveals the dehumanising nature of a system that treats individuals as expendable commodities.

Commentary on examples:

- Announcement 6 highlights the disposability of labour under an exploitative system, where a newcomer eager to contribute becomes a victim. It also emphasises the sponsors' right to try before deciding.

- Announcement 15 requests a domestic worker under the condition of being available for a two-week trial. This illustrates the dehumanising nature of the labour system.

- Announcement 10 pleas for sponsorship transfer or renting highlights the commodification of domestic labour and the disposability of labour in this system. The urgent request for a housemaid emphasises the need for a more objective evaluation of domestic labour.

2. Nationality-based prejudices

The data reveal a recurring theme centred on nationality, where sponsors express distinct prejudices. In various instances, sponsors explicitly state their desire for a specific nationality and signal discriminatory practices based on their national origin. This illustrates the nuanced landscape in which sponsors, driven by prejudice, make decisions that influence the lives of domestic workers.

Commentary on examples:

- The sponsor in Announcement 4 overtly expresses prejudice for a particular nationality, shedding light on discriminatory practices.

- Announcement 5 provides an example of nationality-based prejudice by stating that the reason for the transfer of sponsorship of a domestic worker is the need for another of a different specific nationality.

- Announcement 17 explicitly requests a domestic worker from one of two specific nationalities at the best price and does not specify any additional required job skills.

3. Religion-based prejudices

Religious considerations emerged as a significant factor influencing sponsor bias. In certain cases, the desire to practise religious obligations prompts sponsors to seek sponsorship transfers from domestic workers. Sponsors, in turn, express explicit prejudices based on religion, revealing a layer of control that extends beyond the realm of work.

Commentary on examples:

- In Announcement 2, the housemaid's request for regular prayers influences the sponsor’s decision to seek a sponsorship transfer.

- Announcement 9 explicitly states the religion of the domestic worker as a positive specification, as it matches the common religion in the country.

- Announcement 14 demonstrates the sponsor's request for a worker with a specific cultural background, including strict adherence to religious considerations during the selection process.

4. Sponsorship transfer fees

Although not always explicitly mentioned, economic considerations play a pivotal role in sponsorship transfers. Some sponsors emphasise specific criteria, such as cleanliness, reflecting their willingness to pay a certain fee for transferring the sponsorship of housemaids who meet their standards. Most announcements mention sponsorship transfer fees and/or monthly salary.

Commentary on examples:

- In Announcement 1, the sponsor justifies the sponsorship transfer based on the return of a former housemaid and cost considerations.

- Announcement 13 requests a domestic worker with reasonable pricing as the only specific requirement.

- Announcement 12 explicitly requests the transfer of a domestic worker under the condition that the transfer fee does not exceed a specific amount.

5. Control over personal freedoms

Sponsorship transfers affect domestic workers' work and personal lives. In some cases, sponsorship transfers occur shortly after a domestic worker arrives in the country, highlighting the instability and uncertainty that these workers may face due to systemic prejudices.

Commentary on examples:

- Announcement 7 highlights the paradox of newfound freedom turning into captivity when a domestic worker with 12 years of experience faces sponsorship transfer, despite having worked for the sponsor for only three months and having a sibling working for the same sponsor.

- Announcement 8 showcases a young domestic worker who was brought to the country by their current sponsor and has worked for them for only 3 months. Sponsorship is offered for transfer due to the sponsor's private family arrangement, which has nothing to do with the domestic worker. The domestic worker has fallen victim to this prejudiced system.

- Announcement 3 states that a domestic worker is being transferred due to her sponsor's desire to study abroad, despite having only started the job one and a half months ago and had not yet completed the trial period. This highlights the restricted lives of the domestic workers.

Appendix 1 shows examples of announcements published on multiple digital platforms, where sponsors are looking to transfer the sponsorship of housemaids or request that the sponsorship be transferred to them.

The narrative of a Paralympian

This narrative was chosen to illustrate the daily challenges of many physically impaired and disabled individuals and others as non-customers who are impacted by the modern service interaction of customers with digital platforms. Captured through a semi-structured interview, this narrative highlights the life experience and daily challenges of a visually impaired Paralympic champion. The visually impaired individual is a gold-medallist Paralympian who normally has no problem navigating in the streets and going back and forth to his workplace. He also participated in extreme challenges beyond the Paralympic Games designed for athletes with physical disabilities to promote inclusivity. Unfortunately, the inconsiderate behaviour of electric scooter users has made their navigation of streets very dangerous. These are words from the Paralympian's letter to the Swedish Police (for which he gave us permission to publish).

"*The reason I am writing is that I am blind. Since the electric scooter rental started in Karlstad this summer, I have had to parry hundreds and hundreds of electric scooters that have been standing and lying on footpaths, sidewalks, along house walls, at pedestrian crossings, on boardwalks and in every imaginable place where they should of course not be standing*." This lack of consideration from customers using digital platforms jeopardises the accessibility, safety, and human rights of vulnerable non-customers, such as Paralympians.

In modern urban environments, electric scooters are increasingly utilised as transportation modes. The rapid expansion of this industry has presented several challenges, notably concerning the responsible usage and parking. His exceptional resilience and determination in daily life relies on the accessibility and safety of public pathways, emphasising the significance of urban environments that are both safe and accessible. Electric scooters often obstruct sidewalks and pedestrian pathways, creating significant obstacles for him as he navigates independently. "*When I was walking on one of the footpaths in the city, the night before I had noted with the white cane that there were two electric scooters parked on the right side of my footpath. Therefore, I was extra active with the white stick this morning to feel on the right side so that I could identify the bikes and not bump into them … But, I tripped over a scooter that was absolutely in the middle of the footpath, i.e. on my left and which I could not detect with the cane because I was busy keeping track of the two scooters on the right so I wouldn't hurt myself on them*" a visually impaired Paralympian says.

The UN Convention on the Rights of Persons with Disabilities ensures equal transportation and public space access for individuals with disabilities. Irresponsible electric scooter placement violates these rights, impacting not only the visually impaired Paralympian but also many others with disabilities. Although laws govern scooter use and parking, their enforcement is challenging. Irresponsible parking violates laws that affect safety and accessibility. Balancing the interests of different urban groups, including people with disabilities, scooter users, and pedestrians, is crucial for an inclusive urban environment.

Results and Discussion

Service ethics takes a broader perspective than organizational ethics by including the purpose, process, and outcome of service interactions. As shown in Table 2, exploitation is characterised by conflict-driven intentions, potentially leading to cheating and oppressive cycles, as in the case of indentured servitude. Legal and moral systems seek to control exploitative processes, but may not prevent aggressive exploitation, as presented in the narratives. By contrast, ethical services rooted in mutualism benefit both humans and nature. Mutualistic service systems are designed for careful resource exchange and prevent exploitation by allowing participants to leave. The outcome involves sharing resources in the present and protecting them in the future, aligned with the principles of maintenance, preservation, and conservation. The text emphasises the importance of designing systems that promote mutual benefits and safeguard resources for present and future well-being.

Table 2. *Comparing exploitation narratives versus service ethics*

	Purpose	**Process**	**Outcome**
Intended exploitation of non-customers	A system that primarily benefits service users by exploiting non-customers.	Systematic exploitation	Indentured service workers are systematically exploited and forbidden their basic human rights
Unintended exploitation of non-customers	Exploiting service systems. Neglecting the scooters in a way that is harmful for non-customers.	Neglectful exploitation of resources Not respecting the rules	Exploiting competitive service systems Misuse of the scooters
Ethical service practices	Ethical practices of service customers. Organizations trying to prevent exploitations through service platforms, protecting the customers, non-customers, and the public.	Collaboration that mutually benefits sponsors and workers and enables the well-becoming of workers. Mutualistic service systems Respecting the user of the sidewalk Organization monitoring how their platforms are being used	Employers getting the services they demand in a system that enables workers well-becoming and preserves their rights. Mutual benefit in service interactions: Respecting every user of the sidewalk. Organizations prevent exploitation.

The relationship between service customers and providers in collaborative service platforms, emphasising value co-creation, is central to contemporary service management, and has added significance when viewed through the lens of service ethics. Value co-creation moves away from the traditional model of passive customers receiving services from providers, recognising that value is collaboratively generated. This shift promotes collaborative, ethical, and socially responsible practices, considering fairness, transparency, empowerment, and a commitment to well-being. The service co-creation process, viewed through the prism of service ethics, fosters dynamic and mutually beneficial interactions, and promotes shared responsibility and ethical engagement. By prioritising service ethics, collaborative platforms can establish trustworthy and responsible relationships with customers, positively impacting both individual well-being and broader societal contexts.

Conclusions

This study explored the ethical complexities of service interactions in the modern era. While service interactions are typically conceptualised as dyadic, our research broadens the conceptualisation of service interactions to consider the impact of services on non-customers who are intentionally or unintentionally affected by the service. The integration of digital service platforms into modern life has expanded the range of service interactions and created new ethical challenges.

Our service ethics conceptualization suggests a virtuous path toward resilient, harmonious, and regenerative service systems, ensuring ethical considerations in an increasingly interconnected and diverse world. Service interactions should be mutually beneficial. Service interactions in the digital age can be unethical and contradict the modern conceptualisation of service, as developed in S-D logic. When people follow the mutualistic logic that we describe for service interactions, their collaborative behaviour becomes inherently ethical and encourages others to collaborate.

Implications for practicing service ethics

Nasr and Fisk (2019) shed light on the crucial aspect of understanding human suffering within the realm of service provision. Recognizing and addressing suffering aligns with ethical imperatives and underscores the moral responsibility of service providers in promoting well-being. This underscores the need for service practices that prioritize empathy, compassion, and proactive measures to alleviate suffering. Service ethics play an important role in service research for shaping how service interactions unfold on service system platforms. In this study, we highlight the following points for fostering ethical business practices:

- The development of service ethics within the service research field is essential for enabling the design of ethical interactions on service system platforms.
- Ethical and collaborative value creation is imperative for both social and digital interaction.

- In the modern era, ethical decision-making requires anticipating and addressing potential ethical challenges in both direct and indirect service interactions facilitated by service systems.

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The material topics and distributed value in the sustainable reports: the case of the paper industry

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Abstract

In the recent years the circular model of production and consumption represents both an opportunity and an unavoidable necessity in the business operating. Various industrial sectors, including the paper industry, significantly impact society and the environment. A crucial aspect of this transition is the establishment of a shared monitoring system to assess companies' actions. Sustainability reporting has evolved to incorporate a broader range of aspects, expanding from solely environmental elements, such as environmental declarations, to include factors related to ethics, suppliers, and people. This integration is vital for adopting a holistic view of the company.

While numerous studies have examined the adoption and quality of sustainability reports in the paper industry, there is a gap in research providing a comprehensive overview of how companies in this sector communicate the value generated and distributed in sustainability reports.

This study aims to analyze how paper companies communicate economic value distribution in sustainability reports. The study conducted a content analysis of the sustainability reports from a sample of leading Italian paper companies. It extracted key topics, the value generated and distributed, and the stakeholders involved. Based on the findings, some considerations on possible items of information to be included are given.

Keywords: Paper mill, Report sustainability, Sustainability reporting, Value, Indicators, GRI 201

Introduction

The paper industry is notably associated with substantial socio-environmental impacts, including significant resource consumption, wastewater pollution, and air emissions (Garcia et al., 2017; Sun et al., 2018). This sector is particularly energy-intensive, using 5% of global industrial energy (International Energy Agency, 2023). Additionally, it consumes about 120 billion cubic meters of water annually worldwide (Sonkar et al., 2021). The paper industry also contributed to nearly 2% of total industrial emissions in 2022 (Furszyfer Del Rio et al., 2022). In Italy, the paper industry is the second largest in Europe, with a turnover of EUR 25 billion and over 162,000 employees in 2023. This sector primarily focuses on producing paper for household, hygienic, and sanitary uses, accounting for 20% of European production (Allianz Trade, 2024).

Sustainability reporting offers companies the opportunity to assess the progress of their economic, social and environmental strategies, as well as to communicate their responsible policies (Luque-Vílchez et al., 2023). Sustainability has become a key issue at global, European and national levels, making investment in non-financial reporting systems indispensable (Haller et al., 2017). Within companies, it is now common to draw up sustainability reports that include non-financial aspects, with the aim of informing investors and clients about the sustainability of their investments (Brooks and Oikonomou, 2018). These detailed reports illustrate policies and results in areas such as personnel management, the fight against corruption, respect for human rights and environmental and safety policies (Rajesh, 2020). The adoption of a new approach aims to orient corporate strategies towards the generation of sustainable value for all stakeholders. (Tapaninaho and Heikkinen, 2022).

There are several studies that investigate the adoption of sustainability reports in the paper sector but there is no study that analyses how companies communicate the economic value distributed.

Therefore, the research question of this paper is:

RQ1 How do paper companies communicate economic value distribution in sustainability reports?

To do this, the study analyzed the sustainability reports of a sample of Italian companies. The paper is structured as follows: section 2 provides a literature review introducing the evolution of sustainability reporting and the importance of the value distributed. The next section describes the method used and how the data was collected. Section 4 presents the research results, which are discussed in section 5 with the limitations and future steps of the research.

Literature background

Different sources (Beske et. al., 2022; Calabrese et. al., 2019; Torelli et. al., 2020) refer to materiality as a growing phenomenon. Still, the companies very often disclose only an insignificant amount of related information and they have not succeeded in explaining the methods for the stakeholders identification. For this reason, the basic processes to define the report content remains unclear. Still, the materiality analysis cannot be used strategically to define report content without considering the interests of stakeholder groups and thus, does not improve the reports addressed to those groups (Boesso and Kumar, 2009; Genç, 2017; Signori et. al., 2021). Materiality, so, results to be the driver through which companies can select issues to be included in non financial reports focusing on the expectations of all stakeholders.

Managers must regard the importance of reporting about ongoing materiality assessments, as otherwise, concerns about the overall reliability of the information presented may arise. A low-quality reporting about materiality assessments might lead to possible conflicts with stakeholders that may consider the topics of their interest not sufficiently reflected in the reports. Materiality analysis is a multi-purpose tool for prioritising sustainability issues from the double perspective of companies and stakeholders, meaning that both parties contribute to identifying the present and emerging social and environmental risks and opportunities (Opferkuch et. al., 2022; Newig et.al., 2013; Bovea et. al, 2021).

Still, many studies report that there is no standardisation when communicating the social, environmental and economic performance of organisations, or in the case of the stakeholders (Brand, 2011; Landi, Sciarelli, 2019). This can be confusing for the reports users when interpreting the content of non-financial information disclosure reports.

The power and legitimacy that managers associate with a stakeholder group cumulatively are the most important determinant of how managers go about prioritizing competing claims (Boesso et. al., 2009; Brogi and Lagasio, 2019; Piccarozzi et. al., 2023). It is also evidenced that the higher the priority assigned to a stakeholder group is, the greater the efforts aimed at engaging the stakeholder groups are.

Methods

To address the research question, an exploratory qualitative approach was employed. The study was conducted in two primary steps. First, a content analysis was performed on the reports of the selected companies. Second, the information was examined to evaluate how companies distribute economic value.

Content analysis, a commonly used method for analyzing sustainability reports, was utilized to extract information and identify similarities and differences (Horne et al., 2020). This analysis was done manually, without the aid of software, to prevent potential misinterpretations from automated tools (Kirchherr et al., 2017). The extracted information was classified using an iterative approach among the authors. To ensure the reproducibility and reliability of the classification (Neuendorf, 2016; Wester and Peters, 2000), each author independently analyzed and extracted the information, and then the results were discussed collectively to reach a consensus.

Data collection

From the AIDA database, companies classified under ATECO code 172200 (Manufacture of household and sanitary paper and board products) were selected. This extraction took place on February 24, 2024, yielding a total of 396 enterprises. From this initial group, only companies with revenues exceeding €50 million were considered, narrowing the selection to 48 companies. Out of these, only 21 had available sustainability reports for the year 2022 (see Table 1). Among these 21 companies, only 7 have reported on the economic value distributed in their reports (GRI 201).

Table 1 presents the distribution of reports among the sampled companies.

Type of Companies	No.
Companies belonging to ATECO code 172200	396
Companies with revenues of more than EUR 50 million	48
Companies with sustainability reports in 2022	21
Companies reporting GRI 201	7

Table 1. Sample extraction process. Source: authors' elaboration on AIDA database

The 7 reports were analysed by extracting the following main information: material issues (e.g. air, water, waste, labour...), stakeholders, economic value distributed.

Material collection

Qualitative analysis can be conducted using two methods: inductive and deductive. The analysis process typically involves three main phases: (1) preparation, (2) organization and (3) communication of results. The key difference between the inductive and deductive methods lies in the organization phase (Elo et al., 2014).

Generally, the inductive approach moves from specific observations to broader generalizations, while the deductive approach starts with an existing theory or model and moves from the general to the specific (Polit and Beck, 2004). The inductive approach generates categories directly from raw data without using a theoretical categorization matrix, unlike the deductive approach (Elo et al., 2014).

For the document analysis, three structural dimensions were selected, and analytical categories were defined for each using the deductive approach. Table 2 presents the categories, structural dimensions, and the approach considered.

Approach	Structural Dimension	Analytical category
deductive	GRI	Material Themes
	GRI	Value distributed
	GRI	Stakeholders

Table 2. *Approach, structural dimensions and analytical categories. Source: Authors' elaboration*

Results

The first analytical category examined is the material issues, which are the most significant sustainability concerns for a company that need to be monitored (Calabrese et al., 2019). These issues represent the primary areas where the organization generates direct and indirect economic, environmental, and social impacts (Whitehead, 2017).

Figure 1 illustrates the material themes identified in the companies' sustainability reports. These themes were extracted, classified, and merged based on similarities through an iterative process among the authors. The most frequently mentioned material themes include 'Community involvement' (7), 'Health and safety' (6), 'Governance and business ethics' (6), 'Climate change' (6).

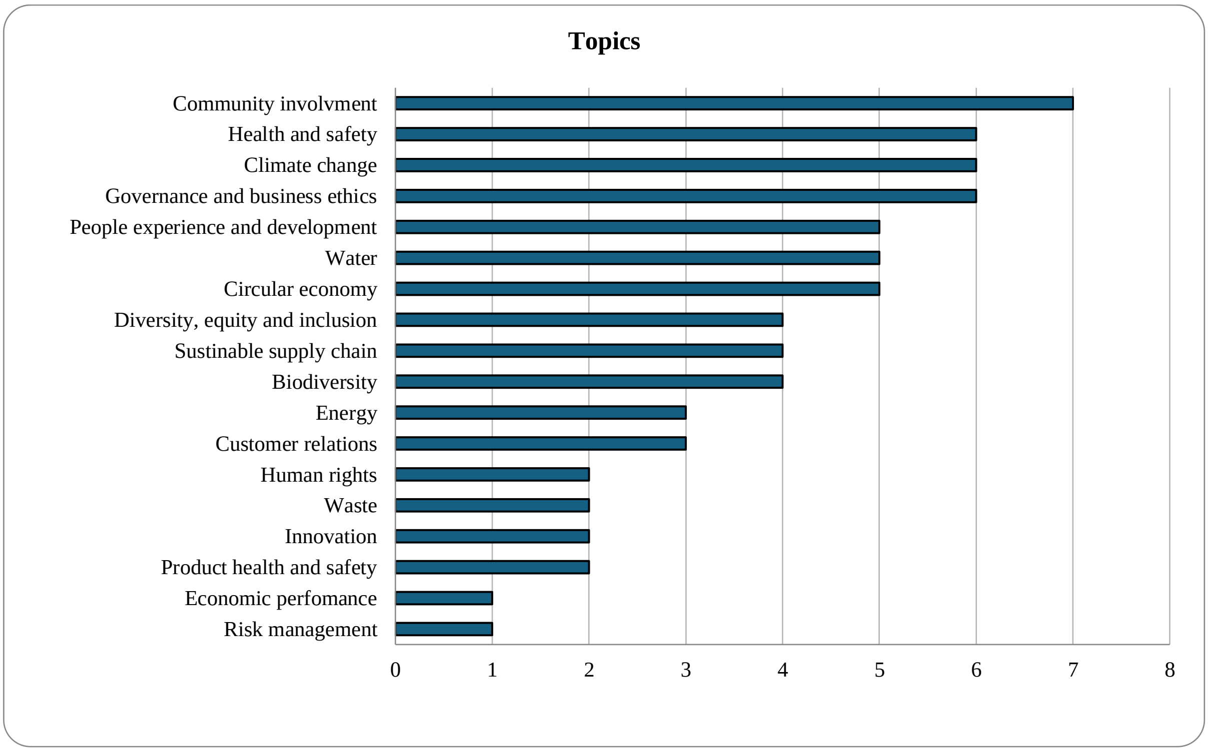

Figure 1. *Topics from sustainability report. Authors elaboration*

The second analyzed analytical category concerns the distributed economic value (figure 2). The distributed economic value is an important parameter for evaluating the wealth generated and distributed to different categories of subjects who, with their various contributions, have participated in its creation or who are in any case among the main reference stakeholders. Communicating clearly to all stakeholders how the received economic resources are managed and what the economic impact on their main stakeholders is represents a priority objective for companies. The economic value distributed to stakeholders is a qualitative and quantitative indicator of the social impact of companies and serves to verify the actual extent of the social responsibility assumed. The most mentioned categories concern "Bank and shareholders" (7) and "Employees" (6).

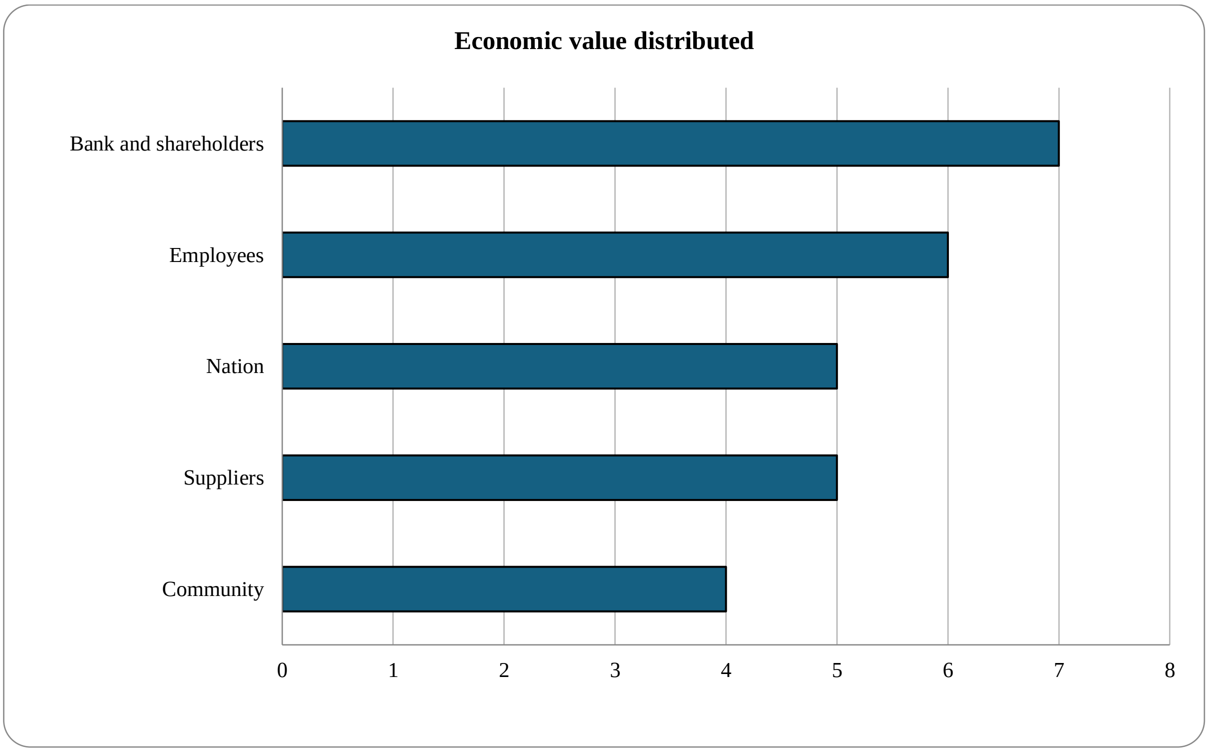

Figure 2. *Economic value distributed from sustainability report. Authors elaboration*

The last analyzed analytical category concerns the stakeholders. The stakeholders involved in the process of creating and distributing value were therefore taken as a reference. Stakeholders have a fundamental role in the future of a company (Goodman et. al., 2017; Tsoi, 2010). In fact, they are able to determine the success of a project providing support, information, and resources (Hristov and Appolloni, 2022).

Figure 3 shows the main stakeholders for the companies represented in the sample. The stakeholder categories were extracted from the sustainability reports and then the authors classified and merged these categories based on their similarities through an iterative process. The most mentioned stakeholder categories are "Employees" (8), "Customers" (8), "Suppliers" (8), "Shareholders" (6), "Local communities" (5).

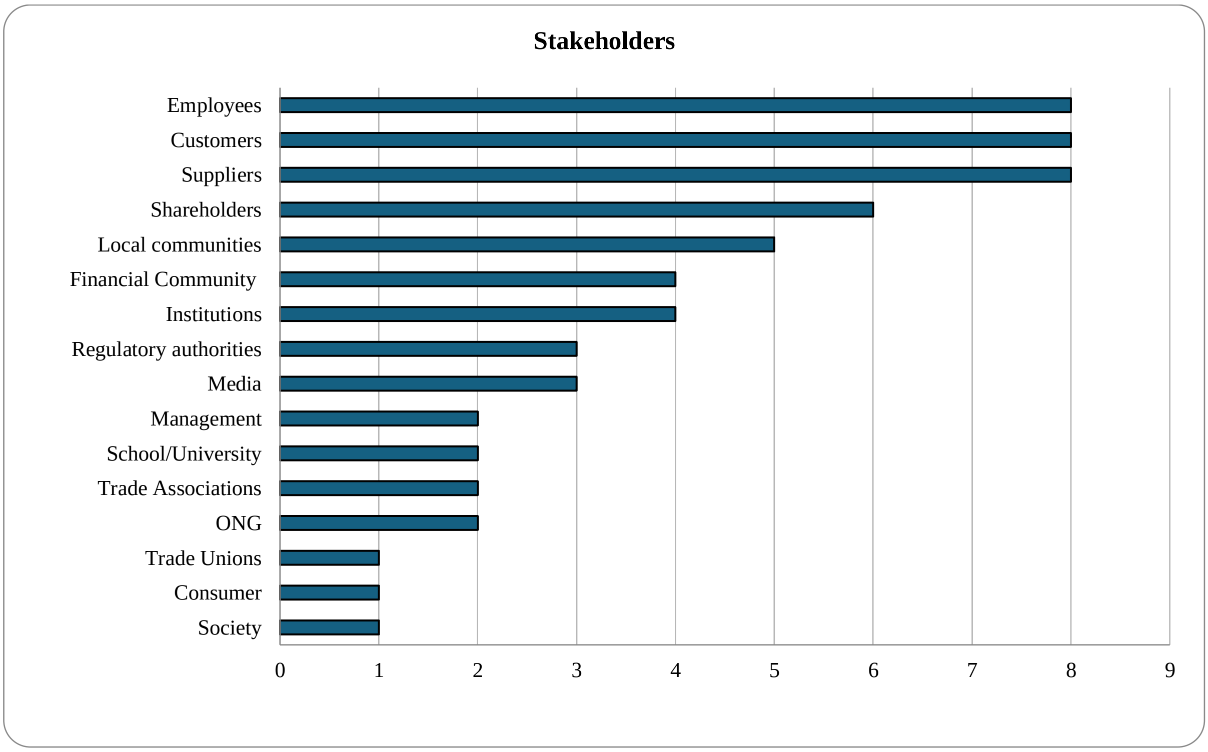

Figure 3 *Stakeholders from sustainability report. Authors elaboration*

Discussion and conclusion

The main results of the research show clearly the main contents of the sustainability reports from different points of view. As far as the economic value distribution is concerned it mostly regards the category "Banks and shareholders", while "Employees", "Customers" and "Suppliers" are the categories, the sustainability reports are mainly addressed to. The topics which are mostly reported on regard "Community involvement", "Health and safety", "Climate change" and "Governance and business ethics".

The study provides insight into how paper companies communicate the distribution of generated value. In particular, it emerges that the main stakeholders to whom the generated value is distributed are the same ones that are most involved in the reporting process. The reported categories, however, are not as detailed and do not allow us to identify which are the main areas in which companies distribute value. In the paper industry, most of the value generated is concentrated in water, energy and raw materials (Bousios and Worrell, 2017). This figure does not emerge from sustainability reports but can be deduced from companies' financial statements. It is therefore possible to imagine a model that takes into account the material aspects with the economic distribution of the generated value by taking up the logic of double materiality (De Cristoforo and Gulluscio, 2023).

The paper, for sure, presents some limits linked, first of all, to the small dimension of the analyzed sample. In fact, the research shows that only 21 of 48 large companies operating in the paper sector presented in 2022 the sustainability reports. So, one of the future lines of research development may regard the extension of the sample to 2023 and the revealing of the dynamics of all the analyzed parameters.

Besides, the research offers some interesting reflection points about the correlation between the contents of sustainability reports and the Sustainable Development Goals achieving. The reported topics from the sustainable reports like "Health and safety", "Climate change", "Water" seem to be strongly linked to different Sustainable Development Goals like SDG 6 "Clean Water and Sanification", SDG 3 "Good Health and Well-being", SDG 13 "Climate Action" and others. This is another aspect that may be deepened using also the quantitative methods of the research.

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Track 16: Sustainability

Environmental Product Declarations: A Comprehensive Review of Current Research and Practices

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Abstract

Communication activities related to the environmental performance of products are on the rise. This is due to growing consumer awareness of sustainability and the opportunity for companies to gain a competitive edge. Environmental labels, also known as eco-labels, have been created to provide the public with information that is clear, transparent and easy to understand. Environmental labels are divided into three categories according to the ISO 14020 series.

The third type of labels - the Environmental Product Declarations - use objective quantification through LCA to ensure comparability, objectivity and credibility of information on the environmental performance of products and services. In this way, comparisons could be made between products in the same class.

Despite their potential, EPDs face significant challenges related to the comparability, completeness and transparency of data, as well as their limited geographical and sectoral applicability. Many studies highlight the lack of standardization of methodologies and harmonization between different EPD schemes and Product Category Rules (PCRs). This hinders comparability and undermines credibility in cross-border contexts.

The aim of the paper is to conduct a systematic literature review (SLR) to critically analyse the existing research on EPDs, to identify key research gaps and to propose future directions to improve the utility and impact of EPDs in environmental communication and decision making. Preliminary findings highlight the need for greater standardization, improved data quality and greater consumer awareness to maximize the effectiveness of EPDs. Addressing these issues could significantly strengthen the role of EPDs in support of sustainable product development and informed consumer choice.

Keywords: Environmental Product Declaration, EPD, Ecolabels, Sustainability labels, Systematic Literature Review

Introduction

To better understand the certification programmes and methodologies being developed around the world, it is necessary to examine the work of the International Organisation for Standardisation (ISO). ISO has defined the basic principles and methodologies for three types of environmental labels: ISO 14021, ISO 14024 and ISO 14025. The Environmental Product Declaration (EPD), also known as a Type III environmental declaration, is a standardised tool (ISO 14025) for communicating the environmental performance of a product (Schmincke & Grahl, 2006).

Based on a Life Cycle Assessment (LCA), the EPD allows for fair comparisons between products (Bergman & Taylor, 2011). This tool is being promoted to improve the quality, reliability and transparency of environmental impact data available to businesses and consumers. In addition, EPDs can be extremely useful for supply chains by enabling clear and transparent communication of quantitative environmental information to customers, particularly in the context of green public procurement.

Several countries are currently considering making EPDs mandatory for international trade. Should one or more countries implement this requirement for products sold in their markets, companies wishing to continue to sell in these countries will need to develop and maintain the processes necessary to produce EPDs and associated LCA data (Bergman & Taylor, 2011).

In 2002, the European Commission's Directorate-General for the Environment (DG Environment) commissioned a study to document and evaluate national and sectoral EPD programmes and compare them with the current state of standardisation work at ISO level. The aim of the study was to stimulate demand for greener products through easily accessible, understandable and credible information (European Commission 2002). EPDs are indeed important tools for disseminating reliable data on the environmental performance of products; however, 22 years after this study, programme harmonisation remains a critical issue. The proliferation of EPD programmes, each with its own requirements, could create barriers to trade. However, these could be avoided through the creation of general guidelines for programme management, the application of LCA and mutual recognition of programmes (Del Borghi, 2013).

The primary objective of this article is to conduct a systematic literature review (SLR) to critically evaluate the current state of academic knowledge on EPDs. The paper aims to identify key gaps in the literature and suggest new research directions to enhance the value and impact of EPDs in environmental communication and decision-making.

Preliminary findings of the review indicate that greater standardisation, improved data quality and increased consumer awareness are needed to maximise the effectiveness of EPDs. The lack of standardised methodologies and guidelines across industries and regions is a significant barrier to the uptake and use of

EPDs. More rigorous standardisation could lead to more consistent and comparable EPDs, facilitating informed decision-making by stakeholders (Minkov et al., 2015).

Methods

Aim of the Systematic Literature Review

The aim of this systematic literature review is to examine the existing literature on EPDs in order to identify gaps and research trends, and to suggest future directions for improving and increasing the impact of third-party labels. The methodology, which includes five steps for literature evaluation, was developed in accordance with the recommendations of Wolfswinkel et al. (2013).

Database, search query and inclusion criteria

Given the popularity of the Scopus database among scholars, the authors elected to use it for their study. The initial phase encompasses the definitions, determination of inclusion and exclusion criteria for articles, study topics, relevant databases, and terminology used in the research. Subsequently, a comprehensive search of the studies is conducted, and papers are selected based on the pre-defined study objectives. The research sample is then examined, key points are organised, and the findings are summarised and reorganised (Macke & Genari, 2019). The search query used in Scopus was as follows:

TITLE-ABS-KEY ("EPD" AND "ENVIRONMENTAL PRODUCT DECLARATION" OR "DECLARATION*") AND (LIMIT-TO (LANGUAGE, "ENGLISH")))

The following criteria were used to select articles for systematic analysis:

- Journal articles, book chapters, conference papers, and reviews.
- Articles in English.
- No time limits were set.

Of 311 abstracts in the analysed sample, 6 were discarded. For 5 of these, there was no text, and one was a duplicate. Finally, the sample of contributions analysed is 305.

Results and Discussions

This section outlines the key characteristics of the reviewed publications. The 311 publications included in the analysis were published between 2001 and 2024 and include journal articles, conference papers, book chapters, and reviews. As shown in Figure 1, there has been a growing interest in the scientific community in Environmental Product Declarations (EPDs). The first three studies were published in 2001. However, from 2014 onwards, a more pronounced interest emerged, with a peak of 38 publications in 2022.

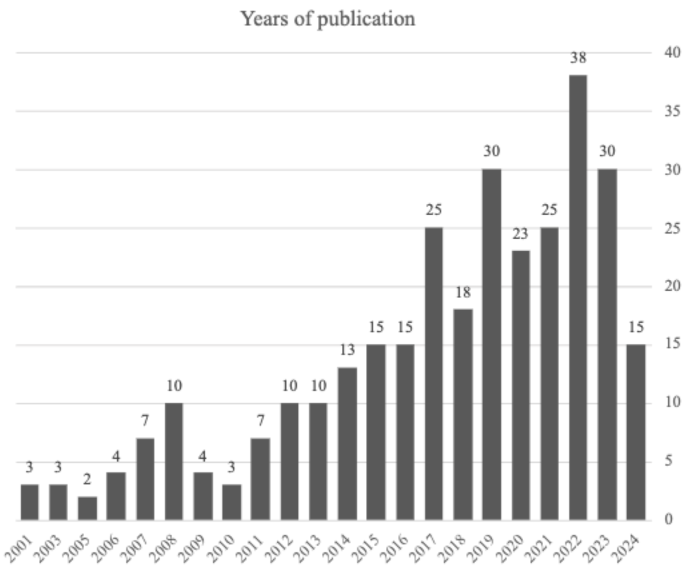

Figure 1 - Number of articles published per year | Source: created by authors

About 40% of the research were published as conference proceedings, while the remaining of the publications are divided into journal articles, book chapters and literature reviews. The prevalence of publications in conference proceedings, coupled with a significant increase in publications since 2014, indicates that EPDs are a rapidly evolving field, driven by legislative reforms and consumer demand for greener products (Pannuti, 2023; Skaar & Fet, 2012). In addition, conferences facilitate rapid dissemination and collaboration, fostering new ideas and relationships that are critical to the advancement of EPDs.

Despite the prominence of conference proceedings, the journals and conferences that have published the most articles on the topic are listed in Figure 2. The top three positions are occupied by three peer-reviewed scientific journals that are key sources for research and development in the field of sustainability and life cycle assessment. Their dominant position in publishing EPD-related articles reflects the importance of these topics in current research.

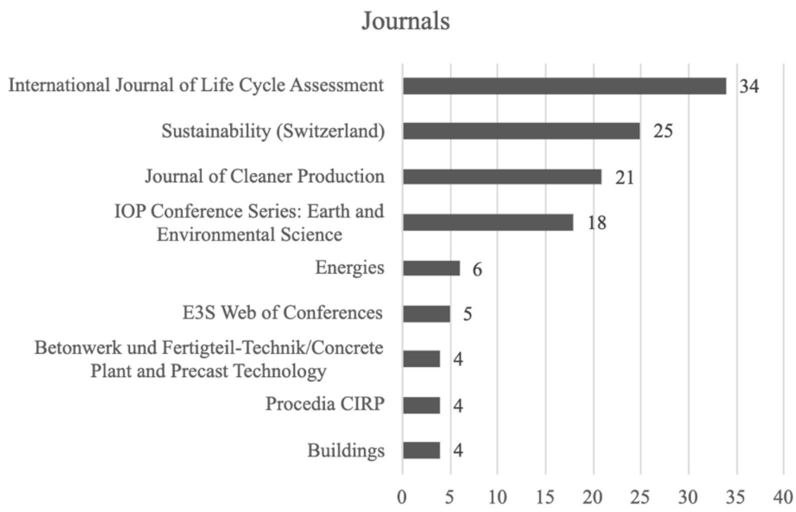

Figure 2 - Number of publications of journals and conferences | Source: created by authors

Publications were categorised as 'yes' or 'no' based on how central the topic of EPD was to the research conducted, guided by the question: "Is EPD the focus of the article?". Of the 311 articles analysed, 62% focused primarily on the analysis of this tool, while 38% mentioned it or considered it to be central to the research conducted (Figure 3).

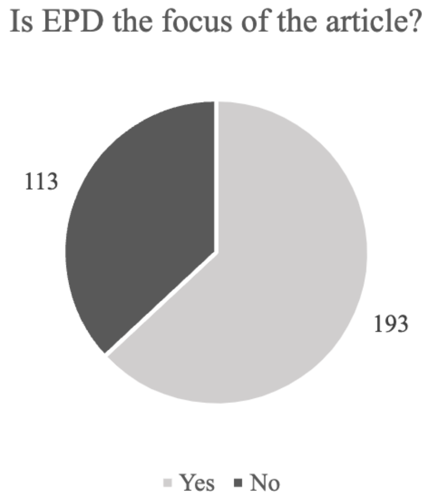

Figure 3 - Number of articles distinguished by EPD centrality to topic | Source: created by authors

This suggests that a significant proportion of the scientific community is interested in EPDs and is devoting considerable effort to understanding and improving this tool. This distinction highlights the dual role of EPDs, both as a central research topic and as a critical component within larger sustainability studies. In some studies, the EPD was not functional for research purposes or was cited without in-depth analysis (e.g. Besana & Tirelli, 2022; Bruce-Hyrkäs et al., 2018; Czernik et al., 2021; Obrecht et al., 2020). In other cases, EPDs have been used as databases for conducting life cycle assessments (LCA) of products or as methodologies for calculating the carbon footprint of a product. This application is particularly notable in the building sector (Morsali et al., 2024; Öztaş & Tanaçan, 2017; Rochlitzer & Lützkendorf, 2022), where third party labels are used to measure the carbon footprint. Also in the construction sector, according to Tazikova & Kozlovska (2013), the EPD is being promoted as a tool for the creation of a database in IFC format for the potential calculation of the environmental impact of building materials. This could reduce the environmental impact during the design phase of construction. This use of EPDs as a tool for LCA calculation is also important in other sectors such as agri-food and forestry. Studies in these areas include Recchia et al. (2019) with a focus on the pasta sector, Miniakhmetova et al. (2022) and Buccino et al. (2019) that explored the ice-cream cups and Tonelli et al. (2018), studying the coffee capsules environmental impact. In the construction sector, EPDs are also used as a source of information to compare building materials, as shown by studies by Linkosalmi et al. (2023), El Sibaii et al. (2023), and Palumbo (2021). Additionally, the growing interest in certification systems such as BREEAM and LEED has increased the demand for manufacturers to produce EPDs. These declarations support sustainability assessments and design decisions at the building scale and are also used for product procurement (Marsh et al., 2023).

Literature Focus

The distribution of articles analysed according to their subject focus is shown in Figure 4.

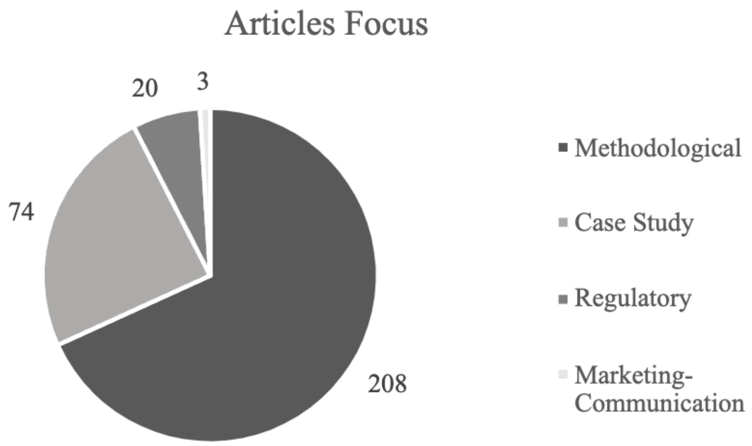

Figure 4 - Focus of the articles analysed | Source: created by authors

Most of the articles - 208 in total - about 68% of the total, focused on the methodological aspects of EPD. This includes studies dealing with methods, strategies and approaches used in practice and research.

Galindro et al. (2020) examines the use of LCA and EPD information from a practitioner's perspective. Methodological limitations and the need for harmonization of Product Category Rules (PCRs) are identified as challenges to study comparisons. The study concludes that LCA and EPD information is used in different ways and that there is a need to standardize benchmarking procedures to improve communication with non-specialist audiences. Of the total number of publications, 24, about 20%, are classified as case studies. These articles provide valuable illustrations and real-world applications of EPDs in different sectors.

In the Agrifood sector, Environmental Product Declarations (EPDs) have been utilized as a database for conducting product life cycle analyses. For instance, Fantin et al. (2012) conducted a comprehensive Life Cycle Assessment (LCA) study on high-quality milk production in Italy, employing Environmental Product Declarations (EPDs) to compare the environmental impacts with those of another milk brand. The EPDs were instrumental in identifying raw milk production as the phase of greatest environmental impact. Cabot et al. (2023) used EPDs to assess the environmental impact of mandarin cultivation in Uruguay. The EPDs were instrumental in analysing field emissions and identifying environmental hotspots, thereby improving the accuracy of environmental assessments using site-specific inventories. Moving into the food waste sector, Dolci et al. (2021) compared the use of paper and bioplastic bags in food waste management through an LCA based on EPD and PEF approaches. EPDs provided an excellent database to show that bioplastic bags have significantly higher environmental impacts than paper bags.

The work of Del Borghi et al. is particularly relevant to the recycling and waste management sector. In 2007, they developed Product Category Rules (PCR) for municipal wastewater collection and treatment services, based on a case study of an active treatment plant in Italy. Later in 2008, they analysed four case studies related to municipal waste management in Italian sanitary landfills. They compared different waste treatment technologies and leachate or biogas management methods in the context of the EPD system.

Another specific sector where an interesting case study has been developed is textiles, in particular carpets. Goerke et al. (2007) investigated how EPDs can be used as a competitive advantage for manufacturers of textile floor coverings. ISO 14025 regulates the production of EPDs based on a life cycle assessment according to DIN EN ISO 14040ff. The German Carpet Research Institute (TFI) conducted a life cycle assessment on behalf of the Environmental Association of the Carpet Industry (GuT), which provided the basis for the preparation of the EPD.

Of the total number of publications, 20 articles, about 7%, are dedicated to regulatory issues. These studies focus on industry-relevant standards, laws, and regulations crucial for developing and implementing Environmental Product Declarations (EPDs).
Gelet & Gauchon (2007) discuss the application of EPDs in the context of electronic products. European Community economists have estimated that 80% of the total environmental impact of products can be reduced at the design stage. Consequently, it has been proposed to define a method to estimate this impact for each individual product, the EPD, based on various criteria such as using renewable or non-renewable resources, electricity consumption, emission impact and waste. The authors also present a case study of FERRAZ-SHAWMUT, which uses CODDE's 'EIME' software to determine the environmental profiles of its products. Finally, three articles - about 1% of the total - focus on marketing and communication issues.

Countries

The distribution of the reviewed articles by country of origin is illustrated in Figure 5. According to the graph, Italy leads with 34 publications, followed by Germany with 22 articles and the USA with 18 articles. These three countries contribute most of the reviewed material. Sweden contributes 10 publications and Spain 9. Other countries such as Turkey and Norway contributed 5 and 6 articles respectively. In addition, Portugal, Poland and the United Kingdom each published 4 articles. The diversity of nations represented suggests that interest in the topic covered by the literature is widespread worldwide. This distribution indicates a strong presence of American research alongside a significant amount of research from European nations, particularly Italy and Germany.

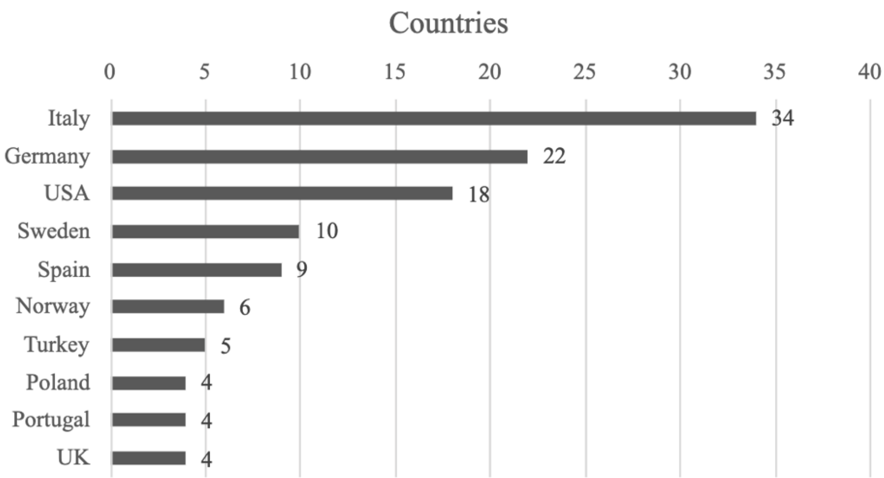

Figure 5 - Countries in the analysed papers | Source: created by authors

Sectors

The distribution of articles by sector is shown in Figure 6. The construction industry is the most represented, with 94 articles, accounting for most of the literature examined. This is closely followed by the building industry with 81 articles. Although associated with the construction sector, the building industry focuses on specific aspects of building design, construction and maintenance, demonstrating complementary but distinct interests. The third largest sector is agriculture and forestry, with 19 articles. The importance of this sector highlights the growing academic interest in sustainable agricultural practices and forestry. Both the energy sector and the wood industry are represented by 11 articles each. The focus on the energy sector stems from concerns about energy efficiency and the development and implementation of renewable energy sources. Conversely, the wood industry is important for its complementary role in the sustainable management of forest resources and for the construction sector. The textile industry, represented by 7 articles, is smaller but still significant, especially given the increasing emphasis on sustainability in the production and use of textiles. The steel industry, with 5 articles, focuses on basic construction materials and their applications. Waste management and recycling are also notable, with 5 articles emphasising the importance of effective waste management in civil and industrial activities. Finally, the 4 articles on roads and procurement illustrate a specific interest in EPD within infrastructure management and the procurement of goods and services.

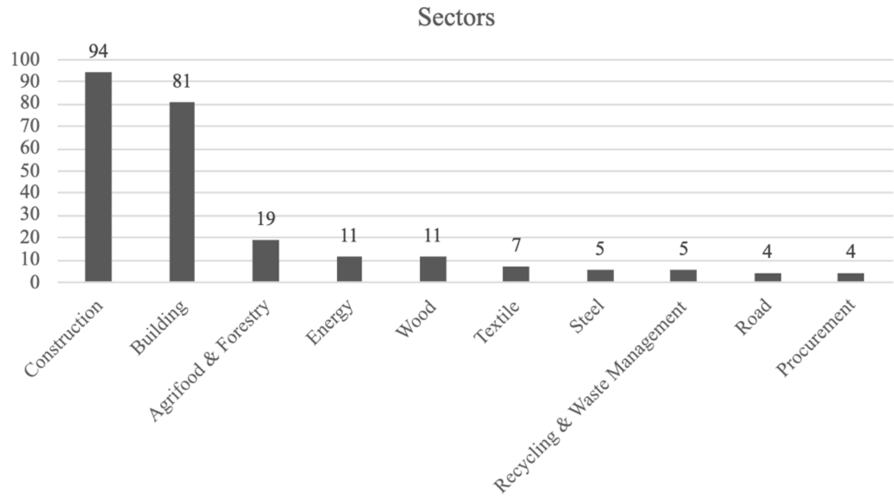

Figure 6 - Sectors in the analysed papers | Source: created by authors

Cross-referencing data on countries studied for the use of EPDs and the sectors in which EPDs are most extensively researched, it is important to focus on the two countries that feature most prominently in publications. Both countries operate within a regulatory framework governed by European standards: Italy and Germany.

Italy has implemented a range of environmental policies and regulations that encourage the use of EPD and LCA. By way of illustration, the National Recovery and Resilience Plan (NRRP) places a strong emphasis on the importance of digital investments in infrastructure design. This requires the verification of environmental contributions through LCA and EPD (Pannuti, 2023). A significant number of Italian research projects are supported by European Union programmes and funds, which promote the adoption of EPD. European cooperation facilitates the exchange of knowledge and technologies, strengthening Italy's ability to develop and implement new environmental assessment methodologies (Signorini et al., 2019).

The building and construction sectors have a considerable environmental impact, and there is a strong interest in improving sustainability in these fields in Italy. A significant number of studies focus on the use of EPDs and LCA to evaluate and enhance the environmental performance of buildings and construction materials (Del Rosario et al., 2021; Palumbo, 2021; Signorini et al., 2019; Sirtoli et al., 2015.). Furthermore, Italian regulations, such as the Ministerial Decree on Minimum Environmental Criteria (CAM), require the use of environmental criteria and documentation that ensures transparency and compliance with environmental regulations in public tenders. This provides a strong incentive for scientific research in this field and justifies the high number of publications (Del Borghi et al., 2007; Napolano et al., 2015; Signorini et al., 2019).

Italy has a long-standing agricultural and agri-food tradition, where environmental sustainability is becoming increasingly important. For example, Zingale et al. (2022) used Environmental Product Declarations (EPDs) to assess the environmental impacts of pasta production in a small Sicilian company. Similarly, Recchia et al.

(2019) explored the environmental impacts of pasta production, focusing on two different production chains: a 'high quality' chain using ancient wheat varieties and a 'conventional' chain using both national and international wheat varieties. Additionally, Bosco et al. (2011) used EPDs to assess greenhouse gas emissions from wine production in Tuscany.

Italy is also making significant investments in the field of renewable energy, which has led to a notable increase in scientific output, particularly in the form of LCA studies on offshore wind farms. Research in this field is crucial for developing more efficient technologies and reducing the environmental impact of new energy infrastructure (Brussa et al., 2023; Vignali, 2017). The second country with the most publications is also part of the European regulatory regime.

Several publications focus on investigating and improving the environmental efficiency of construction products in the German context, such as lightweight concrete blocks and wooden interior doors, and demonstrate the importance of detailed life cycle analysis to optimise production processes and reduce environmental impacts (Krause & Hafner, 2019; Reiners, 2013; Wenker et al., 2016). An interesting comparison by Del Borghi et al. (2020) examines the European Union's Product Environmental Footprint (PEF) and Environmental Product Declarations (EPD), revealing discrepancies and a lack of comparability between the two systems. The authors suggest that these differences have significant implications for Green Public Procurement (GPP). GPP requires consistent and comparable environmental criteria to ensure that products meet certain sustainability standards. As PEF and EPD are not directly comparable, using them interchangeably could lead to inconsistencies and challenges in the evaluation and selection of green products for public procurement.

German legislation requires efficient recycling and reuse of construction materials. Studies by Krause & Hafner (2019) show how recycling potentials can be improved by using LCA parameters in the context of EPDs, with specific modules that quantify the benefits of recycling construction materials.

Brockmann ‘s (2019) research focused on technological innovation and digitisation of data, as well as the creation of an online infrastructure for LCA. These initiatives are being supported by the German government to facilitate access to data and improve the integration of EPDs into Building Information Modelling (BIM) systems.

Finally, some studies focus on EPDs as a means to increase end-user awareness of the environmental and health impacts of products, such as paints and wall coverings, with the aim of making environmental impact information transparent (Rochikashvili & Bongaerts, 2016, 2018).

Italy and Germany both demonstrate a strong commitment to the promotion of Environmental Product Declarations (EPDs) and Life Cycle Assessments (LCAs). However, their approaches to these issues are slightly different, yet complementary. Germany places greater emphasis on digitising data and developing online infrastructure, while Italian research focuses on specific policies such as the National Recovery and Resilience Plan (PNRR) and on the agri-food sector, which is a strategic and central industry for the country. Both countries demonstrate that EPDs and LCA can be effective tools for improving environmental sustainability. However, much remains to be done to harmonise regulations and make results comparable on an international level.

Conclusions

The systematic literature review conducted in this study highlights the crucial role of Environmental Product Declarations (EPDs) in promoting environmental transparency and sustainability. Analyzing 311 articles published between 2001 and 2024 revealed a growing scientific interest in EPDs, with a significant peak in recent years. Despite efforts to standardize EPDs, the primary findings indicate considerable discrepancies in methodology and data quality. This inconsistency hinders the widespread use of EPDs and diminishes their effectiveness as environmental communication tools. Additionally, consumer awareness of EPDs remains low, reducing their impact on consumer choices and sustainable consumption.

To address these challenges, several steps are recommended to improve the efficacy of EPDs. First, increasing standardization by developing and adopting universal standards for EPD processes and reporting is imperative to ensure global uniformity, reliability, and comparability. Furthermore, establishing robust frameworks for data management, collection, and validation is essential to improving data quality. This could be achieved by exploring advanced strategies, such as developing comprehensive databases and integrating cutting-edge technologies. Finally, research should focus on enhancing consumer awareness by investigating the effectiveness of various communication strategies, educational programs, and best practices for disseminating EPD information.

Addressing these issues could significantly strengthen the role of EPDs in supporting sustainable product development and promoting informed, environmentally responsible consumption choices. When used correctly, EPDs can become key tools for improving the transparency of environmental information and guiding the market towards more sustainable practices.

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The socio-economic impacts of a transition from livestock to plant production in Norway

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Abstract

The role of Life Cycle Assessment (LCA) is well known in supporting sustainable agri-food systems, although so far LCA has a weak role in contextualizing its socioeconomic impacts. Studies have shown that there is a big potential to increase production of faba beans and peas in Norway, and dietary shifts to more plant-based proteins have been highlighted as one of the most important ways to increase the sustainability of food systems. At the same time any dietary shifts may have socioeconomic consequences. The goal of this paper is to assess the socioeconomic impacts of an increased production of peas and faba beans in Norway in favour of livestock production. We do this by assessing the social risk of plant production (as a proxy for peas and faba beans, which we collectively refer to as legumes) compared with livestock production, and the employment effects of increasing legumes as a source of protein in the Norwegian diet, which entails a reduction in livestock production as a source of animal- based protein. The results show that the potential social risk from livestock production is three to four times higher than for plant production. Livestock production is also more labour intensive than legumes production, meaning that livestock production creates many more jobs but is much less efficient. We conclude that maximizing production of legumes in Norway and reducing livestock production would lead to a large decrease in total employment – which may be considered a negative – but would lead to a large reduction in the social footprint, which must be considered a positive.

Keywords: S-LCA, social risk, employment, sustainable diet

Relevant Topic: S-LCA and quality

Introduction

The role of Life Cycle thinking is well known in supporting sustainable agri-food system, although there are still many challenges to solve. Dietary shifts towards more plant-based proteins such as legumes and a reduction of meat-based proteins, especially red meat, have been highlighted as one of the most important ways to increase the environmental sustainability of food systems. At the same time, any dietary shift may entail hidden d social consequences. In Norway, 70% of the proteins consumed in an average Norwegian diet come from meat and dairy products (Svanes, 2019). The Norwegian health authority recommends that the consumption of vegetables, fruit and berries, coarse grain products and seafood should increase by 20 per cent for the whole population in the next three years, while it is recommended to eat less red and processed meat (Helsedirektoratet, 2022).

Due to a challenging climate and topography, around 60% of the fruits and vegetables consumed in Norway are imported (Kjos et al., 2022). A dependency on imports can have socioeconomic and environmental impacts if there is a disruption in the source of production, supply shocks, price volatility, etc., while a more local production can instead have positive social impacts such as contributing to economic development of a region and creating job opportunities in new sectors (Kucukvar, Onat, & Abdelmalek, 2020). There is potential to increase the production of peas and faba beans (referred to as legumes from here on) in Norway from 13,000 tonnes in 2023 to 94,000 tonnes a year (Abrahamsen, Uhlen, Waalen, & Stabbetorp, 2019; Tufte & Inderhaug, 2022), which could supply the Norwegian market with around 75,000 tonnes of edible peas and faba beans a year.

The environmental footprint of legumes is significantly lower than animal-based proteins (Nijdam, Rood, & Westhoek, 2012). In Norway specifically, the climate change footprint of dried peas and dried faba beans (0.57 and 0.62 kg CO2-eq/kg product respectively) is much lower than the greenhouse gas emissions from the meat-based protein (the range is 1.2 - 39.2 kg CO2-eq/kg product) (Svanes, Waalen, & Uhlen, 2022) . However, the social impacts of legumes production compared with livestock production has not yet been studied.

The objective of this study is 1) to identify the social impact categories that account for a greater share of the overall risk[5] in the Norwegian plant production used as proxy for legumes (peas and faba beans) in comparison to livestock production, and 2) to assess how an increased production of Norwegian legumes might affect local employment in the Norwegian agricultural sector compared to livestock production.

Methods

Firstly, a social hotspot analysis for livestock and plant production (used as proxy for legumes) was carried out in the social hotspot database (SHDB) database. The database follows the UNEP guidelines for Social Life Cycle Assessment (SLCA) and can identify the main social impacts in the two production systems (UNEP, 2020). Social impacts are quantified using worker-hours (a measure of the activities involved per unit of livestock or legume produced). Social impacts are divided into five impacts categories: 1) Labour rights and decent work, 2) Health and safety, 3) Human rights, 4) Governance, and 5) Community. The five impact categories are weighted equally in the method utilized in the assessment. The results were expressed in Medium Risk Hour equivalent (MRH eq.) per tonne of product, making it possible to calculate

[5]Social risk is a social topic for which an adverse impact is probable; the probability could also be quantified (UNEP, 2020)

the social footprint (i.e., the total medium risk hours equivalent linked to all the inputs needed in the plant and livestock production respectively) and identify the greatest social impacts in the primary production of plant-based protein and animal-based protein per impact category in Norway. A higher MRH eq. means that the potential social risk (i.e. adverse impacts) is elevated and the contribution to total worker hours is high (Benoit Norris, Bennema, & Norris, 2019). Secondly, the direct employment effects in primary production of legumes and livestock in Norway was assessed and presented in Full-Time Equivalent (FTE) employment. We estimated employment effects under two scenarios, one baseline scenario with 2023 levels of production[6], and one scenario where legumes are at maximum possible production in Norway. In the second case the legumes are assumed to replace animal-based food, in such a way that the calorie intake per capita per day remains constant[7].

This means that at baseline (1): production of legumes and livestock remains unchanged from production in 2023 (baseline scenario), and in the future scenario (2): production of legumes is at the maximum that Norwegian farmland can support while the production of livestock is reduced to 70% of baseline production. Data for legumes are from Abrahamsen et al. (2019) and livestock data come from the handbook for operational planning (Hovland, 2022). Employment estimates for each type of production were calculated using average production times, e.g., producing sheep meat takes 29 minutes per kg and legumes take 32 seconds per kg (Abrahamsen et al., 2019; Hovland, 2022).

Results and Discussion

The results from Figure 1 illustrates the social footprint for the five main impact categories: 1) labour rights and decent work, 2) health and safety, 3) human rights, 4) governance, and 5) community. The results show that the potential social risk in livestock production is three to four times higher than in plant production across the five impact categories, the biggest difference in risk being in Labour rights and decent work, and in Community. The social impact category of Health and safety had the highest value in MRH eq. for both livestock production and plant production. The reason is caused by the potential higher probability to suffer injuries and accidents in both types of production.

[6] In 2023, 13,000 tonnes of legumes were produced. The theoretical maximum is approx. 94,000 tonnes (Abrahamsen et al, 2019).

[7] We assumed that the average calorie need in Norway was 2,500-2,600 kcal per person per day and the population number for Norway we have used is 5,521,000.

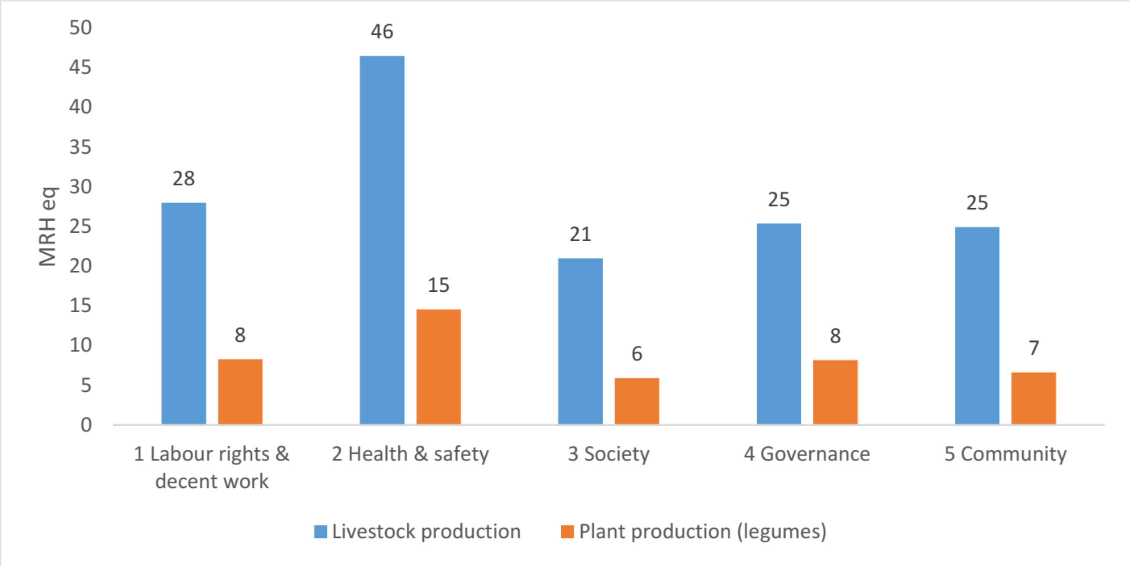

Figure 1. *Social footprint of livestock and plant production (proxy for legumes) expressed in Medium Risk Hours eq. per tonne of product.*

In the baseline scenario, approx. 29,400 FTE employees are working in Norwegian production of livestock and legumes in total (see figure 2). Of these, only 69 worked in production of legumes, which is a production both small in scale and very labour efficient, taking only 32 seconds per kg. Approx. 14,500 FTE employees worked in cattle production, which is both a big production in scale and labour- intensive, taking 15 minutes per kg to produce. Dairy and sheep also had a big impact on labour estimates. In the maximum scenario, employment dropped to approx. 21,100 FTE. Employment from legumes production is 1,020 FTE in this scenario. Thus, in legumes production, employment increased by 952 FTE in the maximum scenario, while overall employment fell by 8,400 FTE.

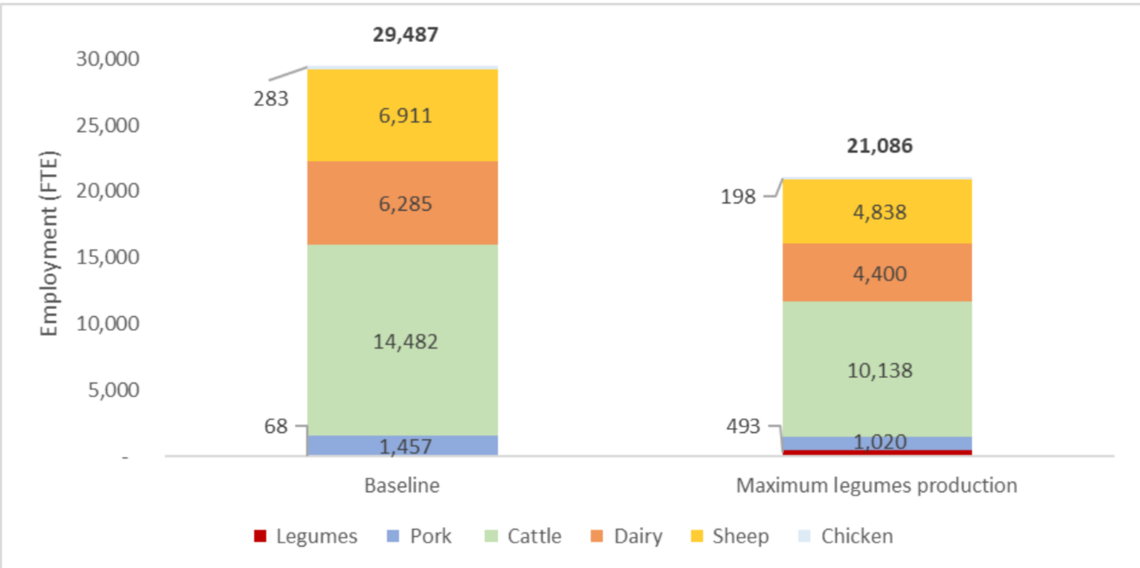

Figure 2. *Estimated employment effects in the two scenarios. Total employment estimates are displayed at the top of each column.*

The labour requirements differ drastically among the two food production systems (animal products against crops production). There is a general pattern of increased labour efficiency due to enormous increases in mechanization, explaining the time efficiency for many food product types (Ibarrola-Rivas et al., 2016). The only exception to this trend of increased efficiency is the production of sheep and cattle (Ibarrola-Rivas, Kastner, & Nonhebel, 2016). The explanation probably lies in a less mechanized system where the Norwegian sheep production is based on the use of outfield grazing resources in mountains and forests in summer (Flaten, 2023). It should also be noted that in Norway, as well as in most other European countries, livestock production, especially sheep and cattle, receives a large share of their income from agricultural subsidies see e.g. (Mittenzwei et al., 2019). This means that employment in this sector is not covered merely by market sales income, and that a replacement of meat with legumes is likely to liberate government funds that can be used for other purposes, including the creation of other forms of employment.

In figure 3, we see the total MRH eq. for the total production of livestock and the total plant production (as a proxy for legumes) in both scenarios. In the baseline scenario, the potential social risk from livestock production is 166 million MRH eq. and the potential risk from plant production is 0.5 million MRH eq., meaning that the total potential risk from the baseline scenario is 166.8 million MRH eq. In the maximum scenario, the potential social risk from livestock production is much lower, while the potential social risk from MRH eq. is slightly higher. In total, the potential social risk in the maximum scenario is 46 million MRH eq. less than the baseline scenario.

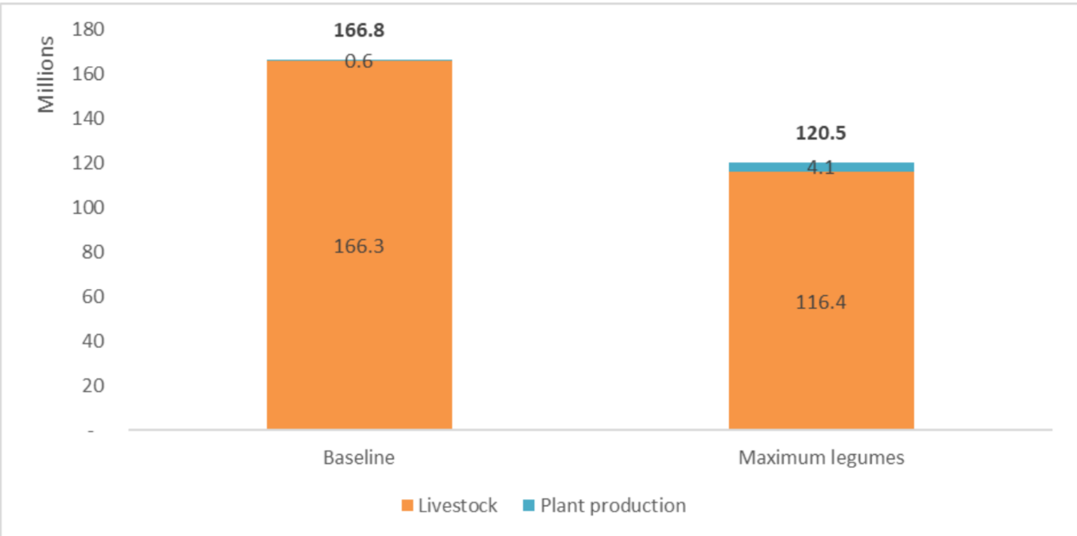

Figure 3. *Total MRH eq. in total production of livestock compared to plant production in baseline and maximum scenarios per social impact category. Total MRH eq. are displayed at the top of each column.*

Conclusions

The study uses two reference units - worker hour and FTE employment – for assessing the socioeconomic impact of plant production compared to livestock production. Livestock production is more labour intensive than legume production, meaning that there are higher potential social risks associated with livestock production, especially in the health and safety domain. Maximising legumes production and reducing livestock production to 70% of the baseline production (2023 levels) will lead to a drastic reduction in total employment but will also drastically reduce the potential social risk associated with producing food to meet the same calorie needs (2500-2600 kcal/per person/per day).

Acknowledgement

This work was supported by the project Green technology for plant based food (GreenPlantFood) funded by the Collaborative and Knowledge-building Project Collaborative Project, the Research Council of Norway, (grant no. 319049). We acknowledge the support of Simen Wilsher-Lohre (NIBIO), Klaus Mittenzwei (Ruralis) and Erik Svanes (NORSUS).

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Track 17: Sustainability in Energy Sector

Measuring the environmental and energy performance of the Southern Adriatic Sea System Authority. An overview of the sustainability achieved by maritime transport

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Abstract.

The analysis focused on the sustainability and efficiency processes implemented by the Southern Adriatic Sea System Authority and regarded the topic *Sustainability and energy transition* with the aim to process a snapshot of the sustainable and energy performance achieved by some ports located in Southern Italy. Based on the assessment of traffic and energy consumption for each port, new measures were implemented to reduce the energy need and emissions. Particularly, several improvement strategies, such as photovoltaic systems, wind farms, controlled lighting strategies, reduction in consumption in land offices, and replacements of malfunctioning meters, were implemented by the Authority to accomplish the transition policies towards green ports. Methodologically, this replicable study used a dual analysis model based on: data retrieved by authority's ports monitoring for assessing indirect emissions and, empirical algorithms composed of several data derived from ships in port, type of traffic (commodities or passengers), type of fossil fuel used, gross tonnage, time of stationing in the port, engine power, etc for quantifying direct emissions. In the reference period 2019-2021, the results displayed the highest reduction of Greenhouse gas (GHG) emissions equal to 33.7% for indirect emissions and the lowest equal to 3.6% for direct GHG emissions. This paper emphasizes the need for a holistic approach to evaluate integrated models of environmental and energy performance considering all impact categories involved in a supply chain, such as the port one, which has significant burdens.

Keywords: environment, energy, performance, maritime transport, Southern Italy.

Introduction

Generally, maritime transport plays a key role in global trade because moves around 80-90% of commodities and products. This international model of maritime transport supports globalized production and consumption patterns (Ozbiltekin-Pala et al., 2024) and the movements of millions of passengers around the world.

Moreover, the functioning of this sector is influenced by environmental factors (e.g. emissions), geopolitical (e.g. tensions between states with channel blocking) and social factors (Ozbiltekin-Pala et al., 2024). Particularly, from an environmental point of view – the core of this study - the volume of emissions released

by the maritime transport sector is very high and threatens global sustainability, influencing life underwater, flora, fauna, coasts and port cities, up to atmospheric emissions.
Nowadays, global Greenhouse Gas emissions (GHG) in maritime transport increased by 90% from 1990 to 2022, due to the expansion in ships crossing the world's oceans, inland waters and canals.
Particularly, in 2022, the share of CO_2 emissions from global maritime transport was 710 Mt (million ton) CO_2 equal to 11% of the total GHG emissions. For this reason, the goal of reducing emissions from international maritime transport by 2040 is to achieve a reduction of 70% (Statista, 2023a).

Snapshot of maritime traffic

In 2023, there were 4,790,186 port calls worldwide of which the majority (57%) related to passenger ships, 12% to liquid bulk carriers, 10% to container ships, 10% to dry bulk carriers, the lower rate concerning other types of ships (oil, natural gas, roll-on and roll-off ships). At the European level, there were 2,527,547 port calls, equal to 53% of global traffic. Also, in Europe, port calls for passenger ships amount to 75% of total calls, dry break bulk carriers to 9% and other kinds of ships count for the lower rate (UNCTAD, 2024). Particularly, at the global level in 2022, Norway with 806,165 had the greatest number of port call arrivals, followed by Japan with 289,069, USA with 261,039 and Italy with 237,195 (Statista, 2023b).
As regards passenger traffic, in 2022 Europe recorded 348.6 million passengers, with a decrease of 16.7% compared to 2019 (the year of the maximum peak equal to over 418 million passengers). Furthermore, in the years 2020 and 2021 - influenced by the Covid-19 pandemic - a decline of 45% and 36% was recorded respectively compared to 2019 (Eurostat, 2023).
At the national level, in 2023 Italy handled approximately 71 million passengers (local, ferries and cruises), over 478 Mt of liquid and solid bulk and various commodities, over 11.3 million TEUs [Twenty (foot) Equivalent Unit]; over 6 million Ro-Ro units (Assoporti, 2024a).
Particularly, in 2023 the Italian ports handled 53.8 million passengers, recording an increase of 13.3% for scheduled ferry passengers and 48.3% for cruise passengers respectively compared to 2022 (Shipping Italy, 2023 et 2024).
At the European level (EU-27), the peak of passenger movement displayed in 2021 by Italy with 57.9 million passengers, followed by Greece (52.3 million passengers), Denmark (33.5), Croatia (27.1), and Germany (19.5) (Statista, 2023c).
Considering commercial traffic, Italian ports documented a constant volume from 2021 to 2023, equal to 11.53, 11.57 and 11.3 million TEUs containers respectively (Assoporti, 2024b). At the European level (EU-27) the average value was 98.1 (2021) and 65.5 (2022) and 61.5 million TEUs (2023). Notwithstanding, in 2019 and 2020, container throughput of EU ports declined year-on-year, mainly due to the COVID-19 pandemic (Statista, 2023d).
Despite a constant movement of containers, Italy remains in the top 5 countries in Europe by volume represented by Spain (17.6 million TEUs), Germany (14,8), Netherlands (13.9), Belgium (13,2) and Italy (11.53) (Statista, 2022).

Energy consumption and Greenhouse Gases emissions issues

The global maritime industry consumes high volumes of energy: in 2022, 9.2 EJ (exajoules) and 2021 8.7 EJ of energy, all coming from the combustion of fossil fuels (IEA, 2023). This is a highly energy-emissions intensive industry particularly at a European level, covering 14.2% of the carbon dioxide (CO_2) emissions related to the entire transport industry (Statista, 2022). Moreover, in this context, Italy comes in seventh place for emissions in ports (5.69 million metric tons of CO_2 eq) preceded by Greece (6.1), Malta (6.3), Sweden (8.1), Spain (23.7), Belgium (25.7) and Netherlands (36.1) (Statista, 2022). Therefore, to reach net zero emissions targets in 2030, the maritime industry must reduce the consumption of fossil fuels, reaching a consumption of 7.6 EJ and introducing low carbon emissions fuels, such as biofuels (0.6 EJ), ammonia (0.1) and hydrogen (0.1), in its energy mix (IEA, 2023).

The case study

This paper is driven by a generalized and growing attention to environmental and energy efficiency issues, especially at the national level, by the regulatory indications introduced by the reform of law no. 84 of 28 January 1994 (Gazzetta Ufficiale, 1994) and the Reorganization of Port Legislation (Legislative Decree no. 169/2016 and subsequent amendments). Moreover, for the first time, this legislative act introduced the art. 4bis, entitled "Energy sustainability", provided an updated and modern reading of the obligations and provisions that stimulate the planning of port activities in terms of environmental and energy sustainability. Furthermore, the art. 4bis has established as mandatory the drafting and constant updating of the Energy and Environmental Planning Document of the Port System (DPEASP, or Document), by the System Authorities (Normattiva, 2024).

This paper provided an analytic and replicable methodological framework useful to analyse the environmental and energy performance in port/shipping activities. Hence, the authors proposed an innovative case study considering the shipping traffic and the related emissions at the local level. They aim to synthesize the evolution implemented in environmental sustainability by the "*Port System Authority of the Southern Adriatic Sea*" because of the evolution of the reference regulatory framework and the need to begin the process of reorganising the Authority's activities in terms of sustainability and efficiency.

Materials and Methods

Materials

Port traffics

This paper analyzed the evolution in the management of environmental sustainability carried out by the Italian port system which includes 16 System Port Authorities (AdSP) located from Northern to Southern Italy. It is a complex system that moves several commodities, containers and passengers. Particularly, from the traffic point of view, in this system emerges the Western Ligurian Sea that includes Genova and Savona-Vado ports, followed by Eastern Adriatic Sea (Trieste and Monfalcone ports), Southern Tyrrhenian and Ionian Sea (Gioia Tauro, Crotone, Corigliano Calabro, Taureana di Palmi, Vibo Marina) and Strict (Messina-Tremestieri, Milazzo, Villa San Giovanni and Reggio Calabria ports) (Fig. 1).

Moreover, observing Fig. 1, it has been highlighted that the high volumes of commodities traffic handled by the 16 authorities followed by passenger traffic.

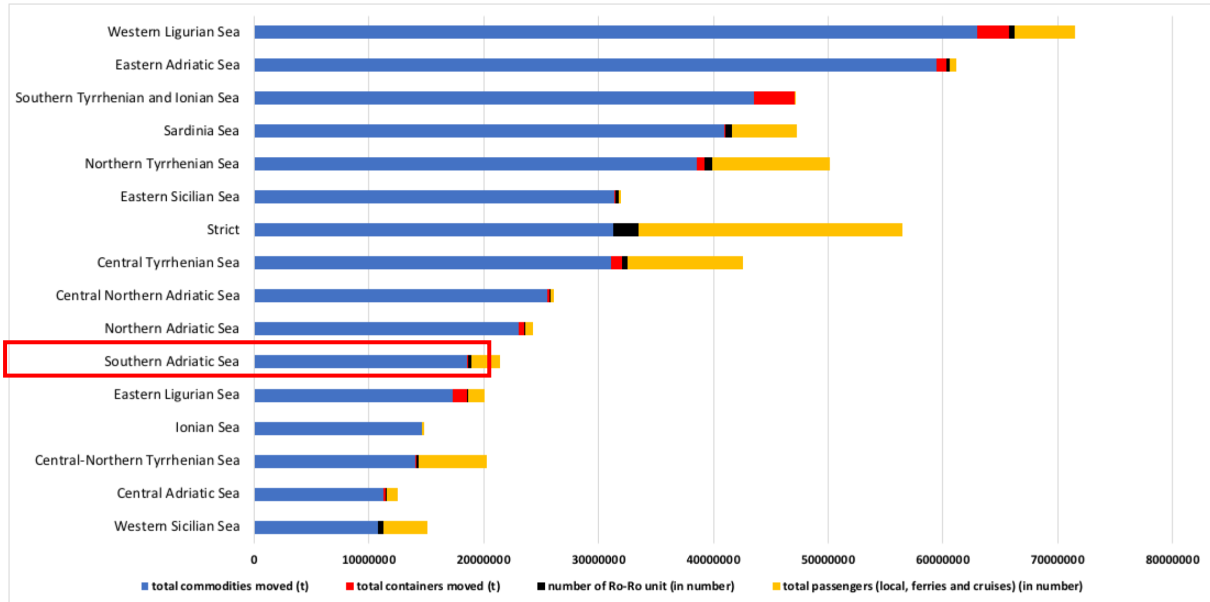

Figure 1. *Port movements for Italian AdSP, 2023.*
Source: Authors' elaboration on data Assoporti, 2024.

Particularly, the authors focused on one of the 16 Ports Systems Authorities, precisely the one located in the Southern Adriatic Sea (AdSPMAM), which includes Bari, Brindisi, Manfredonia, Barletta, Monopoli and Termoli ports (Fig. 2).

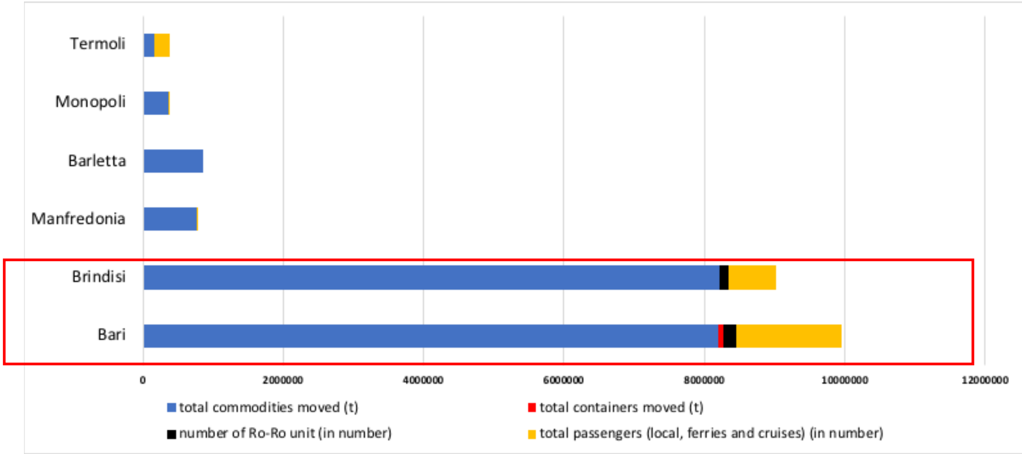

***Figure 2**. Port movements for AdSPMAM, 2023.*
Source: Authors' elaboration on data Assoporti, 2024.

As shown in Fig. 2, Bari and Brindisi's ports are characterized by higher traffic volumes moved, followed by Barletta, Manfredonia, Monopoli and Termoli ports. Particularly, Bari and Brindisi both move 44% of total commodities exchanged in the AdSPMAM ports, particularly Bari documented 100% of container traffic, and Brindisi records 33% of landings and embarkations, compared to 63% documented by Bari.

Furthermore, the authors collected port traffic in 2021 and illustrated in the tables from 1 to 5 for each of the Authority's ports:

Particularly, Tables 1-5 include data on commodities, ferries and passengers moved, with input, output and total values.

***Table 1.** ESPO model 2021 for Port of Bari (Mt).*

DESCRIPTION			IN	OUT	TOTAL
A1		TOTAL	4,552	2,752	7,304
A3		SOLID BULK	1,747	130	1.877
	A31	Cereals	1,611	107	1,718
	A32	Foodstuffs / animal feed / oilseeds	3	0	3
	A34	Minerals / Cements / Lime	31	0	31
	A35	Metallurgical products	0	18	18
	A36	Chemicals	10	0	10
	A37	Other solid bulk	0	5	5
A4		VARIOUS GOODS COMMODITIES IN PACKAGES	2,805	2,622	5,427
	A41	In containers (including Ro-Ro containers)	426	326	752
	A42	Ro-Ro (containers excluded)	2,374	2,291	4,665
	A43	Other miscellaneous commodities	6	4	10
B1		Number of moorings	0	0	2
	B12	Dead Weight Tonnage	0	0	50,116
B2		Number of local passengers and ferries (B21 + B22)	402	395	797
	B22	Ferry passengers	402	395	797
B3		Number of cruise passengers	0	0	211
	B31	"Home Port"	54	55	109
	B32	"Transits" (to be counted only once)			101
B4		Container numbers in TEU (B41 + B42)	38	33	71
	B41	"Hinterland" (B411 + B412)	38	33	71
	B411	Empty	0.4	0.7	1.1
	B412	Full	37	25	62
B5					
	B51	Number of Ro-Ro units	91	86	177
	B52	Number of private vehicles	96	105	201
Printed on 18/01/2022 at 15:14 and edited by the Technological Innovation Office					

Source: Authors' elaboration on AdSPMAM (2022).
*approximate and rounded data.

As shown in Table 1, the total of tons moved by Bari ports is equal to 7.3 Mt, mainly represented by incoming commodities (61.64%) and most of them are cereals (35.55%). Moreover, incoming and outgoing packaged commodities stand at similar values and most of them (85% in total) are moved by Ro-Ro ferries (Roll-on/Roll-of ferries). Moreover, Bari port moved a fair amount of cruise passenger traffic.

Table 2. *ESPO model 2021 for Port of Barletta (Mt).*

DESCRIPTION			IN	OUT	TOTAL
A1		TOTAL	693	36	729
A2		LIQUID BULK	331	0	331
	A22	Refined (petroleum) products	321	0	321
	A24	Chemicals	0	0	0
A3		SOLID BULK	360	33	393
	A31	Cereals	127	14	141
	A34	Minerals / Cements / Lime	84	4	88
	A35	Metallurgical products	6	0	6
	A36	Chemicals	115	15	130
	A37	Other solid bulk	27	0	27
A4		VARIOUS GOODS AND COMMODITIES IN PACKAGES	2	3	4
	A43	Other miscellaneous commodities	2	3	4
B1		Number of moorings	0	0	0
	B12	Dead Weight Tonnage	0	0	0
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Source: Authors' elaboration on AdSPMAM (2022).
*approximate and rounded data.

Contrariwise, as shown in Table 2, the total of tons moved by Barletta ports is equal to about 729 thousand tons, mainly represented by incoming commodities (95%) and most of them are liquid bulk as refined petroleum products (47.76%) and solid bulk as cereals (18.18%) and chemicals (16.60%). Moreover, Barletta port does not move disembarkation or embarkation passenger traffic.

Table 3. *ESPO model 2021 for Port of Brindisi (Mt).*

DESCRIPTION			IN	OUT	TOTAL
A1		TOTAL	5,342	2,284	7,626
A2		LIQUID BULK	1,678	344	2.022
	A22	Refined (petroleum) products	89	25	114
	A23	Gaseous, liquefied or compressed petroleum products and natural gas	575	89	664
	A25	Other liquid bulk	217	0	217
A3		SOLID BULK	2,016	186	2,200
	A31	Cereals	43	0	43
	A32	Foodstuffs / animal feed / oilseeds	250	0.02	250.020
	A33	Fossil carbons and lignites	1,585	0	1,585
	A34	Minerals / Cements / Lime	9,386	372	9,758
	A35	Metallurgical products	76	76	152
	A36	Chemicals	17	0	17
	A37	Other solid bulk	35	109	144
A4		VARIOUS GOODS AND COMMODITIES IN PACKAGES	1,649	1,755	3,404
	A42	Ro-Ro (containers excluded)	1,642	1,745	3,387
	A43	Other miscellaneous commodities	6	10	16
B1		Number of moorings	0	0	2
	B12	Dead Weight Tonnage	0	0	37,830
B2		Number of local passengers and ferries (B21 + B22)	151	161	312
	B21	Local passengers (journeys <20 miles)	0	0	0
	B22	Ferry passengers	151	161	312
B3		Number of cruise passengers	0	0	8,568
	B31	"Home Port"	1.7	1.3	3
	B32	"Transits" (to be counted only once)	0	0	5599
B5					
	B51	Number of Ro-Ro units	63	61	125
	B52	Number of private vehicles	29	34	63
Printed on 18/01/2022 at 13:33 and edited by the Office for Technological Innovation.					

Source: Authors' elaboration on AdSPMAM (2022).
*approximate and rounded data.

Brindisi ports moved 7,6 Mt of commodities, mainly represented by incoming commodities (70.07%) and most of them are liquid bulk (31.46%) and solid bulk (29.59%) and fossil carbon and animal feeds. Moreover, Brindisi exchanges various commodities in packages and 99% of them are moved by Ro-Ro ferries. There is also a fair amount of passenger traffic, of which almost equal parts are embarking and disembarking (Tab. 3)

Table 4. *ESPO model 2021 for Port of Manfredonia (Mt).*

DESCRIPTION			IN	OUT	TOTAL
A1		TOTAL	475	164	639
A2		LIQUID BULK	12	116	128
	A25	Other liquid bulk	12	116	128
A3		SOLID BULK	435	35	470
	A31	Cereals	149	7.550	156.550
	A32	Foodstuffs / animal feed / oilseeds	15	22	37
	A34	Minerals / Cements / Lime	152	0.055	152.055
	A35	Metallurgical products	13	0	13
	A36	Chemicals	91	0	91
	A37	Other solid bulk	15	0	15
A4		VARIOUS GOODS AND COMMODITIES IN PACKAGES	28	13	41
	A41	In containers (including Ro-Ro containers)	0.022	0	0.022
	A43	Other miscellaneous commodities	28	13	41
B1		Number of moorings	0	0	0.245
	B12	Dead Weight Tonnage	0	0	619
B3		Number of cruise passengers	0	0	0.169
	B32	"Transits" (to be counted only once)	0	0	0.169
B4		Container numbers in TEU (B41 + B42)	0.002	0	0.002
	B41	"Hinterland" (B411 + B412)	0.002	0	0.002
	B412	Full	0.002	0	0.002
Printed on 14/01/2022 at 10:12 a.m. and edited by the Technological Innovation Office					

Source: Authors' elaboration on AdSPMAM (2022).
*approximate and rounded data.

Similarly, the port of Manfredonia manages commodities traffic: 74.30% of which is incoming. 91.56% of total tons moved are represented by solid bulk, principally cereals (34%), mineral and cement (34.80%) (Tab. 4).

Table 5. *ESPO model 2021 for Port of Monopoli (Mt).*

DESCRIPTION			IN	OUT	TOTAL
A1		TOTAL	356	165	521
A2		LIQUID BULK	166	157	323
	A25	Other liquid bulk	166	157	323
A3		SOLID BULK	183	0	183
	A32	Foodstuffs / animal feed / oilseeds	34	0	34
	A34	Minerals / Cements / Lime	122	0	122
	A36	Chemicals	27	0	27
A4		VARIOUS GOODS AND COMMODITIES IN PACKAGES	7	8	15
	A43	Other miscellaneous commodities	7	8	15
B1		Number of moorings	0	0	0.112
	BB12	Dead Weight Tonnage	0	0	572
B3		Number of cruise passengers	0	0	0.352
	B32	"Transits" (to be counted only once)	0	0	0.352
Printed on 14/01/2022 at 10:12 a.m. and edited by the Technological Innovation Office					

Source: Authors' elaboration on AdSPMAM (2022).
*approximate and rounded data.

Finally, the port of Monopoli, documented 66.1% of incoming commodities compared to the total (in/out), In particular, this port moved in 2021, 46.47% of commodities in liquid bulk form and 51.54% in solid bulk (most of them equal to 66.67% represented by minerals and cement) (Tab. 5).

Road Transport and Fuel Data

The EN 16258 standard for the calculation of emissions considers both the tonnage of the vehicle transporting the goods and the type of the same, distinguishing it into bulky type goods, medium type goods and loose type goods. By cross-referencing the type of means of transport with the type of goods it was possible, using tabled coefficients, to estimate the quantity of fuel consumed. In particular, in the calculations, reference was made to Table 6 to calculate the fuel consumed per km and t of commodities:

Table 6*. Indicative scheme of consumption by vehicle.*

	HILLY			LEVEL GROUND (FLAT)		
	Volume of commodities	Average commodities	Bulk commodities	Volume of commodities	Average commodities	Bulk commodities
Freight transport	**– Diesel consumption in liter/tkm –**					
Lorry < 7,5 t	0.140	0.078	0.063	0.139	0.077	0.062
Lorry 7,5 – 12 t	0.108	0.061	0.050	0.105	0.059	0.048
Lorry 12 – 24 t	0.063	0.036	0,029	0.060	0.034	0.027
Articulated lorry {24 – 40 t^ (1)}	0.038	0.023	0,020	0.033	0.020	0.016
Container transport		**– Diesel consumption in litre/TEU-km –**				
Lorry < 7,5 t	0	0	0	0	0	0
Lorry 7,5 – 12 t	0	0	0	0	0	0
Lorry 12 – 24 t	0.24	0.26	-	0.22	0.24	0
Articulated lorry {24 – 40 t^ (1)}	0.17	0.19	0.34	0.14	0.16	0.29

Source: Authors elaboration on data HBEFA 3.1 (2023) and TREMOD (2010).

This table also considers the type of road travelled: in this case study, the authors considered only urban routes followed by heavy vehicles for the Apulian ports. Therefore, to take this circumstance into account, a consumption correction was carried out (Tab. 7).

***Table 7**. Conversion factors.*

CORRECTION FACTORS FOR THE USE OF URBAN ROADS	
	Correction Factor
Lorry <7,5 t	0.9
Lorry 7,5-12 t	1
Lorry 12-24 t	1.3
Road train/articulated lorry 24-40 t	1.4

Source: Authors elaboration on data HBEFA 3.1 (2023) and TREMOD (2010).

With reference to the ESPO model tables provided by AdSPMAM (see Tables 1-5), considering the specificity of port activities, it was assumed that all commodities were transported by vehicles weighing more than 12 t. In particular, in the lack of detailed data on the type of carrier and the category of commodities transported, it was hypothesized that (observing the port traffic tables included in the Method section):

- The A1 and A3 types of commodities were considered equally distributed between trucks with a tonnage between 12 and 24 t and articulated vehicles, according to the weight coefficient of 16-18 t assigned by the AdSPMAM. It was considered a type of bulk commodities;
- Type A43 of commodities were considered to be volumetric and transported by vehicles weighing between 12 and 24 t;
- Types A41 and A42 commodities were considered to be Medium type and transported by vehicles weighing between 12 and 24 t;
- Containers (in TEUs) were considered to be transported exclusively by road trains;
- As regards the Port of Brindisi, the t of commodities belonging to the A33 category (coal and lignite) are not considered in the calculation of emissions from heavy vehicles as they are transported to end users via conveyor belts (as for Brindisi port and directed to thermoelectrical power plants).

In this regard, it is important to point out that, although this is an approximation, the electricity consumption to power these transport systems is borne by the concessionaires who have not disclosed the data. Below are the average routes of heavy vehicles, provided by AdSPMAM within the 5 port areas (excluding the port of Termoli), considered equal for incoming and outgoing vehicles:

- Bari: route length 3.9 km

- Brindisi: route length 3 km
- Manfredonia: route length 2.5 km
- Monopoli: route length 0.85 km
- Barletta: route length 0.9 km

After estimating the consumption in liters of diesel, the authors used the following Table 8 extracted from the EN 16258 standard for the accurate calculation of CO_2 emissions.

Table 8. *CO_2 emission per fuel unit.*

	STANDARDIZED ENERGY CONSUMPTION							
	Tank-to-wheels e_T		Well-to-wheels e_W		Tank-to-wheels g_T		Well-to-wheels g_W	
	MJ/kg	MJ/l	MJ/kg	MJ/l	$kgCO_2$/kg	$kgCO_2$/l	$kgCO_2$ /kg	$kgCO_2$/l
Petrol	43,2	32,2	50,5	37,7	3,25	2,42	3,86	2,88
Ethanol	26,8	21,3	65,7	52,1	0	0	1,56	1,24
Petrol E5 (5 vol. % Ethanol)	42,4	31,7	51,4	38,4	3,08	2,30	3,74	2,80
Petrol E10 (10 vol. % Ethanol)	41,5	31,1	52,2	39,1	2,90	2,18	3,62	2,72
Diesel	43,1	35,9	51,3	42,7	3,21	2,67	3,90	3,24
Biodiesel	36,8	32,8	76,9	68,5	0	0	2,16	1,92
Diesel D5 (5 vol. % biofuel)	42,8	35,7	52,7	44,0	3,04	2,54	3,80	3,17
Diesel D7 (7 vol. % biofuel)	42,7	35,7	53,2	44,5	2,97	2,48	3,76	3,15
Compressed natural gas	45,1	n/a	50,5	n/a	2,68	n/a	3,07	n/a
Liquefied petroleum gas	46,0	25,3	51,5	28,3	3,10	1,7	3,46	1,90
Jet kerosene	44,1	35,3	52,5	42,0	3,18	2,54	3,88	3,10
Heavy fuel oil (HFO)	40,5	39,3	44,1	42,7	3,15	3,05	3,41	3,31
Marine diesel oil (MDO)	43,0	38,7	51,2	46,1	3,24	2,92	3,92	3,53
Marine gas oil (MGO)	43,0	38,3	51,2	45,5	3,24	2,88	3,92	3,49

Source: Authors' elaboration on data EN 16258 (2012).

Furthermore, considering the particular type of analysis, which focuses only on port consumption, tank-to-wheel consumption and a 5% mixture of diesel and biodiesel (D5 diesel) was considered.

Methods

Hence, intending to provide a replicable framework to assess the environmental performance of the reference ports, the authors followed two methodological paths:

1) quantifying the indirect emissions documented by AdSPMAM activities from 2019 to 2021 after the implementation of efficiency systems, consumption reduction and cold ironing systems;

2) quantifying the direct emissions related to all stakeholder activities carried out in the area's ports in the period 2019-2023.

Indirect emissions assessment

Therefore, considering the volume recognized by AdSPMAM ports, to analyse the evolution of the sustainability management of this port authority (AdSPMAM), the authors accessed several sources in particular the *"Energy and Environmental Planning Document of the Port System* (DPEASP)". This document was developed in 2018 and approved by the Management Committee of the Southern Adriatic Sea Port System Authority in 2019 and adapted to the indications of the competent Ministries in 2020.

This plan provided a strategy and an implementation tool for achieving the objectives set starting from the analysis of the context. In particular, the DPEASP (AdSPMAM, 2020) defined the reference framework relating to port traffic and the energy consumption of the Authority. Moreover, it outlined the evolution of the regulatory framework regarding the use of renewable energy sources, assessed the energy planning in a logic of emissions reduction, through a plurality of lines of actions (efficiency improvement of existing structures, development of a Simple Production and Consumption System (SSPC) and implementation of "cold ironing"). The DPEASP allowed to evaluation of the technical and economic feasibility of the interventions and established a series of organizational measures towards achieving the objectives and the potential introduction of design changes to correct any discrepancies with the expected results.

Among other actions for monitoring the results achieved, during the year 2022, AdSPMAM promoted the administration of a questionnaire on energy consumption and on aspects of interest in the energy-environmental field addressed to port operators operating in port areas of its jurisdiction (activities in line to review the DPEASP towards the involvement of stakeholders). Unfortunately, the first attempt at involvement did not give the desired results, as it did not collect useful feedback to define the overall picture. For this reason, the authors shifted from primary data retrieved after the questionnaire survey to an analytical and empirical method for the emission calculation related to stakeholders' activities.

Direct Emissions Assessment

Using an empirical method, the authors assessed the direct emissions from 2019 to 2021 related to the activities carried out by all stakeholders involved in the shipping activities at AdSPMAM ports, as indicated in the previous tables (from 1 to 5).

Furthermore, an interesting analysis model based on data and algorithms theorized by Jalkanen (Jalkanen et al., 2009) has been implemented to analyse the impact of naval and heavy vehicle traffic due to the transit of commodities and passengers in the relevant ports (Fig. 3).

Furthermore, for the calculation of maritime traffic emissions documented by the Authority's ports, the authors considered the registers available for the year 2019, separated by commodities and passenger/ferry traffic, in which the following main data were available: name of vessel, gross tonnage, date and time of arrival in port, date and time of departure (data not always reported), port of jurisdiction, passengers and vehicles on board.

From these data, using some databases available on the web (such as marinetraffic.com and others), all the information essential to calculate the fuel consumption of ships within the port area in manoeuvring conditions (for an assumed time of 30 minutes for mooring and 30 minutes for departure) and during the mooring period (during which the auxiliary powers of the vessel are considered active according to “IMO (2014) - Procedure for calculating and verifying the efficiency index energy)”.

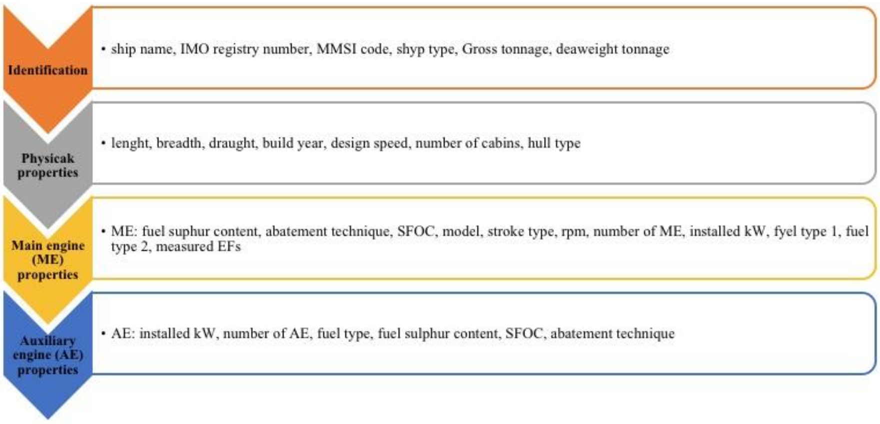

Figure 3. *Input data of the STEAM model theorized by Jalkanen et al. (2009) regarding the properties of ships.*
Source: Authors’ adaptation based on Jalkanen et al. (2009).

Among the data collected, as suggested by Jalkanen et al. (2009), there are engine power, engine fuel, engine operating speed, maximum speed of the vessel in knots, year of construction, type, dimensions, DWT (deadweight tonnage) and draft maximum of the vessel. Regarding the engine speed, where not available, it was assumed that the engine operated at medium speed. Cruise ships not equipped with slow diesel engines were all assumed to be electrically powered.

Furthermore, to estimate the draft of the vessels during the manoeuvre, the tonnage per centimetre (TPC) was calculated considering the width, length and blocking coefficient of the listed vessels. For merchant ships, it was assumed that they travelled with an average load compared to the maximum load. For passenger ships, however, it has been used the number of vehicles and passengers on board, and it was estimated their average weight, used to calculate the draft. Moreover, it was assumed that the speed of the ships in port, essential for the calculation of the instantaneous motive power according to the STEAM model theorized by Jalkanen (Jalkanen et al., 2009) was 5 knots.

As regards the calculation of CO_2 emissions linked to land traffic of heavy vehicles within the Authority's port areas, these were developed in compliance with the EN 16258 standard (EN 16258, 2012). This estimate was carried out starting from the data provided by the Authority itself, relating to the mass of commodities, expressed in t, and the number of TEUs exchanged in and out of the port areas of the 5 Apulian ports under the jurisdiction of the Authority (see the tables included in the Materials section of this study).

The results of the studies and implementations, with a notable analytical approach, are described in the next section.

Results and Discussion

In this section, the authors presented the results achieved through two methodological paths followed. Firstly, the implementation of the DPEASP actions has led the AdSPMAM to achieve positive results (Tab. 9) in terms of reduction in electricity consumption and consequent reduction in indirect emissions (resulting from purchased or acquired energy, such as electricity, steam, heat or cooling, generated off-site and consumed by the business, e.g. the electricity purchased by the utility company is generated off-site).

Table. 9. *Indirect emissions of GHG from energy consumption (2019-2023) by AdSPMAM ports.*

PORT	2019		2020		2021		2022		2023		reduction 2019-2023 (%)
	kWh	$MtCO_2$	kWh	$MtCO_2$	kWh	$MtCO_2$	kWh	$MtCO_2$	kWh	$MtCO_2$	$MtCO_2$
Bari	3823647	1.061	2011978	0.559	2072886	0.575	1871509	0.520	1747760	0.485	-54
Brindisi	2542415	0.706	2082943	0.578	2080712	0.578	1980833	0.550	1675126	0.465	-34
Manfredonia	328746	0.091	279374	0.078	263362	0.073	241283	0.067	228186	0.063	-31
Barletta	126855	0.035	98211	0.027	100957	0.028	86226	0.024	93068	0.026	-26
Monopoli	25588	0.007	22623	0.006	20536	0.006	18916	0.005	18060	0.005	-29
TOT AdSPMAM	**6847251**	**1.901**	**4495129**	**1.248**	**4538453**	**1.260**	**4198767**	**1.166**	**3762200**	**1.044**	**-45**
Emission factor (ISPRA 2000)	277.6 gCO_2/kWh										

Source: Authors' elaboration.

Particularly, as shown in Tab. 9, from 2019 to 2023 the energy consumption in AdSPMAM highlighted an average reduction equal to 45% for electric power used related emission of CO_2. The main actions that have allowed this substantial reduction are:

- activities aimed at the implementation of an integrated Energy-Environment-Quality system according to the technical standards UNI CEI EN ISO 50001, UNI EN ISO 14001, UNI EN ISO 9001.
- Energy efficiency improvement aimed at reducing electricity consumption, implemented in all ports of the AdSPMAM System, replacing the lighting fixtures in the external and internal areas (with an implementation rate of 80% of the structures under the jurisdiction of the AdSPMAM).
- construction of energy production systems from renewable sources (mainly photovoltaic and wind) with sizing aimed at self-consumption to reduce the initial energy requirement.

Secondly, as aforementioned in the methods section, the authors assessed the direct emissions related to AdSPMAM ports from 2019 to 2021 related to the activities carried out by all stakeholders involved in the shipping activities, as indicated in Tables 1 to 5, using an empirical method.

Table 10. *Direct emissions of GHG from commodities traffic (2019-2021).*

PORT	COMMODITIES 2019			2020			2021		
	$MtCO_2$/year Total	commodities [Mt]	[%]	$MtCO_2$/year Total	commodities [Mt]	[%]	$MtCO_2$/year Total	commodities [Mt]	[%]
Bari	4.038	6,100	30.91	4.531	6,845	34.13	4.836	7,304	35.30
Brindisi	6.767	7,543	51.79	6.945	7,742	52.32	6.842	7,627	49.95
Manfredonia	1.059	805	8.10	0.813	618	6.13	0.84	639	6.14
Barletta	0.305	805	2.33	0.272	72	2.05	0.276	729	2.02
Monopoli	0.897	517	6.87	0.713	411	5.37	0.903	521	6.59
TOT AdSPMAM	13.066	15,770	100	13.274	15,688	100	13.697	16,820	100

Source: Authors' elaboration.

Particularly, as shown by Table 10, from 2019 to 2021 commodities traffic increased by 6% and direct emissions of GHG documented an increase of 4.82%.

***Table 11**. Direct emissions of GHG from ferries passengers' traffic (2019-2021).*

PORT	PASSENGERS								
	2019			2020			2021		
	$MtCO_2$/year Total	DWT (Mt)	[%]	$MtCO_2$/year Total	DWT (Mt)	[%]	$MtCO_2$/year Total	DWT (Mt)	[%]
Bari	9.878	61,609	71.69	5.93	36,982	59.29	8.036	50,116	65.96
Brindisi	3.825	35,553	27.76	4.021	37,373	44.20	4.070	37,830	33.41
Manfredonia	0.001	819	0.01	0,001	644	0.01	0.001	619	0.01
Barletta	0.000	819	0.00	0.000	682	0.00	0.000	679	0.00
Monopoli	0.075	570	0.54	0.050	378	0.50	0.075	572	0.62
TOT AdSPMAM	13.779	99,370	100	10.002	76,059	100	12.182	89,816	100

Source: Authors' elaboration.

In terms of passengers, AdSPMAM outlined a decrease of 10%, followed by a decrease in emissions of 11.61% (Table 11).

As regards road transport, taking into account the materials, particularly Tables 6-8 and methods, the authors provided Table 12 which displays the main results of the CO_2 emissions:

***Table 12**. Detailed CO_2 emissions per road traffic in AdSPMAM ports per year.*

PORT	2019	2020	2021
	[Mt CO_2/anno]	[Mt CO_2/anno]	[Mt CO_2/anno]
Bari	5.111	5.639	5.970
Brindisi	4.170	4.361	4.212
Manfredonia	0.434	0.348	0.354
Monopoli	0.098	0.077	0.102
Barletta	0.159	0.142	0.141
TOT AdSPMAM	9.972	10.567	10.779

Source: Authors' elaboration.

Table 12 shows from 2019 to 2021 an increase in emissions of 8.12% was quantified, in particular, due to the activities of the port of Bari which recorded an increase in the impact of 16.82%.

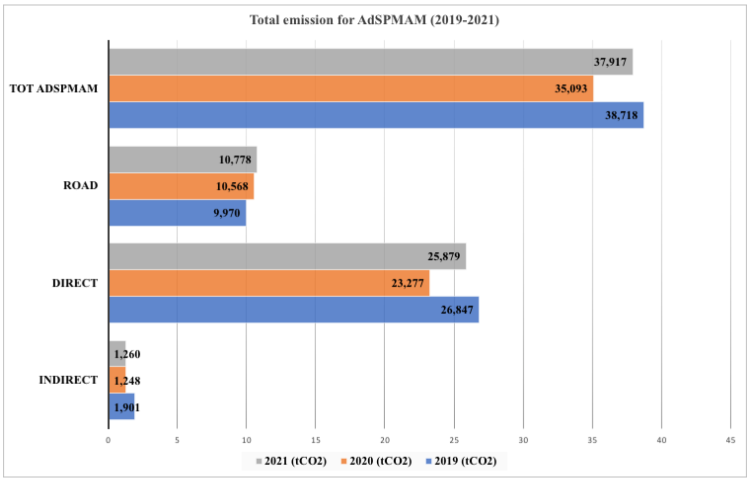

***Figure 4.** Total emission for AdSPMAM ports (road, direct and indirect emission) for the years 2019-2020-2021.*

Source: Authors' elaboration.

Finally, the authors synthetized the amount of indirect emission (mainly linked to the activities of the offices and headquarters of the AdSPMAM ports), the indirect emission (regarding the passengers and commodities traffic in the port areas), the road traffic (related to road traffic of trucks disembarked from Ro-Ro ferries or container trucks moving in the port areas before leaving the customs gates) in the period 2019-2021.
Particularly, as shown by Fig. 4, the largest amount of emissions is that relating to the disembarkation/embarkation of commodities/goods and passengers in port areas: these are direct emissions mainly from the ships' engines which remain switched on during operations and they represented respectively the 71.9% of the total (bar of total AdSPMAM) in 2019, 66.3% in 2020 and over 60.2% in 2021. Instead, emissions related to road traffic were 25.75% of the 2019 total, 30.16% in 2020 and 27.84% in 2021. Finally, the indirect emissions displayed the highest decrease of 33.7% in the reference period.

Conclusion

The present case study includes a replicable methodological path useful to quantify the direct and indirect emissions documented by port activities, using an analytic methodology considering:

- first of all, the indirect emissions related to energy consumption for offices and headquarters and,
- secondly, the direct emissions related to stakeholders' activities in the port area refer to ship movements, truck movements on the road and vessel supply.

This approach improved the DPEASP application and the results were achievable considering that the first version of this plan was based on a notable approximation to match the observations relating to the Port System and the Port with those deriving from the aspects of exclusive competence of the Authority. This first approach considered a partial vision of the energy and environmental context, introducing an incomplete and ineffective reference framework. Hence, all the stakeholders should interact with the port territories to improve the environmental performance for indirect and direct emission of port activities. This approach stimulated the need to rewrite the operational model of the Energy and Environmental System, also in the organization of the Authority. For this purpose, the authors quantified in a timely and scientific manner the emissions relating to the activities of the 5 ports included in the AdSPMAM (excluding the port of Termoli).
Furthermore, regarding the opportunities and limits contained in the present case study, in the absence of information coming directly from the operators, the scientific method described has allowed us not to neglect the contribution of the port activities carried out by private individuals within the areas maritime on the environmental impact of the ports of the Southern Adriatic System, which must therefore be considered in addition to the emissions deriving directly from the Authority's activities and included in the DPEASP.
In terms of future activity, planning is also underway for the construction of cold ironing systems in the ports of Bari, Brindisi and Termoli. These systems will lead to a direct reduction of emissions into the atmosphere thanks to the possibility of powering the services on board ships from land, with the consequent shutdown of the engines dedicated to powering these services.

Finally, this paper emphasizes the application of holistic approaches for evaluating the integrated models of environmental and energy performance implemented by port authorities, considering all impact categories (direct and indirect) involved in the maritime supply chain, which has significant burdens. Therefore, the output of this paper spurs practical and managerial implications in compliance with EU and international regulations. Particularly this replicable framework can be adopted by port management to achieve the main objectives of the green and eco-sustainable ports.

List of technical acronyms

ADSP	AUTORITÀ DI SISTEMA PORTUALE
ADSPMAM	Autorità di Sistema Portuale del Mare Adriatico Meridionale
AE	Auxiliary engine
CO_2	Carbon Dioxide
DPEASP	Documento di Pianificazione Energetico Ambientale del Sistema Portuale
DWT	Deadweight Tonnage
EFS	Experimental value for emission factors of NOx, SOx, CO and PM.
EJ	Exajoules
EU-27	Member States of EU: Belgio, Bulgaria, Repubblica Ceca, Danimarca, Germania, Estonia, Irlanda, Grecia, Spagna, Francia, Croazia, Italia, Cipro, Lettonia, Lituania, Lussemburgo, Ungheria, Malta, Paesi Bassi, Austria, Polonia, Portogallo, Romania, Slovenia, Slovacchia, Finlandia e Svezia
GHG	Greenhouse Gas
IMO	International Maritime Organization
KW	Kilo Watt
ME	Main engine
MMSI	Mobile Maritime Service Identity
$MTCO_2$	Metric tons of carbon dioxide
RO-RO	Roll-on/roll-off: horizontally loaded or rotatable ferry ships) designed for the loading and unloading transport of wheeled vehicles and loads, arranged on flatbeds or in containers, loaded and unloaded by means of vehicles equipped of wheels autonomously and without the aid of external mechanical means
RPM	crankshaft revolutions per minute
SFOC	Specific Fuel Oil Consumption
SSPC	Simple Production and Consumption System
STEAM	Ship Traffic Emission Assessment Model
TEUS	Twenty-foot equivalent unit (used for containers traffic)
TPC	Tonnage per centimetre

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Hydrogen implementation in the mix ensuring the energy transition: a bibliometric analysis

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Abstract

The acceleration of the transition towards renewable energy requires effective and rapid strategies to counteract climate change and mitigate its effects to achieve carbon neutrality by 2050. This study aims to analyse the evolution of the role of hydrogen in the energy transition through a bibliometric analysis of the literature, highlighting the state of the art in this vast research field and identifying relevant trends. The choice of the time frame is significant, considering publications of journal articles starting from 2015, the year in which the United Nations adopted the 2030 Agenda for Sustainable Development, a program of actions that countries commit to achieving. Among the strategies adopted, hydrogen plays a crucial role concerning actions aimed at climate change (SDG 13) and clean and affordable energy (SDG 7) (United Nations, 2015).

The bibliometric analysis conducted examined 671 articles identified in the Scopus database using broad keywords. The macro-criteria of inclusion refers to articles in journals and reviews, in the energy field, avoiding the ones of technical and engineeristic nature. A managerial lens is adopted to pursue this study. The techniques used in the study are those of science mapping, including co-citation analysis to investigate past studies and references, and keyword co-occurrence, which led to the identification of the most influential thematic clusters and their networks. The main clusters are hydrogen storage, hydrogen production, and renewable energies. The use of additional indicators and tools such as Bibliometrix R and VOSviewer allowed for a network analysis that provided greater understanding and completeness of the research.

Keywords: Hydrogen, Energy transition, Sustainability, Bibliometric Analysis, Co-occurence, Co-citation.

Relevant Topic: Energy Transition and Hydrogen technology

Introduction

Given the urgency to change course in the polluted world we are currently living in, the energy transition has become a fundamental theme to get into high gear. Along, with the need to satisfy an increasing energy demand and the requirement to switch to renewable sources that will substitute fossil fuels. According to (IRENA, 2023) the renewable energy share accounted for 16% of the total global primary energy supply. Hydrogen is considered as a key component of the global strategy for a sustainable and effective ecological transition, since it is capable of acting as a clean energy carrier. Its use in fuel cells, leads to emit only water as a byproduct, making it an ideal solution for reducing greenhouse gas emissions. It is a versatile element that allows different applications across various sectors, including transportation, industry, and power generation, helping not only to decarbonize processes that currently rely on fossil fuels, but also to promote environmental sustainability in the long term. Moreover, its intrinsic role is linked to the ability to store excess renewable energy, generated in wind and solar production plants. The aim is to stabilise the electric grid and to ensure a continuous energy supply, despite the intermittent nature of renewables. Additionally, when we come to innovation and sustainability hydrogen is accounted as a clear energy vector, since by producing it from water electrolysis and renewable electricity, is able to contribute to carbon neutrality and net-zero emissions (Agarwal, 2022).

The policies and strategies imposed by the European Commission gave concern to increasing interest in hydrogen, leading to the rise of scientific publications and projects in the field. Although public funding is not yet enough, considering that only 1.1 billion $ has been invested during the previous years, the first steps have been moved by private companies investing in the development of hydrogen production technologies, recognizing its potential to revolutionise the global energy system and meet climate goals. The major limitations come from the lack of infrastructures and extremely high costs of the technology.

Lastly, the global adoption and deployment of the hydrogen technologies will be driven by a social acceptance from the public and ensure the active collaboration of the stakeholders (Emodi et al., 2021). The involvement of all relevant stakeholders is necessary to identify barriers and opportunities within the value chain, as well as to determine social acceptance in local communities. The various actors thanks to a continuous two-way communication are able to directly influence the decision-making processes and strategies for the implementation of hydrogen on a market scale, as well as to identify and mitigate risks (Stalker et al., 2022).

This study has the intent to provide a comprehensive examination of the existing literature on hydrogen in the energy field and thus, to identify relevant themes, influencing authors, keywords consolidation, to analyse current and future paths, and to provide insights and considerations with a managerial lens that has never been adopted since today. In the study performed by (Kar et al., 2022), it highlights the multidisciplinary nature of the hydrogen economy, it refers to aspects such as production, storage, transportation, final use, public policy. All these aspects define the whole value chain and their comprehensive assessment will lead to a growth.

Methods

This section will present the methodologies used to the objective of the study and to identify the state of the art relative to the role of hydrogen in the energy transition, identifying at the same time relevant trends.

Bibliometric Analysis

Bibliometric analysis is a quantitative study that provides a quantity view to map and decipher scientific knowledge and its developments in a specific field of research. It is useful because it allows you to work with a large amount of data, which can hardly be analysed manually. The interpretation of the data that can be used can be objective, when using a performance analysis; and subjective, when proceeding to the analysis of themes (Donthu et al., 2021).

The techniques used in the study are those of science mapping, including keyword co-occurrence, that led to the identification of the most influential thematic clusters and their networks; and the co-citation to identify the most frequently cited publication and the thematic clusters of the research field. Co-citation analysis is a technique used in science mapping to highlight the relationships between frequently cited publications, with the aim of identifying interdisciplinary themes within the research field and describing its thematic structure.Co-citation analysis involves tracking pairs of papers that are cited together in the source articles. When the same pairs of papers are co-cited by many authors, clusters of research begin to form (Surwase et al., 2011). The co-cited papers in these clusters tend to share some common themes and a comprehensive analysis of the past. The co-citation map is a form of exploratory data analysis (EDA) that relies on graph theory to explore the data structure (Fahimnia et al., 2015).

In particular, the total number of publications per year, by newspaper, the average number of quotations by year, the newspapers with a high number of published, the countries in which it is published most often and the affiliation of authors were analysed. The tools used to conduct the analysis are Bibliometrix R-Tool, capable of meeting the techniques required for quantitative studies as it boasts of statistical completeness and accuracy of the outputs. Additional tool is VOSviewer, used for network visualisation and maps, that enable the visualisation of the field's progress over time and illustrate the scientific research's structural and dynamic aspects, providing a description of the groupings of methodological approaches. Specifically this software develops a map based on a co-occurrence matrix in three different stages (Van Eck & Waltman, 2010) initially a similarity matrix is developed to apply the VOS mapping technique, using the force of association, then a map is built that reflects the measure of similarity between the items and finally you have the translation, rotation and reflection to correct the optimization problem that is described in the literature (Moral-Munoz et al., 2020).

Protocol SPAR-4-SRL

To adopt a comprehensive vision, the Scientific Procedures and Rationales for Systematic Literature Reviews (SPAR-4-SLR) protocol developed by (Paul et al., 2021) is adopted.

The first stage “Assembling” seeks to identify and acquire the necessary data for review. For this purpose, we resort to Scopus as database, given the fact that there are a great number of indexed publications with the possibility to resort to filters, rankings and detailed data. The search was conducted during May 2024, using the search phrase hydrogen AND “energy transition” in abstract, titles, and keywords. The time frame considered for this study was from 2015, the year in which the Paris Agreement was implemented, for addressing greenhouse gas emissions mitigation, adaptation, and finance aiming to keep the rise of the earth's average temperature well below 2°C (UNFCCC, 2015). At the same time, the 2030 Agenda established the United Nations’ Sustainable Development Goals with strategies that improve health and education, reduce inequality, and spur economic growth (United Nations, 2015). These are milestones in the commitment to combat climate change and implement an ecological transition to clean and sustainable energy sources. The number of articles returned from the research were 1,509.

In the following stage “Arranging” the data acquired were purified through inclusion and exclusions. The subject area for carrying on the study was limited to energy field, social sciences, business, management and accounting, economics and decision sciences; in this way all articles of technical and engineeristic nature were excluded. So, during the purification stage other articles were excluded, reaching the final assessment of 671 of articles. The search strategy for gathering data was coded using the article title, author names, journal title, country of affiliation, keywords, number of citations.

The last step “Assessing” involves evaluation, in which are discussed the analysis methods and tools used for evaluation and trend analysis; and reporting. Since data was accessible from everyone, there is no requirement for ethics clearance.

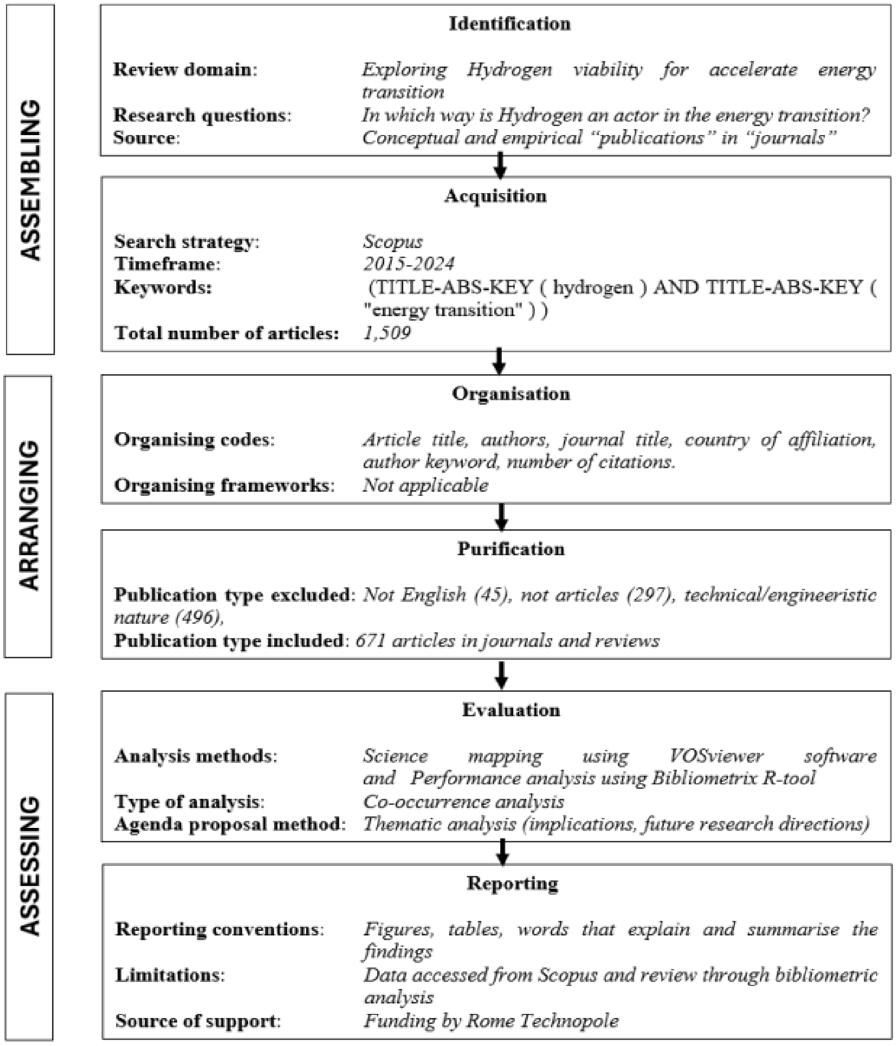

Fig. 1. *Research design follows the SPAR-4-SLR protocol.*

Results

This section presents the results of the bibliometric analysis, highlighting first a descriptive analysis and the performance of the documents included in the study; subsequently a focus on the outcomes of the co-occurrence analysis where the identified clusters are described; and lastly the co-citation analysis to reveal the thematic structure of the research field.

Performance Analysis and Science Mapping

The first statement to be made is about the publications of the articles over the years. Starting from a small number of articles (2) in 2015, despite the strategic initiatives promoted by the European Union following the Paris Agreement and the introduction of the 2030 Agenda (UNFCCC, The Paris Accord), production remained scarce until 2019. (17). Next, we can see the exponential growth of publications starting in 2020 (37), when the COVID-19 pandemic and the Russia-Ukraine war have put the world in danger, pushing on the need to increase the supply of renewable energies to cope with possible future energy crises and climate change, thus forcing to intensify research in the field, and giving room to a growing interest in hydrogen. The trend that has occurred in the following years is the doubling of the number of articles: 70 new publications in 2021 and 150 in 2022. The peak was reached in 2023 with 200 publications. In the current year (until June 2024) the recorded items are 168, confirming the trend of growth and making it difficult to make accurate forecasts.

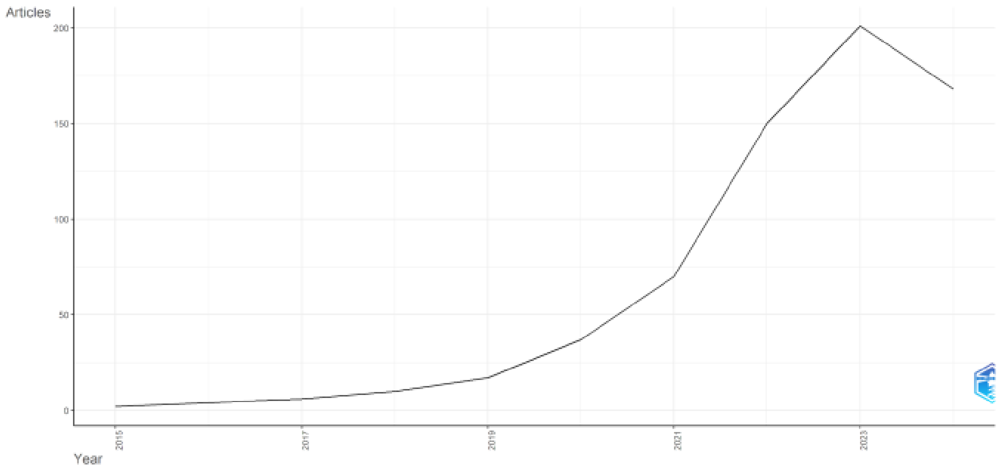

Fig. 2. *Annual scientific production (Biblioshiny).*

Considering the average number of quotations per year, it is possible to say that there is a peak of 41.5 in 2015 and that following the trend shown was a decrease in the average numbers of citation, as shown in Figure 3. The highest averages occur in 2018 with 13.6 and in 2021 with 12.8. By contrast, the minimum peaks occur in 2023 with an average of 4.1. We can see a fairly stable trend between 2016 and 2022, where average values have not changed much.

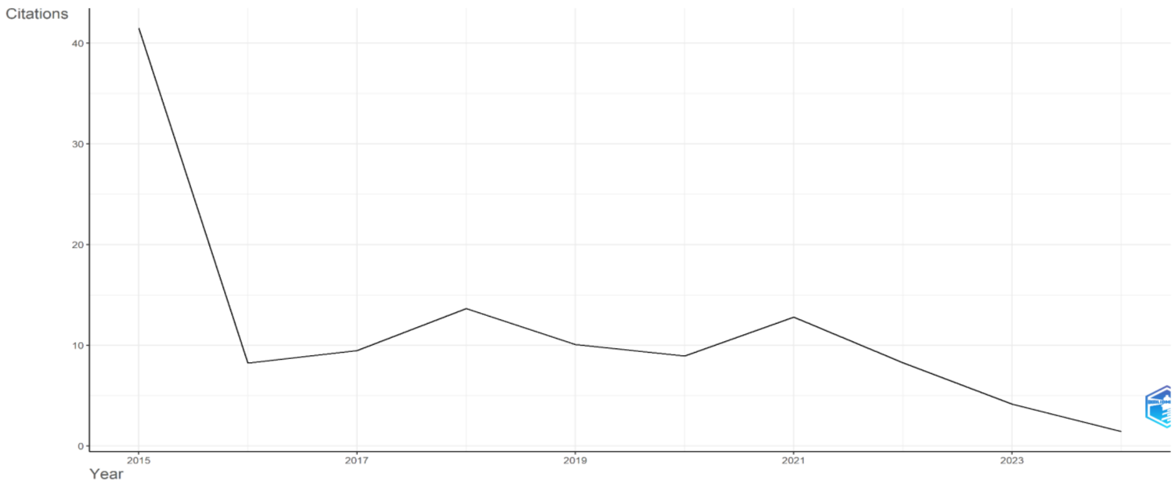

Fig. 3. *Average citations per year (Biblioshiny).*

With regard to the articles with the highest number of citations (over 300) the following documents are highlighted, while the graphic representation is provided by the figure 4.

- N. Abas, A. Kalair, N. Khan, (2015). Review of fossil fuels and future energy technologies. Futures.

Volume 69 with 801 citations.

- Meiling Yue, Hugo Lambert, Elodie Pahon, Robin Roche, Samir Jemei, Daniel Hissel, (2021). Hydrogen energy systems: A critical review of technologies, applications, trends and challenges. Renewable and Sustainable Energy Reviews. Volume 146 with 800 citations.
- Ankica Kovač, Matej Paranos, Doria Marciuš, (2021) Hydrogen in energy transition: A review.

International Journal of Hydrogen Energy. Volume 46, Issue 16 with 501 citations.

- David Parra, Luis Valverde, F. Javier Pino, Martin K. Patel, (2019). A review on the role, cost and value of hydrogen energy systems for deep decarbonisation. Renewable and Sustainable Energy Reviews. Volume 101 with 400 citations.
- Vasileios Kyriakou, Ioannis Garagounis, Anastasios Vourros, Eirini Vasileiou, Michael Stoukides,

(2019). An Electrochemical Haber-Bosch Process. Joule. Volume 4, Issue 1 with 333 citations.

- Noussan, Michel, Pier Paolo Raimondi, Rossana Scita, and Manfred Hafner, (2021). The Role of Green and Blue Hydrogen in the Energy Transition—A Technological and Geopolitical Perspective. Sustainability 13, no. 1: 298 with 308 citations.

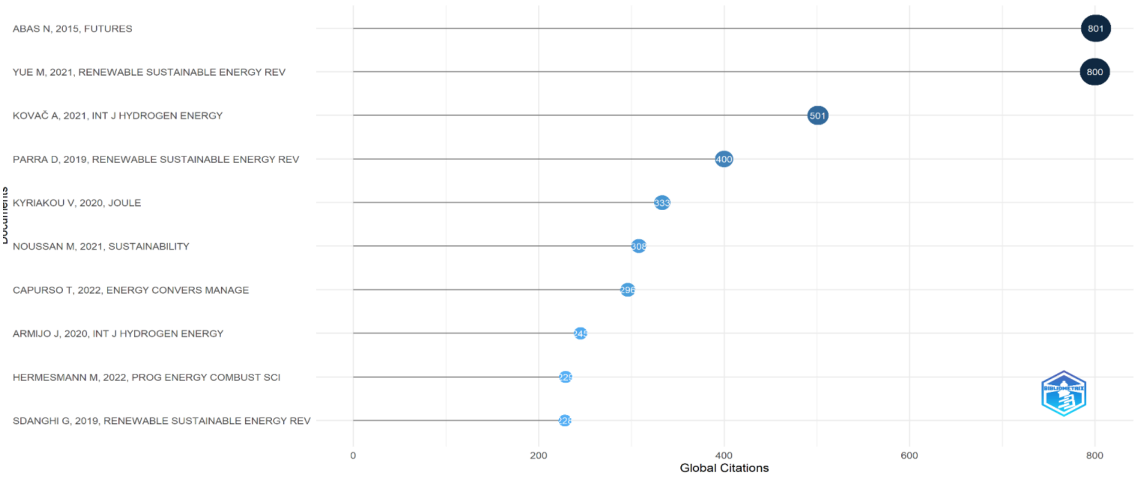

Fig. 4. *Most cited articles (Biblioshiny).*

Focusing on the journals in which the 671 articles were published, it can be noticed that these are divided among 164 different journals. To better understand the composition of the publications, 60% of the journals published a single article, consistent with the phenomenon analysed; 10% have published a pair, while 14% of the journals published a trio. 11% of the journals have published between 4 and 20 articles. It is the remaining 5% that represent the most influential journals (in the Figure 5), among which "International Journal of Hydrogen Energy" stands out with 131 articles, followed by "Energies" with 74, "Applied Energy" and "Renewable and Sustainable Energy Reviews" tied with 26 publications respectively, the same number has "Sustainability (Switzerland)," then "Energy Conversion and Management" 24, "Journal of Cleaner Production" 23, and "Energy."

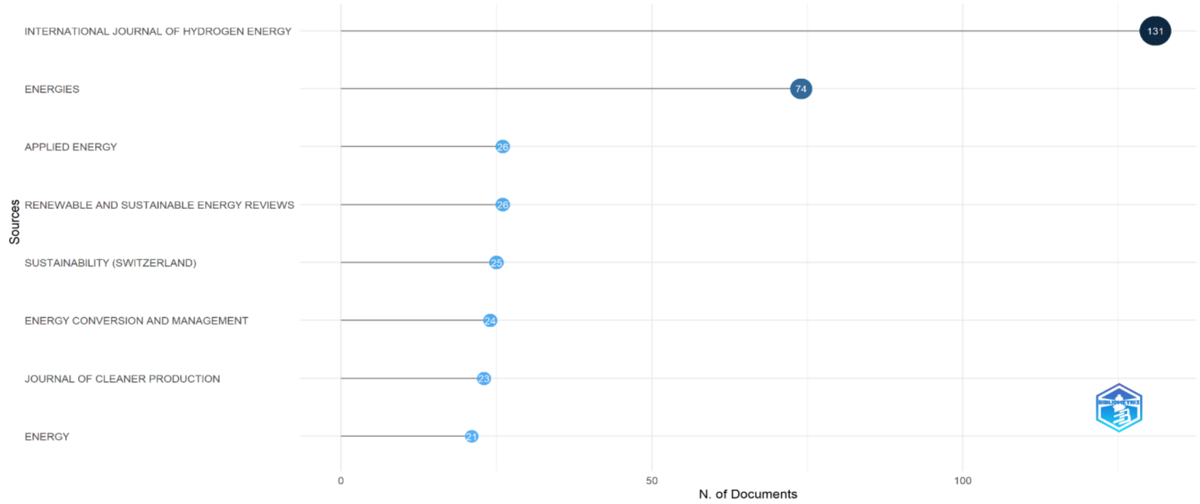

Fig. 5. *Most relevant Sources (Biblioshiny).*

Another critical variable in mapping scientific production is the country of publication. The most active country is Germany, with 200 published articles, followed by China with 130 and Italy with 113. Then comes the United States, with 111 published articles. The countries with a number of articles between 50 and 100 are the following: United Kingdom (91); France (78); Australia (75); Spain (52); and Netherlands (51). The rest of the countries have less than 50 publications for each.

Being the top four countries, with over 100 articles each, it is possible to discuss the trend of scientific production related to this topical through-the-years subject of hydrogen in the energy transition. This is the content of Figure 6. Germany has not played a pioneering role but started to be visible in 2017—at first slightly and then in fast growth since 2020. China began a year after Germany (2018) and has since then shown the same stable, sharp rise in production rates since the year 2021. Italy, too, started its growth even earlier, in 2016, but with very sluggish growth until 2021, when the rate of research suddenly accelerated. The US is one of the countries that relatively recently started research in this area, just two years ago in 2019, but only by 2022 did the rate of its growth get rapid.

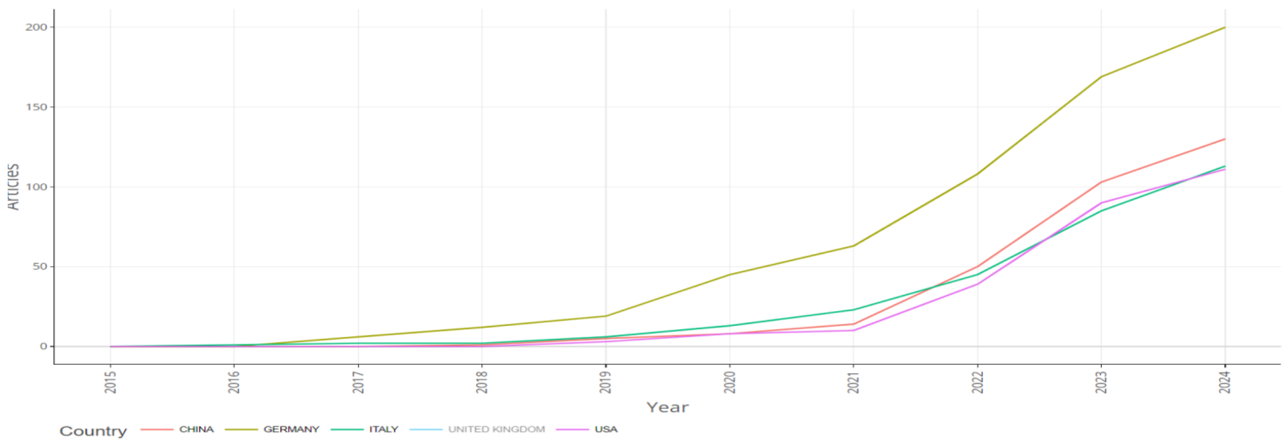

Fig. 6. *Countries' Production over time (Biblioshiny).*

In addition, the data of the affiliations of the authors disclose few in number of affiliations: only those with several affiliated publications equal to or over 10 are Imperial College London (16), Sapienza University of Rome (12), Curtin University (10), and Delft University of Technology (10); on queue with nine articles of a similar nature are Aalborg University, Massachusetts Institute of Technology, and China Electric Power University. Figure 7 shows the universities having several affiliated publications equal to or greater than 9.

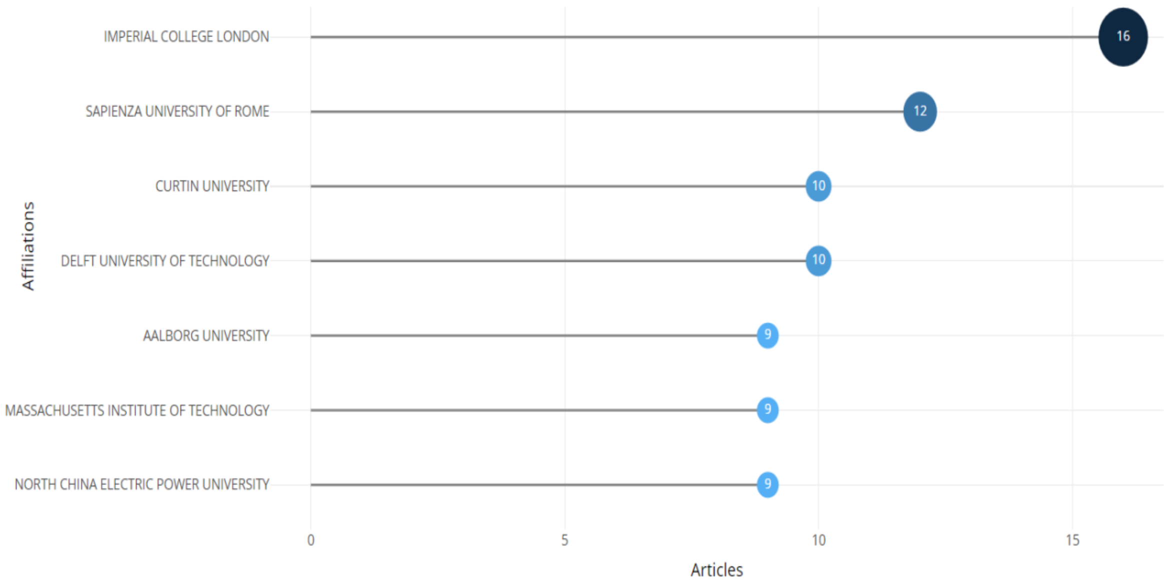

Fig. 7. *Most relevant affiliations (Biblioshiny).*

Co-occurrence analysis

The purpose of the paragraph is, therefore, to carry out a more in-depth assessment of the main themes defining research along this line and their relationships through keyword analysis. Of greater significance, however, are identified eight clusters through the use of detected keywords that span from 2015 to 2024. These thematic areas will give an impression of how the principal topics within the literature have developed in the past nine years. Keywords with at least five occurrences were set. The graphical representation is provided by VOSviewer software. It is possible to underline the links between different clusters, each one marked by a different colour, in the "network visualisation" in Figure 8. Node size means the number of publications in which the term appears and follows a direct proportionality: the larger the node, the more publications. Similarly, the lines' distance from one another and the words carry information about the relationships that exist; since co-occurrences are being measured, this is an inverse relationship, the less the two lines of words differ in distance or closeness, the stronger the linkage between the keywords.

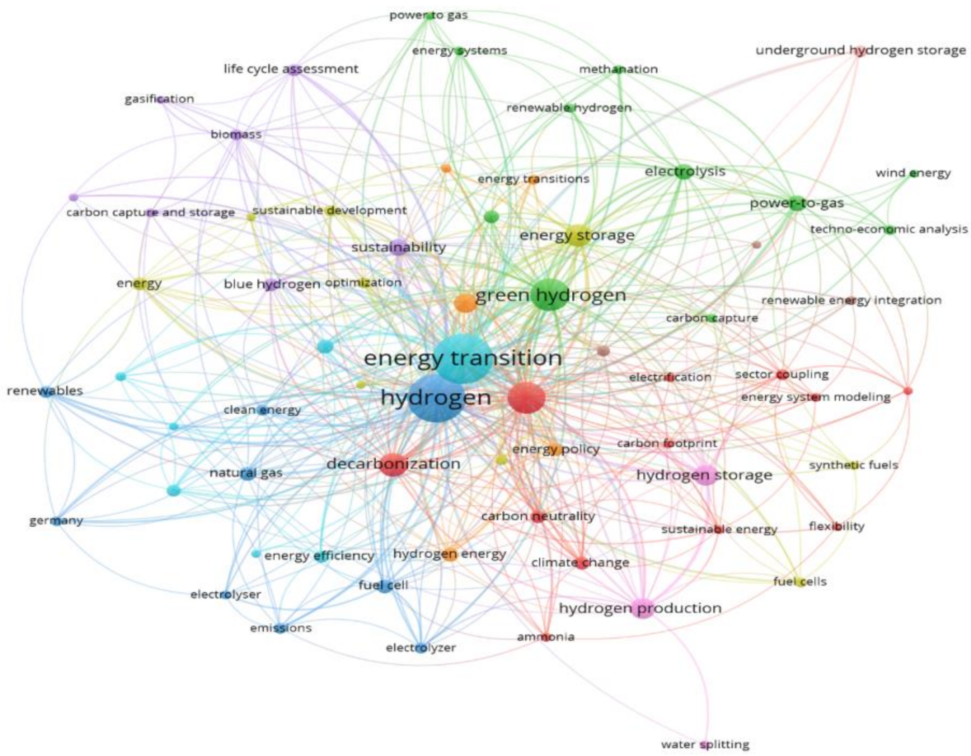

Fig. 8. *Network visualisation co-occurrence (VOSviewer).*

In Figure 9, "overlay visualisation co-ocucrrence", the proximity to blue indicates the age of the publications, whereas the tendency towards yellow indicates more recent works.

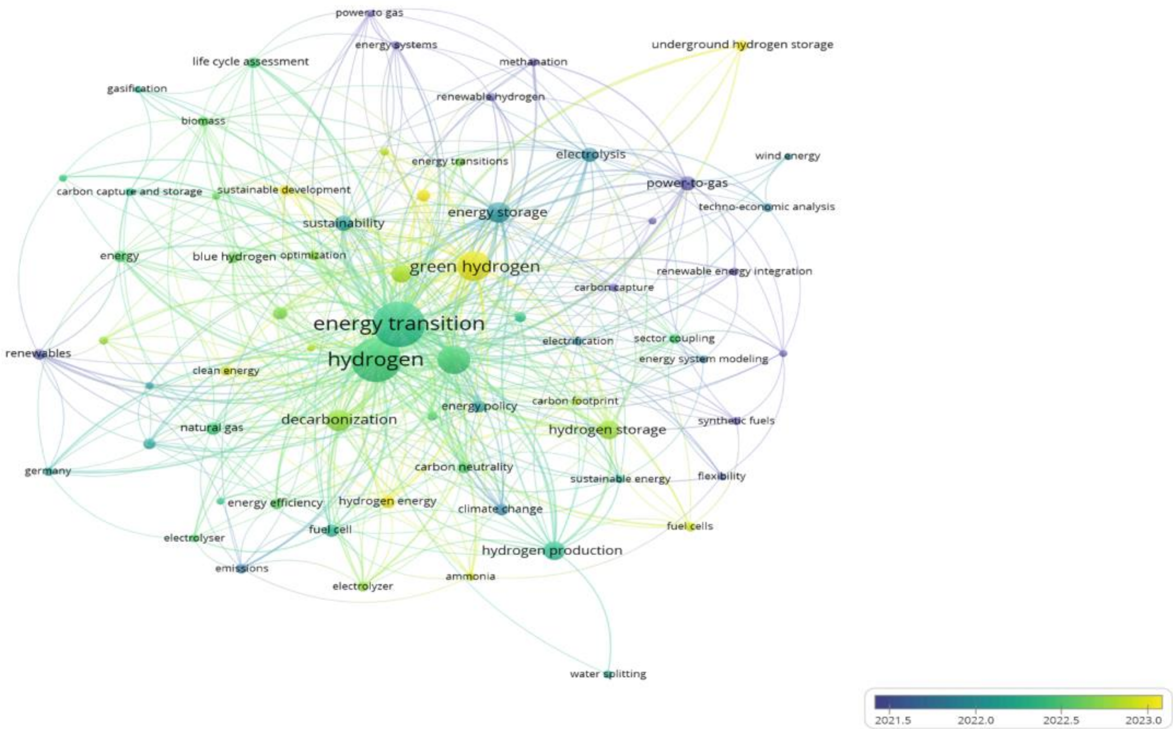

Fig. 9. *Overlay visualisation co-occurrence (VOSviewer).*

Based on the occurrences, link strength, and average level of citation for all the words, Table 1 shows the composition of each group. This allows us to visualise the words with the highest number of occurrences, which have been most used by authors to summarise the article's theme: “energy transition” with 188 occurrences, “hydrogen” with 170, and “green hydrogen” with 81. The clusters were 8 altogether, and each will be presented along with a description and the keywords that characterise them.

Cluster 1 - “Integrated Energy System”: The words in this first group refer to various interconnected aspects of the green hydrogen lifecycle, highlighted by terms like “green hydrogen” (81) and “renewable hydrogen.” Specifically, it considers the production steps: “electrolysis,” “carbon capture” (with the highest average citations in the cluster, nearly 330,000), “wind energy”; up to the integration into pre-existing energy systems: “power-to-x” and the subcategory “power-to-gas”; or to synthesise synthetic fuels such as “methanation” and “green ammonia” (with closed 200,000 citations).

Cluster 2 - “Energy Transition and Decarbonization”: Analysing this cluster, we can assert that another central theme is energy transition, aiming for carbon neutrality by 2050, and the reality of “climate change”, word that shows few occurrences (13) but a substantial number of average citation (735,000) . However, the central role in terms of themes is played by "renewable energy” with 74 occurrences and 500,000 average citations; closely connected to “decarbonization” with 41 occurrences. “Electrification” and “sector coupling” are necessary to improve the integration of energy systems and increase flexibility.

Cluster 3 - “Hydrogen”: The highlighted theme is hydrogen production, with the keyword “hydrogen” having 170 occurrences, the highest value found so far across the study. “Natural gas” is still relevant (14), as it is currently the most feasible alternative, but the long-term goal is its replacement with hydrogen-based solutions to reduce the carbon footprint. Reference to the technology of “fuel cell” for hydrogen production is considered by the average number of citations that is 775,000.

Cluster 4 - “Hydrogen Technology”: Energy planning is essential to coordinate these technologies and resources, ensuring sustainable development that considers current and future needs. To ensure “sustainable development” (10), it is necessary to “optimise” (10) the hydrogen value chain and the resources used in its production. The central theme of the cluster is therefore “energy storage” with 40 occurrences. The average citation number of the cluster is scarce, except for the word “energy” that reaches near 300,000.

Cluster 5 - “Hydrogen Life Cycle Assessment”: This cluster concerns renewable hydrogen production, aiming to ensure “sustainability”, a keyword that characterises the requirements for clean production with its high occurrences (22) and highest score (478,000). The main referral is to LCA, due to its large score of 325,000. Although discussing green hydrogen today is quite challenging due to high costs, the focus is on “blue hydrogen” (12) associated with “carbon capture and storage” (7) systems to ensure lower emissions.

Cluster 6 - "Hydrogen Strategy for Energy Transition": In today's context, "energy transition" is of significant importance, reaching the highest number of occurrences, 188, indicating substantial research on the topic. Hydrogen plays an important role in increasing the efficiency and energy security (11) of renewable sources. The score of the keywords of the cluster is particularly high, each with at least more than 100,000 citations, except for "low-carbon hydrogen", "energy system modelling" and "hydrogen strategy".

Cluster 7 - "Hydrogen Economy": This group refers to the crucial role played by energy policies (12 occurrences) in facilitating this transition through incentives, regulations, and investments in clean technologies. In a broader sense, justice ensures universal access and reduces risks. The "hydrogen economy" is the keyword with the most occurrences in the cluster (30), but low score (353); further research on the topic should be expanded to achieve market competitiveness and hydrogen commercialization.

Cluster 8 - "Hydrogen Production and Storage": The last cluster has a technical nature, as the words within it refer to hydrogen production (34) and storage (32) with very similar occurrences, even though the score for each is over 250,000 citations. Additional keywords characterise the previous ones, particularly "water splitting," which refers to the process by which hydrogen is separated from oxygen from water, while "underground hydrogen storage" refers to the method of naturally storing hydrogen, where favourable temperature and pressure conditions can be found for more efficient and safer gas management.

Label	Cluster	weight<Occurrences>	score<Avg. citations>
green hydrogen	1	81	175432
electrolysis	1	20	2505
power-to-gas	1	20	502
power-to-x	1	12	1525
green ammonia	1	9	196667
techno-economic analysis	1	8	3325
renewable energy integration	1	7	22
carbon capture	1	6	331667
energy systems	1	6	19
methanation	1	6	425
renewable hydrogen	1	6	50
hydrogen supply chain	1	5	312
power to gas	1	5	682

wind energy	1	5	352
renewable energy	2	74	444865
decarbonization	2	55	253902
climate change	2	13	735385
carbon neutrality	2	12	2075
sector coupling	2	9	117778
ammonia	2	7	374286
energy system modelling	2	7	14
electrification	2	6	9
renewable energy	2	6	206667
carbon footprint	2	5	58
energy system analysis	2	5	24
flexibility	2	5	694
hydrogen	3	170	264176
fuel cell	3	15	774667
natural gas	3	14	197143
renewables	3	11	265455
electrolyzer	3	10	10
clean energy	3	9	251111
emissions	3	9	15
germany	3	8	1275
electrolyser	3	6	142
energy storage	4	40	36025
energy	4	12	281667
optimization	4	10	137
sustainable development	4	10	6
fuel cells	4	8	175

renewable energy sources	4	8	18875
synthetic fuels	4	6	475
energy planning	4	5	78
solar energy	4	5	68
sustainability	5	22	478182
blue hydrogen	5	12	3175
life cycle assessment	5	11	324545
biomass	5	9	102222
carbon capture and storage	5	7	13
biofuels	5	5	368
gasification	5	5	96
energy transition	6	188	267766
energy efficiency	6	11	203636
energy security	6	11	161818
low-carbon hydrogen	6	7	77143
energy system modelling	6	5	162
hydrogen strategy	6	5	1138
hydrogen economy	7	30	353
hydrogen energy	7	15	73333
energy policy	7	12	315
energy transitions	7	8	975
energy justice	7	6	146667
hydrogen production	8	34	348529
hydrogen storage	8	32	265938
underground hydrogen storage	8	11	83636
water splitting	8	6	183333

Table. 1. *Keywords included inside each cluster (VOSviewer).*

Co-citation analysis

The objective of this paragraph is to achieve a better understanding of the correlation between the articles through the analysis of the most frequent citations, thereby determining a thematic structure. To conduct this investigation, the VOSviewer software was once again implemented for graphical representation. During the selection of the minimum number of citations of a cited reference, 10 was chosen as the criterion for the study. Of the 47,060 cited references, only 26 meet this threshold. Figure 10, "network visualisation co-citation," highlights the interconnections between articles. The size of the nodes refers to the publications with the highest number of citations, while the distance of the lines represents the strength of the link.

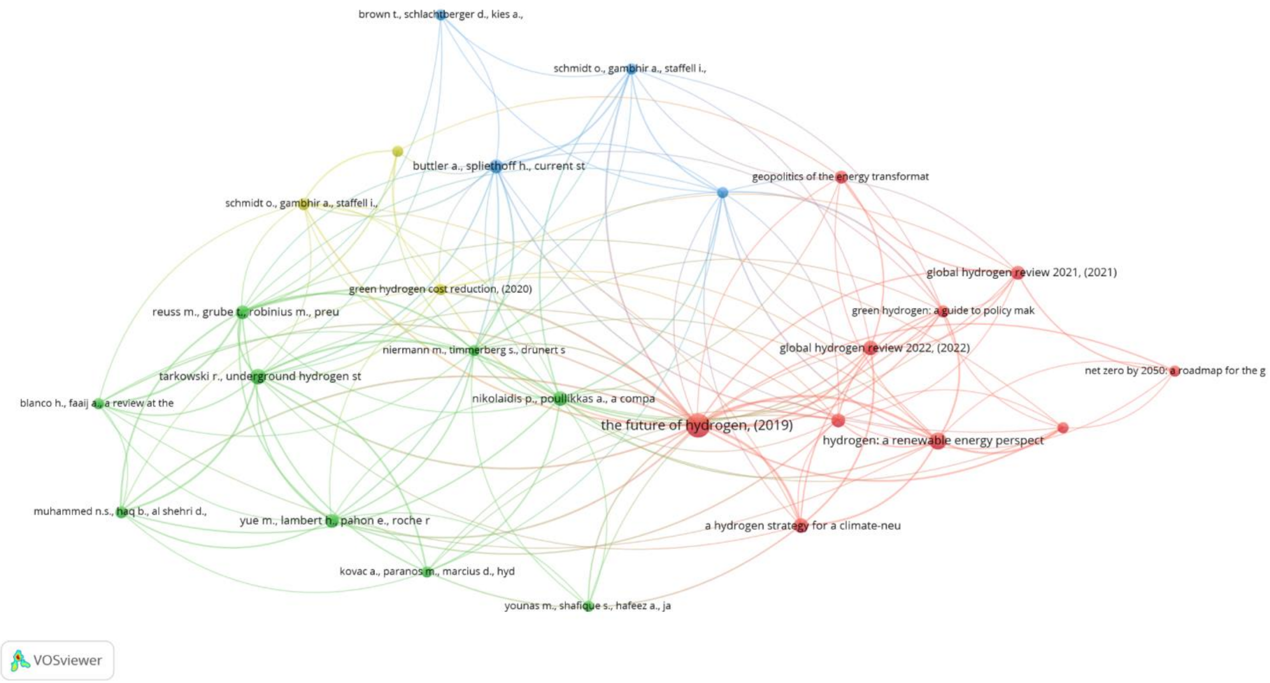

Fig. 10 *Network visualisation co-citation (VOSviewer).*

The frequency with which articles are co-cited defines similar thematic areas, characterized by a strong co-citation relationship as highlighted in Table 2. Through careful analysis, it was possible to identify clusters and label them by defining specific areas of research interest based on their characterization. Specifically, four clusters were identified that classify thematic literature from a conceptual and empirical perspective.

Cluster 1 - "Hydrogen Overview and Strategy". This first cluster groups together articles that discuss national strategies, policies, and future perspectives of hydrogen and its role in the energy transition. It refers to regulatory modelling as the basis for establishing a hydrogen economy. The authors of the reports and reviews included are the European Commission, the International Renewable Energy Agency and the International Energy Agency. The most frequently cited article in this cluster is "The Future of Hydrogen" by the International Energy Agency (IEA), with 49 citations and an equally high total link strength (58). Within the cluster, it is followed by the review from the International Renewable Energy Agency (IRENA) titled "Hydrogen: a Renewable Energy Perspective" with 24 citations, and the guidelines from the European Commission titled "A Hydrogen Strategy for a Climate-Neutral Europe" (18).

Cluster 2 - "Hydrogen Production and Storage". The articles belonging to this thematic area have a technical nature, discussing the technologies, production processes, and storage of hydrogen. This embryonic technological development is necessary to achieve the ideal configuration to maximize energy yield while reducing costs, making hydrogen economically accessible. The article with the highest number of citations is by Tarkowski R. titled "Underground Hydrogen Storage: Characteristics and Prospects" (20), which is also the oldest article (2013), published before the Paris Agreements. Following this is the article by Nikolaidis P. titled "A Comparative Overview of Hydrogen Production Processes" with 18 citations but a higher total link strength of 31, one point more than the previous article.

Cluster 3 - "Electrolysis and Sector Coupling". This cluster has a similar technical nature but specializes in the electrolysis process and, therefore, electrolyzers. In this area, the article by Buttler A. and Spliethoff is the most relevant in terms of the number of citations (15) and total link strength (22), followed by Carmo M.'s "A Comprehensive Review on PEM Water Electrolysis" and Brown T.'s "Synergies of Sector Coupling and Transmission Reinforcement in a Cost-Optimised, Highly Renewable European Energy System," both with 11 citations.

Cluster 4 - "The Cost of Hydrogen". This final theme is characterized by two articles with the least relevance in terms of citations (10, which is the minimum criterion chosen). These articles provide guidelines and projections for a long-term strategy in the field of hydrogen.

Article	**Author**	**Cluster**	**Links**	**Total link strength**	**Citations**
A hydrogen strategy for a climate-neutral europe	European Commission	1	9	20	18
Geopolitics of the energy transformation: the hydrogen factor	International Renewable Energy Agency (IRENA)	1	7	9	14
Global hydrogen review 2021	International Energy Agency (IEA)	1	9	13	15
Global hydrogen review 2022	International Energy Agency (IEA)	1	9	17	17
Green hydrogen: a guide to policy making	International Renewable Energy Agency (IRENA)	1	12	20	12
Hydrogen from renewable power: technology outlook for the energy transition	International Renewable Energy Agency (IRENA)	1	8	13	11

Hydrogen: a renewable energy perspective	International Renewable Energy Agency (IRENA)	1	13	28	24
Net zero by 2050: a roadmap for the global energy sector	International Energy Agency (IEA)	1	5	7	10
The future of hydrogen	International Energy Agency (IEA)	1	21	58	49
The national hydrogen strategy	European Commission	1	14	19	15
A review at the role of storage in energy systems with a focus on power to gas and long-term storage	blanco h., faaij a.,	2	9	14	10
Hydrogen in energy transition: a review	kovac a., paranos m., marcius d.,	2	9	14	11
A review on underground hydrogen storage: insight into geological sites, influencing factors and future outlook	muhammed n.s., haq b., al shehri d., al-ahmed a., rahman m.m., zaman e.,	2	8	17	12
Liquid organic hydrogen carriers and alternatives for international transport of renewable hydrogen	niermann m., timmerberg s., drunert s., kaltschmitt m.,	2	14	21	11
A comparative overview of hydrogen production processes	nikolaidis p., poullikkas a.,	2	19	31	18
Seasonal storage and alternative carriers: a flexible hydrogen supply chain model	reuss m., grube t., robinius m., preuster p., wasserscheid p., stolten d.,	2	14	29	16
Underground hydrogen storage: characteristics and prospects	tarkowski r.,	2	14	30	20
An overview of hydrogen production: current status, potential, and challenge	younas m., shafique s., hafeez a., javed f., rehman f.,	2	5	6	10
Hydrogen energy systems: a critical review of technologies, applications, trends and challenges	yue m., lambert h., pahon e., roche r., jemei s., hissel d.,	2	12	20	16

Synergies of sector coupling and transmission reinforcement in a cost-optimised, highly renewable european energy system	brown t., schlachtberger d., kies a., schramm s., greiner m.,	3	5	5	11
Current status of water electrolysis for energy storage, grid balancing and sector coupling via power-to-gas and power-to-liquids: a review	buttler a., spliethoff h.,	3	14	22	15
A comprehensive review on pem water electrolysis	carmo m., fritz d.l., mergel j., stolten d.,	3	14	19	11
Future cost and performance of water electrolysis: an expert elicitation study	schmidt o., gambhir a., staffell i., hawkes a., nelson j., few s.,	3	10	16	10
Green hydrogen cost reduction	International Energy Agency (IEA)	4	10	12	10
Long-term patterns of european pv output using 30 years of validated hourly reanalysis and satellite data	pfenninger s., staffell i.,	4	6	8	10

Tab. 2 *Articles most cited and related clusters*

Conclusions

This work evidences and confirms the critical role of hydrogen in the energy transition through an integrated overview of state-of-the-art of the research, enabling it to identify critical trends and influential themes. To fulfil this goal, a methodology of bibliometric analysis has been applied to the existing literature from 2015 given global efforts orientated towards carbon neutrality and strategic initiatives of the European Union. The scientific production in this field has been growing exponentially since 2020, a year marked by the COVID-19 pandemic and by the outburst of conflicts that jeopardise the world's energy system and create the conditions for a fast switch to renewable sources of energy.

This investigation has contributed to the existing research in several ways. As for the analysis of increasing attention from the scientific community, the number of publications and average citations, as well as their changes over time, can be reviewed. This also showed the journals that publish more frequently on studies related to the research topic, according to the parameters given in the search. It added the contributions of individual countries to this line of research, mostly dating from 2020, and those of universities, identifying a need for collaboration and interaction to achieve an economy of scale for hydrogen. In short, the keyword co-occurrence analysis detected the keywords with the highest recurrence levels in the publications, which generate clusters representing the main themes arising from the preliminary study of this research field. Similarly, the co-citation analysis identified the thematic structure of the research, highlighting specific areas such as strategies and policies, technologies, production processes, and future forecasts to reduce costs and identify best practices. Significant gaps were also identified regarding the evaluation of socio-economic and environmental impacts, whose resolution, for example through detailed LCAs, could accelerate the adoption of hydrogen and ensure a sustainable energy future.

Despite the advancement made, in 2021, the production of clean hydrogen accounted for only 0.7 Mt/yr with an electrolyzer capacity of 0.5 GW. There is a critical need for accelerated development to reach projected shares of green hydrogen of 40% by 2030 and 94% by 2050 (IRENA, 2023). The most important obstacles relate to high technological costs and the absence of infrastructure, while the best opportunities relate to the engagement of private companies and a growing scientific focus. This bibliometric analysis can allow newer insights for further research in the field of hydrogen energy. There is a definite need to go deep into niche markets with new frameworks that could further speed up clean production. Databases used in the future study must be expanded and inclusion criteria refined to gain an in-depth understanding of the research phenomenon; on top of that, the keywords for searching must be further refined.

Acknowledgments

Project ECS 0000024 Rome Technopole, - CUP B83C22002820006, NRP Mission 4 Component 2 Investment 1.5, Funded by the European Union - NextGenerationEU".

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Towards Sustainable Hydrogen Production: Innovations in Nanostructured Catalyst Synthesis

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Abstract

This paper presents a literature review focused on Life Cycle Assessment (LCA) regarding the development of innovative synthesis methods for producing nanostructured catalysts. These catalysts are based on non-critical raw materials and are intended for efficient production of green hydrogen through water electrolysis powered by renewable energy sources. Currently, high throughput water electrolyzers, employing proton exchange membrane technology, require significant loading of precious metal electro-catalysts such as Ir, Pt, Ru, along with costly titanium bipolar plates and Ti/Pt-based porous transfer layers. The synthesis of nanocatalysts, utilizing sustainable materials, can potentially replace the use of precious metals while maintaining high efficiency and stability at a lower cost. This review will emphasize the development of recycling and reusing processes to enable sustainable synthesis and full material recovery at the end of their life cycle, either through regeneration or secondary utilization. Current production methods of electrocatalysts for hydrogen production involve complex, expensive, and often hazardous processes such as multistep procedures and high-temperature phosphorylation, resulting in harmful waste generation detrimental to both humans and the environment. Therefore, there is an urgent need for the development of non-toxic, eco-friendly, and reliable methods for electrocatalyst production. In the context of a circular economy (CE) approach, the development of novel materials must undergo careful life-cycle assessment (LCA) to ensure their sustainability and environmental impact mitigation.

Keywords: Green hydrogen, urban mining; industrial waste; renewable energy solutions, life cycle assessment, electrocatalysts

Relevant Topic: Sustainable Supply Chain Management, green supply chain and quality.

Introduction

Talking about green hydrogen means redesigning many industrial processes and revolutionising the production chain to achieve a decisive decrease in environmental impact, especially in terms of reducing pollutant emissions.

In heavy industry, green hydrogen could represent a radical breakthrough: it has been calculated that it would eliminate more than 800 million tonnes of carbon dioxide emitted into the atmosphere each year by the steel and steel processing industry. Green hydrogen can be used to process metals, alloys, but also glass and in the production of semiconductors and electronics components. In the chemical industry, green hydrogen is also successful in the production of ammonia and methanol (Lo Vecchio et al, 2020; Zignani et. al. 2022).

Not only industry. First of all, green hydrogen can be the key to heavy and long-distance transport for trucks, aircraft. If electric charging seems too complicated for these vehicles, the greener alternative is hydrogen, which can be used in fuel cells. At the same time, it represents a viable opportunity in rail and road public transport (ISO 14687:2019).

The hydrogen (H2) industry has a leading role to play in Europe's energy transition pathway, which has set itself the challenging goal of becoming the first zero-emission continent by 2050, also aiming to increase the use of hydrogen to a share of 13-14% in the energy mix, from the current 2%.

Italy has included actions on hydrogen in its strategic guidelines with a PNRR allocation of EUR 3.64 billion to promote its production, distribution and end uses. In order to understand where the Italian hydrogen supply chain stands, what growth prospects are expected and what critical issues need to be overcome, (Intesa Sanpaolo's Research and Studies Department, 2024).

In recent days, an HVO investment project was presented in Sicily. The acronym HVO stands for hydrotreated vegetable oil, i.e. a hydrogenated fuel obtained from sustainable raw materials (e.g. used frying oil, animal fat waste, vegetable oil). Italy's largest investment is included in Axpo's Italian green hydrogen projects: the Swiss energy company - already a partner of Infinite Green Energy for the Arrowsmith Italy initiative - VPGH2, in Abruzzo. The company has signed a cooperation agreement with French energy investor ENEGO to study the feasibility of a 100 MW green hydrogen plant in Sicily. The project will be built in the industrial district of Priolo-Augusta, on the east coast of Sicily. In addition to contributing to the creation of a so-called 'hydrogen valley' between Catania and Syracuse, the new plant would help meet the demand for clean energy from industries in the surrounding area (Hydronews, 2024).

The construction of a large plant for the production of 'green hydrogen' in the industrial area between Catania and Syracuse is full of diverse and beneficial direct and indirect local and widespread economic, financial, social and, of course, environmental spin-offs.

In fact, in the short term, i.e. during the plant's construction phase, there will be greater economic and social benefits at the local level, especially for the lower and middle social classes, which are more interested in the demand for the labour force needed to build the infrastructure and the plant itself, and which are characterised by a high labour/capital ratio. In the long and medium term, however, as the plant becomes operational, its technological management, production, distribution and sale of green hydrogen will require increasingly skilled labour, as well as highly specialised technicians and managers. This will trigger a proactive process in the labour market, capable of counteracting at least in part the well-known 'brain drain' phenomenon that affects southern regions in particular. Also not to be underestimated are the potential benefits resulting from the supplementary income that agricultural enterprises could obtain from the supply of processing waste products that can be used for the production of biomass.

In particular, the investments required for hydrogen production, related to:

- Investments in hydrogen distribution and consumption facilities (hydrogen trains and trucks, refuelling stations, etc.)
- Investment in Research and Development,
- Some investment in infrastructure (such as gas networks) to properly integrate hydrogen production with end uses.

Some impacts of the investment can be assessed:

- Local economic growth: The construction and operation of a large-scale HVO plant could create significant economic activity in the Sicilian region. This could include the creation of direct and indirect jobs in sectors such as construction, engineering, logistics and maintenance.
- Investment attraction: A large investment such as this could also act as a catalyst for further investment in the energy and environmental sector in the Sicily region. This could lead to greater economic diversification and the creation of a more favourable environment for innovation and technological development.
- Reduction of fuel imports: HVO, being an advanced biofuel, could help reduce dependence on imported fossil fuels, improving the energy security of the region and the country as a whole. This could also have positive impacts on the trade balance.
- Reducing emissions: The use of biofuels such as HVO can contribute significantly to reducing emissions of greenhouse gases and other air pollutants. This could lead to improvements in air quality and have public health benefits by reducing the costs associated with pollution-related diseases.
- Development of agricultural supply chains: vegetable oils are needed to produce HVO, which could come from local crops. This could stimulate the development of regional agricultural supply chains, increasing the demand for agricultural raw materials and providing additional income opportunities for local farmers.

On the other hand, the substantial investments, made by a foreign investor and required for the construction of the plant, will constitute new and significant financial flows, in the short term immediately injected into the liquidity circuit of the companies involved in all phases of the site's construction; they will in turn generate new investments at the local level, favouring the birth and development of a further industrial induced activity, especially technological and logistic, with a significant multiplier effect on income. In the operational phase, then, with the production and marketing of hydrogen, apart from the economic and financial benefits due to the remuneration of production factors at the local level, the investment made will also have positive repercussions on local public finance, as a result of tax revenues from business profits and labour income.

Finally, the obvious and undeniable environmental benefits at the local level and the job opportunities offered by direct and induced investments will constitute a considerable incentive for the population to remain in their

places of residence, also as a direct consequence of the improved hygienic and sanitary conditions, which today are precarious with considerable damage to the health of residents and negative demographic effects.
Each of the aspects mentioned above will undoubtedly have a positive impact on GDP and the regional trade balance, which will further benefit from the export of hydrogen produced and sold to companies outside the region, able to offset the expected losses resulting from the drop in exports of petroleum products from the Syracuse industrial hub, also as a result of the increase in energy production from renewable sources.
While the cost of this process is still expensive, the future will increasingly be based on green hydrogen due to the expected reduction in the cost of electrolysers, the enormous progress in the efficiency of photovoltaic cells and wind generators, and the consequent reduction in the cost of kWh from renewable sources. All these new technological opportunities are rapidly changing the energy scenario with more institutions and companies focusing on green hydrogen as a new energy carrier.

Critical row materials

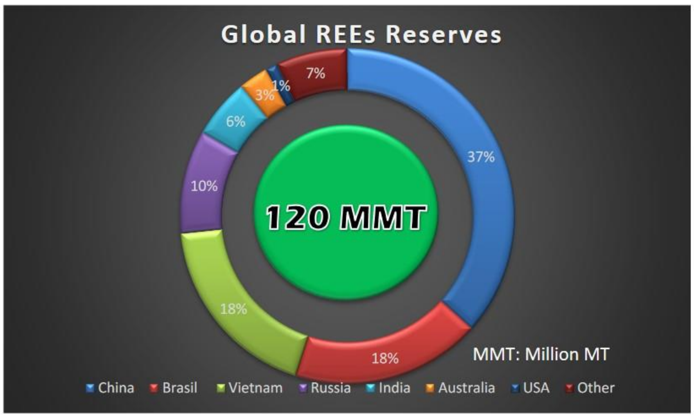
Non-energy raw materials are very important for all industrial sectors and for driving technological innovation, such as in low-carbon and digital energy technologies. Some raw materials present critical issues for secure and sustainable supply, and the European Commission (EC) has therefore drawn up a list of critical raw materials (CRMs) to identify those with economic significance and high risk of supply disruption, such as rare earths, cobalt and niobium.
Already since 2008, the EC has regulated CRMs in order to strengthen resource efficiency and recycling. In 2015, with the Communication on the 'Action Plan for the Circular Economy', it improved this interrelationship by proposing specific actions. A report on CRMs and the circular economy was published. The Joint Research Centre (JRC) worked on assessing the role of recycling in reducing supply risk, using up-to-date data on stocks and material flows (Filiou et al, 2003).
Furthermore, in 2017, the criticality assessment methodology was revised, evaluating 78 non-energy and non-agricultural commodities, of which 27 were identified as critical. The EC is constantly monitoring and adapting this methodology to better meet EU needs and maintain policy relevance.
Recycling becomes a significant source of secondary raw materials (SRM), contributing to security of supply and promoting the circular economy in the EU. The end-of-life recycling rate (EOL-RIR) is a key indicator that determines how much of the material used in production is obtained by recycling post-consumer 'old scrap'. Despite the high recycling potential of some CRMs and government efforts, the EOL-RIR is generally low. Factors leading to a low end-of-life recycling rate include both the lack of economical recycling technologies and the dispersion of materials during use, as well as the immobilisation of CRMs in long-life assets. Many CRMs, such as PGMs, have insufficient recycling rates compared to growing demand. Therefore, while some CRMs have promising recycling rates, most fail to adequately meet EU demand, highlighting the need to improve recycling technologies and infrastructure (Khosravi et al, 2021). .
The economy will be competitive if it can adopt the paradigms of the circular economy. Fuel cell and hydrogen (FCH) technologies can stabilise the electricity grid. Among these technologies, the alkaline water electrolyser

(AWE) and polymer electrolyte membrane electrolyser (PEMWE) are the most mature for hydrogen production (Wübbeke J., 2016).

Despite the commercial maturity of FCH technologies, there is much scepticism as a result of challenges related to infrastructure and social acceptance. The FC-HyGuide project of the FCH JU has published guidelines for life cycle assessment (LCA) of FCH technologies, recommending a cradle-to-grave approach. The main factors determining environmental impact are system efficiency, fuel type and electricity mix used. The end-of-life (EoL) phase is a significant obstacle due to the lack of clear data and recycling technologies for rare earth elements (REE) (Zhou, B, 2017).

We present some information on the global consumption of rare earths (REE) in 2019.

. ***Figure 1***. *Global consumption of rare earths (Yan et. Al, 2020).*



As can be deduced from the following diagram, REEs have excellent electrical properties, magnetic, catalytic and optical properties. Global consumption in 2019 was estimated at approx. 120,000 tonnes.

In Table 2. shows the uses of REE.

. ***Figure 2**. Global use of rare earths (Yan et. Al, 2020).*

REE	Symbol	Application
Scandium	Sc	Aerospace lightweight high-strength Al-Sc alloys, electron beam tubes
Yttrium	Y	Capacitors, phosphors, microwave filters, glasses, oxygen sensors, radars, lasers, superconductors
Lanthanum	La	Ceramics, car catalysts, phosphors, hydrogen storage, special optical glass, accumulators
Cerium	Ce	Polishing powders, ceramics, phosphors, glasses, catalysts, pigments, misch metal, UV filters, abrasives
Praseodymium	Pr	Ceramics, glasses, pigments, high strength magnesium alloy, lasers
Neodymium	Nd	Permanent magnets, catalysts, IR filters, pigments for glass, lasers
Promethium	Pm	Sources for measuring devices, miniature nuclear batteries, phosphors
Samarium	Sm	Permanent magnets, microwave filters, nuclear industry
Europium	Eu	Phosphors (red and blue), lasers, fluorescent glass
Terbium	Tb	Green phosphor, permanent magnets, laser
Dysprosium	Dy	Phosphors, ceramics, nuclear industry, permanent magnets
Holmium	Ho	Ceramics, lasers, reactor control rods, pigments
Erbium	Er	Ceramics, dyes for glass, optical fibers, lasers, nuclear industry
Ytterbium	Yb	Metallurgy, chemical industry, lasers
Lutecium	Lu	Single crystal scintillators, petrochemical catalysts, high refractive lenses, positron tomography
Thulium	Tm	Electron bean tubes, visualization of images in medicine
Gadolinium	Gd	Visualization of images in medicine, optical and magnetic detection, ceramics, glasses, crystal scintillators

Data and methods

Nanostructured catalysts are based on non-critical raw materials and are intended for efficient production of green hydrogen through water electrolysis powered by renewable energy sources. Currently, high throughput water electrolyzers, employing proton exchange membrane technology, require significant loading of precious metal electro-catalysts such as Ir, Pt, Ru, along with costly titanium bipolar plates and Ti/Pt-based porous transfer layers.

Nanocatalysis plays a crucial role in the achievement of the Sustainable Development Goals, namely SDG 7 (Affordable and Clean Energy), SDG 12 (Responsible Consumption and Production), SDG 9 and SDG 13 (Climate Action) as it facilitates the transition to low-carbon energy sources.

Nowadays, climate change requires an energy transition, and the development of environmentally friendly and efficient materials for that transition is crucial for that goal. Also, the Critical Raw Materials (CRMs) list published by European society is a milestone for new sustainable research projects (Wei, 2019), indeed it suggests a route for the materials to avoid the development of new technologies.

According to the Circular Economy principle, wastes are considered resources, for this reason, we can talk of Urban Mining as a good new practice (Soni and Chelliapan, 2022).

Today nanostructured catalysts attract great interest because the large exposed surface allows them to obtain Hydrogen Evolution Reaction (HER) and Oxygen Evolution Reaction (OER) with superior performances than related bulk materials. HER and OER are the two chemical reactions needed for water splitting process and today the best catalysts are based on Pt and Ir, which are CRMs (Filho and Matandirotya, 2023).

Following the previous suggestions, we concentrate our research project on Molybdenum (Mo) which is a promising transition metal, it is a non-CRM and widely studied in literature for its features in catalytic applications, both as oxide and sulphide (Critical-raw-materials, Ding et al., 2016). Mo-powder recycled by industrial waste was employed to obtain nanostructures active for OER and HER reactions. The recycled powder was produced by an Italian industry (Spirit S.r.L.) after several thermal treatments at high temperatures. We developed a synthesis process to obtain nanostructured catalysts based on recycled Mo. We rely on hydrothermal treatment, which can be considered a low-cost method, due to the low temperature and the energy amount required for the equipment. Thanks to the described process pure orthorhombic Molybdenum trioxide (α-MoO3) is obtained starting with recycled Mo and hydrogen peroxide. α-MoO3 is the most stable phase within the Molybdenum oxides (Chen et. Al, 2010). The synthesized material appears with nanobelt morphology, hence nanostructures with a cross-section of about 50 nm x 200 nm and about 10 µm long. The α-MoO3 was testd for OER application, showing promising electrochemical performances with respect to the state-of-the-art; these α-MoO3 shows an overpotential of 324 mV, about three times lower than commercial MoO3, a Tafel slope of 45 mV dec-1, which stands for a very fast kinetic of the electrochemical reaction.

Also, molybdenum sulphide (MoS2) attracts interest for water splitting catalysis. Utilizing α-MoO3 nanobelts, MoS2-MoO3 nanostructures were synthesized using the hydrothermal treatment again in thiourea solution. The resulting morphology is characterized by cubes, about 200-300 nm in size. The presence of both the species MoS2 and MoO3 within the sample allowed to reach superior electrochemical performances for HER application. An overpotential of 208 mV, and a Tafel slope of 94 mV dec-1, were measured.

In recent years, the application of catalysts has progressed significantly. To properly evaluate these innovations, it is necessary to use a comprehensive life cycle assessment (LCA). LCA is a systematic methodology that analyses the environmental impacts associated with a product or process throughout its life cycle, providing a holistic view on sustainability (Lei, H.; Li, L.; Yang, W.; Bian, Y.; Li, C.-Q. An analytical review on application of life cycle assessment in circular economy for built environment. J. Build. Eng. 2021, 44, 103374).

Life cycle assessment (LCA) is a key tool for analysing the overall environmental impact of renewable energy systems, particularly those based on hydrogen.

LCA has become more specialised and refined, including hybrid and consequential approaches that allow an accurate assessment of environmental implications, considering local factors, temporal dynamics and indirect consequences (Vance, C.; Sweeney, J.; Murphy, F. Space, time, and sustainability: The status and future of life cycle assessment frameworks for novel biorefinery systems. Renew. Sustain. Energy Rev. 2022, 159, 112259).

The LCA optimises the choice of materials for catalysts by assessing raw material extraction, catalyst energy production and waste management, helping to reduce the ecological footprint (Martin, N.; Madrid-López, C.; Villalba-Méndez, G.; Talens-Peiró, L. New Techniques for Assessing Critical Raw Material Aspects in Energy and Other Technologies. Environ. Sci. Technol. 2022, 56, 17236-17245).

Catalysts are designed to ensure energy efficiency and reduce emissions during heavy metal removal. LCA studies quantify environmental benefits and guide further research into sustainable design. LCA also evaluates the disposal and recycling of catalysts, facilitating strategies for their sustainable end-of-life management (Deng, B.; Meng, W.; Advincula, P.A.; Eddy, L.; Ucak-Astarlioglu, M.G.; Wyss, K.M.; Chen, W.; Carter, R.A.; Li, G.; Cheng, Y.; et al. Heavy metal removal from coal fly ash for low carbon footprint cement. Commun. Eng. 2023, 2, 13).

LCA studies also incorporate socio-economic and health impacts, examining the effects on workers, local communities and social implications, ensuring an overall assessment of sustainability. In summary, LCA is essential for assessing the sustainability of catalysts, providing a multidimensional perspective that includes environmental, socioeconomic and health aspects. This tool guides research and development towards more sustainable, efficient and responsible heavy metal removal technologies.

Hydrogen can be produced by various methods, including electrolysis, reforming and biomass gasification. Electrolysis uses electricity to split water into hydrogen and oxygen. When powered by renewable sources such as wind or solar energy, electrolysis produces minimal greenhouse gases (Swennenhuis et al., 2022). Reforming produces a chemical reaction that emits CO2 (Swennenhuis et al., 2022). In the biomass gasification process, organic materials become available (Swennenhuis et al., 2022). The subsequent stages of storage and transport are crucial in assessing the environmental impact of the system. Hydrogen can be stored in gas or liquid form and transported via pipelines or tankers, each of which has a different environmental footprint (Li and Cheng, 2020).

Hydrogen has applications in fuel cells or combustion engines for power generation. It is essential to evaluate these applications to identify potential areas for reducing environmental impact (Liu et al., 2020; Liu et al., 2021; He et al., 2024).

The **Technology Readiness Level** (TRL) helps assess the maturity of hydrogen technologies from basic research to commercial application. Hydrogen production technologies, especially electrolysis from renewable sources, have reached a high TRL, indicative of an advanced stage of development (Petrovic and Hossain, 2020). Storage and transport technologies have also evolved significantly (Kampker et al., 2020).

The system considered for evaluation is from cradle to gate: that is, from the extraction of the raw materials used along the electrocatalysts for hydrogen distribution chain. The raw materials used along the hydrogen distribution chain (e.g. to produce the electrolyser or to generate electricity) until the hydrogen is delivered to the end user are analysed (Lotrič, et al., 2021). Emissions from the production of the necessary infrastructure along the distribution chain are also included in the evaluation. A simplified flow chart with the main processes included in the evaluation is presented in Figure 3.

***Figure 3**. Main processes (Arrigoni et al, 2024).*

The approach adopted for the LCA is an "attributional" one, as the scope of the assessment is limited to the life cycle comparison of the formulated electrocatalysts for hydrogen type (Arrigoni ed al. 2024).

Decreased quantities of pollutant emissions are expected to be analysed by means of Life Cycle Assessment applications according to the international ISO 14040 series of standards and Carbon footprints in order to also quantify value changes within the Emission Trading market.

The data from the former were combined with the inventories found in the literature and the hydrogen production data with the Ecoinvent database version 3.9 (cut-off system model) for the life cycle inventory (Wernet, G., et al., 2016). Version 9.2 of the SimaPro software was used for the evaluation.

Problems in LCAs include undefined system boundaries, data that are not always complete in life cycle inventory (LCI) databases, and recycling technologies still in the research and development phase.

LCA applied to electrocatalysts for hydrogen investments

Sustainability and life cycle assessment (LCA) are crucial in assessing the environmental impact of nanocatalysts. These innovative materials, used in various industries, show enormous potential in improving the efficiency of chemical reactions and reducing energy consumption (Kool et al., 2019).

The LCA of nanocatalysts includes analysis of energy consumption, resource depletion, emissions and waste generation throughout the life cycle. Previous studies have highlighted the need to reduce raw material extraction and energy-intensive production processes (Chen et al., 2021)

The production of nanocatalysts may involve the use of energy-intensive chemicals and procedures. It is essential to assess and mitigate the environmental risks associated with their synthesis and production (Tristão et al., 2020). Key challenges include stabilisation of nanocatalysts and scalability of the synthesis (Corma & Garica, 2008).

The steps of the LCA are outlined below.

Functional unit

The functional unit considered is a volume-based unit, i.e., 1 cubic meter of hydrogen (1 m^3 H_2), about 200-300 nm in size. Nanostructured catalysts based on recycled Mo.

Life cycle impact assessment

The assessment covers the 16 life cycle impact categories recommended by the EF impact assessment method (European Commission, 2021): acidification, climate change, ecotoxicity (freshwater), particulate matter, eutrophication (marine), eutrophication (freshwater), eutrophication (terrestrial), human toxicity (cancer), human toxicity (non-cancer), ionising radiation, land use, ozone depletion, photochemical ozone formation, resource use (fossils), resource use (minerals and metals), water use.

Life cycle inventory

The inventory for the evaluation is mainly based on the supply of H_2. Deliveries are not expected before 2030 and therefore the data reflect expected efficiencies and emission factors.

Some of the processes considered in the study (e.g., packaging and unpacking of hydrogen carriers) are at an early stage of development. Therefore, inventory data are subject to a high level of uncertainty. The reference database for the evaluation is the Ecoinvent 3.9 cut-off system model (Wernet et al., 2016). The cut-off model was chosen for easier traceability.

Impact assessment

The assessment covers the 16 life cycle impact categories recommended by the EF method: (https://green-business.ec.europa.eu/environmental-footprint-methods_en) acidification, climate change, ecotoxicity (freshwater), particulate matter, eutrophication (marine), eutrophication (freshwater), eutrophication (terrestrial), human toxicity (cancer), human toxicity (non-cancer), ionising radiation, land use, ozone depletion, photochemical ozone formation, resource use (fossils), resource use (minerals and metals), water use.

Sensitivity analyses

The analysis is performed by varying one parameter at a time, to understand how a given factor may influence the results. The parameters include: electrolyser efficiency (5.1), power generation (5.2), short-term climate impact, long-term environmental impact, short-term climate impact, leakage, transport fuel, distance, water source, energy for unpacking, carbon capture and storage, process efficiency and impact assessment method.

Results and discussions

The principles of Eco-design and sustainable development are essential to minimise the environmental impact of nanocatalysts. The integration of these principles can guide the eco-design process, reducing energy consumption and waste generation, and promoting the use of recyclable or biodegradable materials (Helland et al., 2021).

Despite progress, challenges such as improving the efficiency and cost-effectiveness of hydrogen systems compared to conventional fossil fuels and increasing the durability of fuel cells remain. These issues require continuous research to improve the feasibility and reliability of hydrogen technologies (Pinsky et al., 2020; Lindorfer et al., 2020; Riemer et al., 2023).

In conclusion, we obtain efficient and stable nanocatalysts active for water splitting applications starting from recycled industrial waste, opening a new route for the applications of these and showing the importance of Urban mining.

The synthesis of nanocatalysts, utilizing sustainable materials, can potentially replace the use of precious metals while maintaining high efficiency and stability at a lower cost. This review will emphasize the development of recycling and reusing processes to enable sustainable synthesis and full material recovery at the end of their lifecycle, either through regeneration or secondary utilization.

A comprehensive environmental and economic assessment, together with a detailed life cycle and technology readiness assessment, highlights the potential and challenges of hydrogen-based renewable energy systems and nanocatalysts. These assessments provide essential insights to optimise environmental benefits and address economic and technological barriers, paving the way for sustainable energy solutions.

Conclusion

Current production methods of electrocatalysts for hydrogen production involve complex, expensive, and often hazardous processes such as multistep procedures and high-temperature phosphorylation, resulting in harmful waste generation detrimental to both humans and the environment. Therefore, there is an urgent need for the development of non-toxic, eco-friendly, and reliable methods for electrocatalyst production.

In the context of a circular economy (CE) approach, the development of novel materials must undergo careful life-cycle assessment (LCA) to ensure their sustainability and environmental impact mitigation. The LCA analysis showed a tangible environmental impact. In the future, highly qualified skills and heavy investment in R&D will be required to solve the complexity electrocatalysts for hydrogen technology. In the current context of the energy crisis, an acceleration of business has been noted to move from the current level of demonstration plants to the concrete development of a electrocatalysts for hydrogen production chain. Public involvement is needed for the provision of clear and long-term regulations, demand development strategies and support for the construction of the national distribution infrastructure.

One can therefore understand how the innovation resulting from the use of electrocatalysts for hydrogen production can be the driving force behind the energy and ecological transition of the entire Mediterranean basin.

Acknowledgements

This study was funded under the Innovative non-critical raw materials-based electrocatalysts for electrolytic green hydrogen generation-IMAGE.
CUP E53D23016050001

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Track 18: Innovation

Innovation in Glass Sorting and Selection: A Literature Review

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Abstract

Annually, approximately 209 million tons of glass are produced worldwide, serving a wide range of industries. Given this vast production, the recycling of this essential yet finite raw material is imperative not only for natural resource conservation and environmental protection, but also to ensure its future availability. Despite the high efficiency and recovery rate of glass recycling, losses still occur at three critical stages in the circular glass system: collection, selection, and waste distribution. To optimize these processes and maximize environmental benefits while minimizing losses, this literature review aims to identify the challenges, current technologies, and future opportunities for enhancing the efficiency of glass collection and selection processes.

The efficient separation of recyclables is significantly influenced by the collection methods employed. Countries utilizing mixed collection systems demonstrate lower efficiency in glass recycling compared to those with segregated collection systems. Deposit Return Schemes (DRS) are currently implemented in a few countries; however, some studies suggest that a more comprehensive and well-structured DRS could significantly enhance collection rates.

With the advent of innovative technology, it has become possible to automate the sorting process and increase recycling rates. The glass selection process is continuously evolving, with advancements in sorting techniques, technological innovations for impurity removal, and improvements in high-impact environmental processes.

This review demonstrates that the implementation of advanced glass recycling technologies, along with continuous efforts to improve collection and treatment procedures, is crucial for optimizing the recovery of this valuable material and enhancing its quality and efficiency.

Introduction

One of the most important materials in the global economy is glass. It serves a wide range of industries, from traditional sectors such as construction, automotive, and packaging to cutting-edge fields like telecommunications, medical research, space exploration, and optics (Testa et al., 2017). Annually, approximately 209 million tons of glass are produced worldwide (International Commission on Glass, 2022). The main sector globally is glass packaging, the largest one, used in a diverse array of products for food, beverage, cosmetic, and pharmaceutical packaging. Following this, flat glass plays a critical role in construction, transport, and photovoltaics. Additionally, continuous filament glass and glass wool are also employed for insulation, roofing, and reinforcement of composite materials. Lastly, domestic and specialty glass products range from drinkware, baking dishes to optical glass, screens for electronic devices, and lighting glass (Kua et al., 2024).

Glass packaging is considered one of the most recyclable materials in the world and is frequently preferred by consumers for its ability to preserve product quality. Furthermore, compared to plastic, it is often perceived as more sustainable (ASSOVETRO, 2023). In reality, an important amount of silica sand (70–74%), a non-renewable resource, is needed to make glass. Sand extraction from rivers, beaches, and quarries—a frequent activity in the glass industry—has been linked to major environmental harm to ecosystems worldwide (Zhao et al., 2020). Furthermore, the production of glass containers is one of the most material and energy-intensive industrial processes, consuming enormous amounts of non-renewable resources and thermal energy. This is due to the necessity of high temperatures (up to 1550 °C) to melt the raw materials (Testa et al., 2017). In this context, recycled glass, which constitutes only 15% of the raw materials in the production of new glass, emerges as a less impactful alternative (Kua et al., 2024).

In the last two decades, before the development of recycling approaches and public policies, a larger proportion of post-consumer packaging materials was landfilled or incinerated (Ibrahim et al., 2023). The current state of waste management in Europe is complex, with heterogeneous raw materials and different extended producer responsibility systems on the one hand, and an increasingly arsenal of emerging sorting and recycling technologies on the other. These challenges make optimal waste management difficult and require a balancing act between technical limitations, economic equilibrium and environmental impacts (Roosen et al., 2023).

The recycling of packaging waste entails the collection, separation, reprocessing, and marketing of secondary raw materials (CONAI, 2023). Italian regulations aimed at preventing the generation of packaging waste are outlined in the European Directive 2008/98/EC, which was expanded upon by Directives 2018/851/EU and 2018/852/EU. The goal is to reduce both waste and its negative impact on human health and the environment. Furthermore, the European Commission's Circular Economy Action Plan emphasizes the importance of high-quality recycling as a tool for a more sustainable and circular economy. This plan emphasizes the need to improve the quality of recycling to increase the use of secondary raw materials in new products. The success of this process is contingent upon several factors, including consumer behaviour, the efficiency of collection processes and the technical properties of secondary raw materials derived from heterogeneous waste (Roosen et al., 2023). In Italy, article 218(1)(h) of legal Decree 152/2006 defines prevention as the reduction of the quantity and environmental hazard of substances and materials used in packaging. This can be achieved through the development of non-polluting technologies and products. Moreover, this approach must consider the entire life cycle of packaging, from production to post-consumer management (Fondazione per lo Sviluppo Sostenibile & CONAI, 2019).

Italy is now among the most efficient European nations in accordance with the common target of 70% for packaging waste recycling by 2030 (European Parliament, 2024). The country has achieved considerable strides in the last ten years, with its municipal waste recycling rate rising from 37.6% to 49.2% (ISPRA, 2023; Ronchi et al., 2024). After a slight decrease in 2021, mainly due to the negative impact of the pandemic, the glass recycling rate showed a significant recovery in the following two years, increasing to 80.8% (COREVE, 2023). Post-consumer packaging waste represents a potential alternative to virgin raw materials. If carefully separated and collected, it can be transformed into secondary raw materials and thus reintroduced into the consumption cycle, maintaining a circular, continuous and loss-free process (Rigamonti et al., 2019).

Glass is therefore a perfect example of the circular economy. The production of 100 kg of glass requires approximately 117 kg of virgin raw materials (sand, soda, carbonates, etc.) or 100 kg of cullet (COREVE, 2023). Other studies indicate that a 10% increase in the use of recycled glass compared to virgin raw materials results in energy savings of 3% (Kua et al., 2024). This energy saving is also reflected in a reduction in the use of fossil fuels and the associated emissions (Butler & Hooper, 2005; Vellini & Savioli, 2009). For example, one ton of recycled glass can prevent the emission of more than 500 kg of CO2. In addition, a 10% increase in the use of waste glass can reduce sulphur and nitrogen oxides by 10% and 4% respectively. Glass made from recycled material has been shown to reduce air pollution by 20% and water pollution by 50% (Kua et al., 2024). For every ton of recycled glass used to replace raw materials, approximately one ton of natural resources is conserved, including 590 kg of sand, 186 kg of soda, 172 kg of limestone and 73 kg of feldspar (Kua et al., 2024).

Despite the environmental benefits previously outlined, losses in the circular glass system occur at three critical stages: collection, sorting and waste distribution. The greatest material losses occur in the collection phase (Barbato et al., 2024). Furthermore, the utilization of cullet in the recycling process results in additional CO2 emissions of 0.5 to 0.7%, related to the stages of collection, sorting, shredding and transport to recycling plants. These emissions are greatly affected by the logistics involved (Golub et al., 2022).

Given the necessity to optimize these processes to maximize environmental benefits and minimize losses, this study aims to examine current methodologies and innovations in the field of glass collection and recycling. The investigation seeks to identify and address challenges and opportunities for enhancing the efficiency of the collection, selection and recycling processes of glass.

Methods

The literature review provides the conceptual basis for the recyclability of glass and current collection and recycling methodologies. The purpose of this article is to examine and discuss the potential and problems related to improving the effectiveness of the processes involved in the separation, collection, and recycling of glass packaging components. Scopus, Web of Science, and Google Scholar were the databases used for the search. Six keywords were used in a targeted search to find a selection of articles: Recycling, Glass, "Circular Economy", Innovation, "Glass Packaging", "Waste Management". To refine the search, boolean variables such "OR" and "AND" were used. 68 articles were identified in the initial search, and these were further filtered using useful screening criteria. The search was conducted with journal articles, reviews, conference proceedings, and grey literature (reports). Language also served as an exclusion factor, with the removal of any texts written in languages other than English and Italian. In the end, 48 were found to be relevant for analysis, and their quality and uniqueness were evaluated; the citations served as research cues.

The "Results and Discussion" section starts with an overview of the glass recycling system and identifies the two crucial steps in the system maximization process: collection systems and selection systems. Each of these main sections is further organized into relevant subsections. The section on collection systems addresses the differences between various collection methods and collection efficiency issues, with a focus on Deposit Return Schemes and the glass collection system in Italy. The section on selection systems delves into technological advances in sorting techniques, innovations for the removal of impurities, and related environmental considerations and existing technological solutions.

Results and Discussion

There are several prevailing types of glass, the most important of which is sodium-calcium glass, which is widely used for food-contact packaging (COREVE, 2023). During the recovery process, glass is progressively broken down into small pieces, known as 'cullets' (Close the Glass Loop, 2023). These fragments are transported from the point of collection to recycling facilities, where they mix with particles from other waste, resulting in the formation of 'glass fines' (Flood et al., 2020). To facilitate an efficient recycling process, it is crucial to avoid mixing diverse types of glass (Ahmet & Aybuke, 2017). Moreover, the cullet must be sorted by colour to ensure the quality of new glass products (Ibrahim et al., 2023). In fact, the physical and chemical properties, colour, impurity content and homogeneity of the cullet affect the quality and value of the final product (Grant et al., 2020).

In this context, the global recycling rate of glass is estimated at 21% of total production (Kua et al., 2024). Higher rates of approximately 32% have been achieved for packaging glass, whereas the recycling rate for flat glass is only 11% (Kua et al., 2024). Compared to the global average, the European Union has a significantly higher average glass recycling rate (Close the Glass Loop, 2023; Glass for Europe, 2020). However, there is a considerable disparity in glass recycling rates within the EU. For instance, countries with efficient waste collection and separation systems, such as Sweden, Slovenia and Belgium, have achieved recycling rates above 95%. On the contrary, countries such as Cyprus, Turkey, Malta and Greece have glass recycling rates that are considerably below 50% (Close the Glass Loop, 2023). This discrepancy can be attributed to the "collection gap" within the EU, differences in government incentives, and the broader economic framework (Glass for Europe, 2020; Kua et al., 2024). In certain countries, a considerable proportion of recyclable materials, such as glass, is erroneously discarded in mixed municipal solid waste, resulting in its disposal in landfills, incineration, or treatment at mechanical biological treatment facilities (Dias et al., 2015; Meylan et al., 2013). This turns a readily recyclable product into one that is difficult to recover, with negative impacts both environmentally and economically.

Within this framework, the efficiency of recycling processes can significantly affect the amount of glass recovered and the purity of the recycled material, reducing the risk of improper disposal. The following section will examine two pivotal phases in the process of maximising glass recycling: collection and selection.

Collection Systems

Glass recycling suffers from significant losses during collection, sorting and distribution to various end markets. Most of these losses can be attributed to colour and pollution contamination problems, particularly in the initial phase of collection (Zero Waste Europe, 2022). It is evident that the method of glass collection has a significant impact on its potential for circularity. A separated collection system, for example, reduces impurity presence and makes most of the cullet suitable for glass manufacture, thereby increasing the potential recycling rates in comparison with mixed systems which collect glass alongside other materials (Barbato et al., 2024). Separated glass collection can be implemented in two ways: by mixing various glass colours or by keeping them separate (Grant et al., 2020). The former approach entails greater losses than the latter, as additional sorting is required to differentiate the cullet by colour, thus reducing recycling efficiency (Barbato et al., 2024). Glass colour is a fundamental attribute that must be preserved; once compromised, its recovery becomes impractical (Flood et al., 2020). Therefore, the production of clear glass requires colourless cullet with minimal presence of coloured glass, while amber and green glass can be produced using cullet that includes a certain amount of green and clear glass and a wider variety of colours, respectively (Grant et al., 2020).

The efficient separation of recyclables depends on collection methods, both mono- and multi-material, whether they are curbside or at designated drop-off locations (Dijkgraaf & Gradus, 2021; Giugliano et al., 2011). Countries that employ mixed collection systems, such as the United Kingdom and the United States, demonstrate a lower level of efficiency in glass recycling compared to those with segregated collection systems, such as Germany and France. This can be attributed to the higher contamination rates and losses during sorting (Zero Waste Europe, 2022).

Deposit Return Schemes (DRS)

Deposit Return Schemes (DRS) are currently in place in a few countries. Under these schemes, customers pay a small deposit when buying beverages in containers like bottles and cans (Magrini et al., 2020; Reinkingh et al., n.d.). When the empty container is returned to approved collection locations, the deposit is reimbursed (Bao et al., 2023; Kulshreshtha & Sarangi, 2001). These programs aim to decrease waste output, boost collection rates, and offer incentives for recycling (Agnusdei et al., 2022). Known as "bottle bills," these deposit-refund systems (DRS) are used in a few states in the United States. Those states that have implemented such legislation report collection rates between 75% and 89%, whereas the average in states without such laws is 32%. This suggests that a more comprehensive and well-structured DRS could markedly enhance collection rates. Other DRS systems in Europe that include glass have achieved collection rates between 84% and 89% in 2019. In 2021, Finland reported a collection rate of 98% (Zero Waste Europe, 2022).

Glass collection in Italy

In Italy, the recycling system is almost exclusively operated by national municipal waste collectors, with a small portion of material coming from pre-selection plants (Close the Glass Loop, 2023). Glass packaging waste collection had a 3.8% increase in 2022, with 91.4% of the material collected going toward recycling. Waste generated during treatment operations, which was mainly composed of glass that was recyclable but rejected at the facilities during the sorting and removal of pollutant material, was disposed of in landfills (COREVE, 2022).

Selection Systems

With the advent of cutting-edge technology that have made it possible to automate the sorting process and boost recycling rates, the glass recycling sector has experienced constant evolution since the early 1970s (Dias et al., 2015). Significant advancements in the field, including the introduction of mechanical selectors and metal detectors in the 1990s, as well as chromatic sorting of cullet, mark major technological milestones in glass recycling (Bonifazi & Serranti, 2006).

Once collected, waste glass is subjected to a crucial process of crushing and preliminary separation to ensure the quality integrity of the reused material (Yuan et al., 2024). Glass fragments derived from both industrial processes and urban separate collection contain a variety of pollutants, including ferrous metals, wood, paper, plastic, and ceramic or glass-like contaminants (Bonifazi & Serranti, 2006; Farcomeni et al., 2008). Such elements can have a significant impact on both the manufacturing process and the quality of the final products. Consequently, reducing contamination levels is of critical importance for the economic sustainability of the glass recycling process (WRAP, 2023).

Sorting Techniques

After the crushing and screening stages, the glass is subjected to drying and further processing, which employs direct and indirect sorting techniques. Direct sorting makes use of the inherent physical properties of materials, such as magnetic susceptibility, electrical conductivity, and density. These parameters permit the separation of materials using external fields, including magnetism, eddy currents, and gravitational force (Gaustad et al., 2012; Mesina et al., 2003; Svoboda & Fujita, 2003). Indirect sorting employs advanced sensor technologies to identify and, in many cases, pinpoint the location of recyclable materials within waste (Gundupalli et al., 2017; Yuan et al., 2024).

At this stage, it is crucial to employ optical separation techniques to ensure that glass is sorted according to its colour, effectively distinguishing and segregating the main products from the by-products (Gundupalli et al., 2017). This stage is vital to ensure the quality of the recycled material is maintained, thus facilitating the efficient production of new glass products (Dias et al., 2015). To further refine the quality of processed cullet, a variety of optical identification technologies are employed. These include X-ray fluorescence, infrared, ultraviolet, spectral imaging, and spectroscopy (Beerkens et al., 2011).

Optical identification of glass has also been widely adopted in sectors such as coal preparation and agriculture (Vasishth P. & Bavarva, 2015). This method significantly reduces manual labor by using compressed air to blow away impurities based on their optical properties like color, shape, size, or even chemical composition (Yao et al., 2021).

Technological Innovation for Impurity Removal

The removal of some impurities is still quite difficult, even with major advancements in flow technology and optical sorters employed in the glass recycling sector (Grant et al., 2020). Sub-spherical contaminants such as stones provide significant challenges in terms of removal. Once identified by optical sensors, these elements tend to roll along unpredictable trajectories within sorting systems, often being mistakenly recovered along with glass cullet. This results in contamination of the recycled material that can compromise the quality and integrity of the final product (Dias et al., 2012, 2015). According to Bonifazi and Serranti (2006), this problem has been well documented and is still one of the key technological obstacles to the efficacy of glass recycling. German manufacturer Redwave uses digital imaging techniques for color-based separation and X-ray fluorescence spectroscopy to distinguish glasses with different chemical compositions, like window glass or leaded glass. In addition, Redwave uses infrared sensors to isolate ceramics, minerals, porcelain, and metals (Flood et al., 2020). However, while these systems adequately identify material types, particle size poses another significant challenge. Redwave machines can only handle particles up to 8 mm in size, making them unsuitable for processing glass fines, which are smaller particles. When trying to separate these tiny particles, the sorting process is significantly less successful (Flood et al., 2020).

The adoption of spectral imaging technology combines the techniques of spectral reflectance measurement and image processing, thus significantly enhancing the ability to distinguish between types of glass on the grounds of spectral properties (Gundupalli et al., 2017). For instance, Bonifazi et al. (2006) devised methodologies for the identification of glass ceramics based on the specific spectral signatures associated with these materials. This approach enabled the differentiation of useful materials from potential contaminants through comparison with reference samples of glass and ceramics of various shapes, thicknesses and colours. Furthermore, hyperspectral imaging was employed to identify and distinguish amber glass, which is more challenging to discern due to its comparatively low reflectance levels in comparison to white glass (Flood et al., 2020). Dias and Carvalho (2015) demonstrate a significant reduction in contamination in glass waste using RecGlass on a laboratory scale. This instrument was developed with the specific purpose of separating sub-spherical particles, such as stones, from flat particles, with the focus on glass (Dias et al., 2015; Flood et al., 2020). The challenge of scaling these solutions for industrial applications remains a significant obstacle.

Technological Innovation & Environmental Considerations

Finally, the conventional glass recycling process results in the production of organic wastewater (Blengini et al., 2012). It is estimated that each ton of treated glass generates approximately 0.4 tons of organic wastewater, which necessitates further interventions for its treatment (Yao et al., 2021). Reducing or eliminating the production of these effluents is a key objective of advanced recycling technologies. As a response to the necessity, an innovative glass cleaning technology that does not result in wastewater production has been developed (Yao et al., 2021). This technology employs a low-temperature fluidized bed rotary furnace to remove labels and other impurities, thereby circumventing the generation of liquid effluents. This approach represents a substantial advancement in reducing the environmental impact associated with the glass recycling process (Yao et al., 2021).

Conclusions

Glass recycling is an essential process not only for waste management but also for natural resources conservation and environmental protection. To ensure efficient and sustainable recycling, each type of glass—from borosilicate glass used in pharmaceutical applications to sodium-calcium glass used in food packaging—needs a different treatment (Testa et al., 2017).

Preventing contamination is a major difficulty in glass recycling since combining several types of glass can seriously lower the quality of the final recovered product. Consequently, meticulous selection and separation of glass by colour and type before its reuse in new product manufacturing is essential to maintain the high quality and transparency of recycled glass.

Despite the challenges associated with recycling glass in the European Union, the overall rate of glass recycling remains high. Since effective mechanisms for waste sorting and collection have been implemented, certain nations have reached rates that are higher than 95%. Still, there are significant differences across the member states, which are impacted by regulatory, infrastructural, and economic variables. These disparities highlight the need for efficient incentives and policies from governments to promote consistent and efficient recycling methods across the European Union.

The development of innovative technologies, such waterless glass cleaning, represents a significant advancement in the reduction of environmental impacts. These technologies not only enhance the efficiency of recycling, but also reduce the production of waste and effluent.

The literature review demonstrates that the implementation of advanced glass recycling technologies, along with continuous efforts to enhance collection and treatment procedures, is crucial to optimise the recovery of this valuable material and to enhance its quality and efficiency. Investing in cullet treatment centers in Italy, where used glass is selected, purified from impurities, and crushed to produce clean cullet ready for transformation into new glass, is a priority. Potential solutions may include reorganising the waste supply chain, optimising collection routes and reverse logistics, and encouraging a 'closed loop' recycling model through partnerships and stakeholder networks at various levels, promoting the sharing of knowledge and expertise (Agnusdei et al., 2019; Meylan et al., 2015; Testa et al., 2017). This study can provide a foundation for decision-makers in guiding policies for glass recycling, ensuring that regulations align with the implementation of effective and sustainable operational practices. Furthermore, it offers research institutes a solid starting point for future empirical investigations.

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TQM and Industry 4.0: an analysis of key enabling technologies about Critical Success Factors (CSFs)

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Abstract

Total Quality Management (TQM) and Industry 4.0 (I4.0) are established and widely developed frameworks in the management literature. Ten years after the implementation of I4.0, this contribution aims to analyse the integration between the two themes, focusing on the use of enabling technologies concerning the Critical Success Factors (CSFs) of TQM. For this purpose, the following methodologies were used: a systematic literature review to define the sample and a content analysis to highlight elements applicable to the research questions.

The results provide an overview of which enabling technologies are used in CSFs and which are the primary motivations for using specific technologies over others.

From a managerial point of view, the paper offers insights for managers and practitioners to further support the relationship between TQM and I4.0 and enable the latter's technologies to be an effective operational arm in achieving quality objectives through CSFs.

Therefore, the paper contributes an overview of the state of the art and a dynamic view of the evolution of the constructs over time from a holistic perspective.

Keywords: Industry 4.0; Critical success factors; Total quality management; enabling technologies, revision

Introduction

Adaptability and effective management of the entire value chain are crucial for organisational survival in the current business landscape, characterised by multifaceted environmental, social, economic, and technological challenges. The industry 4.0 (I4.0) revolution, which involves digitizing the entire value chain, presents companies with opportunities to enhance customer satisfaction through innovative digital offerings and quality assurance activities, making this research highly relevant and engaging.

Integrating Total Quality Management (TQM) with I4.0 can significantly improve enterprise sustainability and ensure long-term survival (Bag and Pretorius, 2022; Carvalho *et al.*, 2019; Saha *et al.*, 2022). TQM, which emphasises meeting quality requirements in all processes to meet customer needs quickly and accurately through the contribution of all employees, aligns well with I4.0(Baran and Korkusuz Polat, 2022). I40's combination of human and technological systems has influenced various quality management approaches, such as Lean Six Sigma, lean manufacturing, and TQM practices, making TQM an essential aspect of I4.0 (Canbay and Akman, 2023).

Several reviews have investigated the relationship between TQM and I4.0 from different perspectives, including systematic literature reviews, bibliometric analyses, and descriptive literature reviews (Ali and Johl, 2022; Baran and Korkusuz Polat, 2022; Broday, 2022; Chiarini, 2020; Dias *et al.*, 2022; Liu *et al.*, 2023; Ranjith Kumar *et al.*, 2022; Saihi *et al.*, 2023; Sony *et al.*, 2020; Souza *et al.*, 2022). These reviews have provided valuable insights into the topic, highlighting the evolving concept of Quality, the integration of technology, Quality, and people in the industrial scenario, and the development of the "quality curve theory"(Liu *et al.*, 2023).

The synergy between TQM and I4.0 has led to the emergence of Quality 4.0. This modern quality management approach aligns quality management practices with I4.0 technologies, such as artificial intelligence (AI) and digitization, to improve overall product quality and enhance business efficiency (Broday, 2022; Saha et al., 2022; Thekkoote, 2022).

Q4.0 represents a departure from traditional quality practices and can be classified as an I4.0 approach that emphasises quality and performance goals by analysing the interactions between individuals, systems and emerging technologies (Carvalho *et al.*, 2024; Radziwill, 2018). The aim of Q4.0 is to pursue performance excellence and achieve quality goals, using digital tools (Dias *et al.*, 2022).

The relationship between TQM and I4.0 and, thus, Quality 4.0, an emerging concept, deserves further theoretical development to facilitate a comprehensive understanding of its principles (Chiarini and Kumar, 2022). Understanding the concept and its importance is necessary for a successful Q4.0 transition (Dias *et al.*, 2022). Furthermore, despite the potential benefits of Quality 4.0, there is a paucity of empirical evidence regarding successful implementation strategies (Zonnenshain and Kenett, 2020).

As for the implementation of TQM, also for Quality 4.0 several studies (Joshi et al., 2024;Antony et al., 2022; Sony et al., 2021) have focused on identifying the main critical success factors (CSFs) of Q4.0. However, the readiness factors required for the implementation of Q4.0 have not yet been adequately explored in the existing literature (Gunasekaran *et al.*, 2019) and therefore, the literature is still not in agreement on which CSFs of Q4.0 we are.

However, it is now imperative to develop a solid theoretical framework capable of supporting companies in successfully implementing both quality objectives and I4.0 tools. For this reason, this study aims to provide an overview of the main CSFs applied in I4.0 and the main enabling technologies. After analysing the possible correspondences between the new CSFs of Q4.0 and the CSFs of TQM, this paper aims to answer the following research questions.

RQ1 What are the main CSFs of TQM that recur most in I4.0?

RQ2 What are the main enabling technologies applied in connection with TQM?

The article is structured as follows: section two describes the main recent studies on CSFs of Q4.o and the main enabling technologies of I4.0. Section three describes the methodology, while the results and discussions are described in section four. Conclusions with their limitations, future research steps and main managerial and scientific implications are described in section five.

Literature review

CSFs of TQM and Q4.0

According to (Valmohammadi and Roshanzamir, 2015), Total Quality Management (TQM) comprises a set of interconnected principles, each supported by specific practices and techniques. The successful implementation of TQM is crucial for its effectiveness within an organization (Mohammad Mosadegh Rad, 2006). Therefore, analysing the Critical Success Factors (CSFs) that contribute to TQM implementations' success is paramount **(Hietschold *et al.*, 2014)**. Ebrahimi and Sadeghi (2013) further assert that these CSFs positively impact corporate performance. Despite the absence of a unified framework in the literature regarding CSFs in TQM, recent research by**(Aquilani *et al.*, 2017; Dezi *et al.*, 2022; Hassan and Jaaron, 2021)** and Hietschold et al. (2014) has identified 12 key CSFs. (1) Benchmarking; (2) Continuous Improvement; (3) Culture and Communication; (4) Customer Focus; (5) Human Resource Management; (6) Information and Analysis; (7) Leadership; (8) Process Management; (9) Social and Environmental Responsibility; (10) Strategic Planning; (11) Supplier Partnership and (12) Training and Learning.

As for TQM, also for Quality 4.0, several authors in the literature have tried to investigate the motivations and barriers, but above all, CSFs related to its implementation in organisations. In this context, a literature review developed by Liu et al. (2023), in which the authors provide a comprehensive mapping of existing studies related to Q4.0 aimed at highlighting current research trends, key topics and areas for future research, identifies eleven articles, of which seven focus on Q4.0 CSFs. The first study on this topic is developed by Sony et al. (2020), who recognised eight critical factors for the effective implementation of Q4.0: (1) Handling big data, (2) enhancing prescriptive analytics, (3) effective vertical, and horizontal and end-to-end integration, (4) strategic advantage, (5) leadership, (6) training, (7) company culture, and (8) top management support. In 2021, Sony et al. (2021) not only identified the main barriers and motivations for implementing Q4.0, but also described the following 'readiness factors': (1) top management support, (2) quality culture, (3) leadership, (4) Quality 4.0 strategy, (5) quality knowledge and awareness, (6) customer-centredness, (7) supplier-centric, (8) training, and rewards. Antony et al. (2023) also focuses on the "readiness factors" identified by Sony et al., (2023) but at an intercontinental level, and, using a qualitative research methodology, the authors conclude that commitment, leadership and organisational culture of top management are the three main readiness factors for Q4.0 implementation.

In an in-depth analysis, Thekkoote (2022) investigated the crucial determinants for the successful integration of Q4.0 in the context of digital transformation. The study identified key factors such as data utilisation, analytical expertise, connectivity optimisation, collaborative frameworks, application development strategies, scalability considerations, adherence to regulatory standards, organisational culture alignment, leadership effectiveness and training initiatives as crucial elements influencing the implementation of Q4.0. Similarly, Ali and Johl (2022) explored the intersection between TQM and I4.0, examining objective and subjective dimensions. Their research highlighted essential success factors for the efficient adoption of Q4.0, including constant top management support, a customer-centric approach, continuous employee training and development, effective use of big data for quality analysis, streamlined process management, a culture of continuous improvement and strategic product/service design considerations.

Sureshchandar (2023) hypothesised that Q4.0 is a multifaceted concept characterised by 12 distinct dimensions, comprising traditional quality and technical factors as key components of its transformation. Traditional quality factors, such as leadership, organisational culture, customer focus, quality systems, metrics and data analysis, play a key role in successfully implementing Q4.0. In addition, technical factors, including data governance, innovation and advanced analytics, are equally important in this process.

Finally, Yadav et al. (2021) empirically evaluated Lean Six Sigma success factors in Q4.0, revealing that seven Q4.0 factors and 11 traditional factors were considered critical. Specifically, the critical Q4.0 factors identified by Yadav et al. (2021) include timely and accurate data availability, data processing software, enterprise resource planning (ERP) systems, application software with the ability to adjust processes automatically, radio frequency identification (RFID)-enabled inventory systems, data analysis and prediction systems, and automation. In summary, according to Sureshchandar (2023) and Yadav et al. (2021), the successful implementation of Q4.0 requires a holistic approach that integrates both traditional quality and technical factors.

Table 1 shows the list of CSFs in Q4.0.

Authors	**CSFs of Quality 4.0**
Sony et al., (2020)	Company culture,
	Effective vertical horizontal and end-to-end integration,
	Enhancing prescriptive analytics,
	Handling big data,
	Leadership
	Strategic advantage,
	Top management support
	Training
Sony et al., (2021)	Customer centredness,
	Leadership
	Quality 4.0 strategy,
	Quality culture,
	Quality knowledge and awareness,

	Supplier-centric,
	Top management support
	Training and rewards
Yadav et al., (2021)	Application software with the capability to auto-adjust processes,
	Data analysis and prediction system, and automation.
	Data availability,
	Data processing software,
	Enterprise resource planning (erp) system,
	Radio frequency identification(rfid)-enabled inventory system,
Ali and Johl (2022)	Continuous improvement,
	Customer focus,
	Employees training and learning,
	Process management,
	Product/ service design.
	Quality of big data and analysis,
	Top management commitment,
Thekkoote (2022)	Collaboration,
	Compliance,
	Connectivity,
	Data, analytics,
	Development of apps,
	Leadership,
	Organisation culture,
	Scalability
Antony et al., (2023)	Customer centredness
	Knowledge and awareness on quality 4.0
	Leadership
	Organisational culture towards quality 4.0
	Quality 4.0 vision and strategy
	Supplier-centric,
	Top management support
	Training and rewards
Sureshchandar (2023)	Training
	Analytical thinking
	Competence
	Compliance
	Customer centricity
	Data governance
	Innovation
	Metrics and data-driven decision making
	Quality culture
	Quality management system
	Strategic leadership

Source: our elaboration

A review of the literature reveals that the topic of Quality 4.0 CSFs is still in its nascent stage and constantly evolving. There is no universally accepted consensus on CSFs in the academic community.

Industry 4.0 and its enabling technologies

The Fourth Industrial Revolution (I4.0), also known as Industry 4.0, is arising because of various advancements that are revolutionising the design, production, operation, and services associated with manufacturing systems or products in a significant and swift manner (Mabkhot et al., 2021) and also signifies a radical innovation in not only business but also various fields, sectors, and disciplines **(Piccarozzi *et al.*, 2018)**. Launched in Germany in 2012, Industry 4.0 (I4.0) encompasses a wider range of advancements compared to its predecessors. The first revolution, which commenced in the 1700s, introduced coal and witnessed the growth of textiles and transportation. The second revolution, around 1900, centred on oil and industrial production. The third revolution, during the 1960s, emphasised electronics and information technology in manufacturing. However, I4.0 surpasses them all in terms of its comprehensive scope and transformative potential **(Xu *et al.*, 2018)**. I4.0, which combines information technology and electronics, has created a comprehensive and versatile model that has expanded beyond the industrial sector to other contexts, bringing benefits, simplifications, and improvements **(Rüßmann *et al.*, 2015)**. Initially, I4.0 was focused on manufacturing and related benefits, but the topic has since expanded to include various processes, functions, and business sectors **(Roblek *et al.*, 2016)**.

I4.0's radical change has significantly impacted the entire value chain and business models, contributing to the creation of new jobs and organisational dynamics and affecting total quality management (TQM) **(Ali and Waheed, 2024; Souza *et al.*, 2022)**. I4.0's application uses different tools and technologies, such as Cyber-Physical Systems (CPS), which analyse data to make processes faster, quicker, more flexible, and efficient. This reduces costs and environmental impacts and makes businesses more competitive and effective (Ghobakhloo, 2020). The tools and innovations I4.0 relies on are numerous and have been increasingly developed over the years, reaching full scale today**(Bigliardi *et al.*, 2020)**. Some authors have introduced the concept of "pillars" or "enabling technologies" of I4.0, identifying a group of tools that, when combined or individually, represent the operational arm of this revolution (Bortolini et al., 2018; Brunelli et al., 2017; Büchi et al., 2020; Forcina and Falcone, 2021; Rüßmann et al., 2015). According to these authors, the enabling technologies of I4.0 can be summarised in nine main pillars: 1) Industrial Internet of Things (IIoT); 2) Big Data; 3) Horizontal and vertical integration of systems; 4) Simulations; 5) Clouds; 6) Augmented Reality; 7) Autonomous Robots; 8) Additive Manufacturing and 9) Cyber Security (Bortolini et al., 2018; Brunelli et al., 2017; Büchi et al., 2020; Forcina and Falcone, 2021; Rüßmann et al., 2015). The role and functioning of enabling technologies are also explained by the critical factors of I4.0: integration and interoperability. Indeed, the enabling technologies must be understood from a system perspective and in synergy with each other. Each has a specific function that maximises its usefulness when applied in a broader context of interoperability and integration **(Sanchez *et al.*, 2020)**.

IIot is one of the most talked about and in-depth technologies of I4.0, stemming from the application of IoT to industry and manufacturing **(Boyes *et al.*, 2018)**. IIoT uses data that connects physical or cyber objects through wireless or computer networks, unifying and integrating different tools into a shared infrastructure **(Madakam *et al.*, 2015)**. Boyes et al. (2018) provide a broad overview of such technology with a definition that pulls together all the characteristics of the literature, considering IoT as a system comprising networked intelligent objects, Cyber-physical resources, associated generic information technologies, and optional cloud or edge computing platforms that enable real-time, intelligent and autonomous access, collection, analysis, communication and exchange of process, product and/or service information within the industrial environment in order to optimise the overall production value'.

Big data technologies are closely related to IoT; indeed, the merging of the two technologies is a key part of Industry 4.0. Data analysis makes numerous activities that improve production and activate smart manufacturing possible **(Hajjaji *et al.*, 2021)**. Big Data powers business processes and functions by providing details on customer orders, supplier deliveries, production, inventory, and logistics information **(Dilberoglu *et al.*, 2017)**.

Horizontal and vertical integration of systems are again connected to IoT and Big Data contributing to the creation of the Smart Factory **(Wang *et al.*, 2016)**. Horizontal integration ensures that machines, IoT devices, and programming processes work seamlessly together (Chen, 2017). Vertical integration, on the other hand, allows data to be used to make decisions about the company and its personnel by making the shop floor and other horizontally integrated systems, such as Enterprise Resource Planning, communicate **(Marques *et al.*, 2017)**.

Simulation serves to support planning and forecasting models to guide decision-making and assist in the design of complex production systems, as before in Smart Factories for example **(Alcácer and Cruz-Machado, 2019; de Paula Ferreira *et al.*, 2020)**. In both manufacturing and supply chain management, simulation enables the testing and validation of products, processes, and system designs, as well as the prediction of their performance, thereby reducing costs (Negahban and Smith, 2014).

Cloud complements the previous tools with computing, storage, and virtual communications resources, thus potentially unlimited, and it also allows interaction with the external context, with consumers, for example **(Aceto *et al.*, 2020)**. It is especially important to store data generated during the entire production process, considering that machines and sensors produce massive amounts of data and that these data are always connected. Furthermore, the cloud reduces investment in technological resources, allowing storage space and processing capacity to be contracted on demand. This provides flexibility, agility, adaptability, and reduces cost(Thames and Schaefer, 2016).

Augmented Reality also enable interaction with the end consumer and the possibility of an immersive experience with products and services**(Nayyar and Kumar, 2020; Rai *et al.*, 2021)**. The use and combination of enabling technologies are achieving high degrees of maturity, achieving goals not only strictly economic and productive but also creating benefits in environmental sustainability, inclusiveness, and the social sphere **(Tortorella *et al.*, 2023)**.

Another interesting tool is autonomous robots. Robotics has been entering production systems for years now, but with I4.0, robots become autonomous and can independently manage production processes, contributing efficiently and flexibly to improving production performance while also creating a safer environment (Bahrin et al., 2016; Rüßmann et al., 2015).

The evolution of robotics also passes through the enabling technology of additive manufacturing, which introduces 3D printers into manufacturing systems **(Prashar *et al.*, 2023)**. These tools enable the production of parts, components, and semi-finished or finished products using 3D printers, helping to reduce raw material costs and speed up production by reducing waste **(Parmar *et al.*, 2022)**.

All these new tools have resulted in the need for improved cybersecurity systems, leading to the introduction of Cyber Security, the set of technologies, processes, and protection measures designed to precisely reduce the risk of cyber-attacks **(Corallo *et al.*, 2020)**. Cybersecurity is not only limited to cybersecurity related to production processes but also involves the business sphere of the enterprise to ensure privacy and data security for end consumers as well **(Liu *et al.*, 2022)**.

In summary, the analysis of I4.0 enabling technologies and their usefulness in the context of business management, particularly manufacturing, allows us to understand how the ecosystem within the enterprise has drastically changed and evolved and how, in such a scenario, technology, people, consumers, and quality are closely interconnected **(Gorkhali, 2022; Souza *et al.*, 2022)**.

Methods

A systematic literature review approach (SLR) was utilised to investigate the research inquiries. SLR is crafted to "identify, evaluate, and interpret research relevant to a specific topic area, research question, or phenomenon of interest" **(Kitchenham *et al.*, 2007)**. Initially emerging in the field of medicine **(Saade *et al.*, 2020)**, SLR has been embraced in diverse disciplines including social sciences, engineering (Bastas and Liyanage, 2018; Sassanelli et al., 2019), economics, business (Colicchia and Strozzi, 2012) Merli et al., 2018), and environmental sciences**(Alshqaqeeq *et al.*, 2020; Silvestri *et al.*, 2021)**. SLR facilitates a thorough exploration of a specific subject through both qualitative and quantitative content analysis **(Hill *et al.*, 1995; Seuring and Müller, 2008; Silvestri *et al.*, 2021)**, assisting in addressing literature biases and presenting substantial evidence of a phenomenon across different contexts and empirical methodologies**(Adjei-Bamfo *et al.*, 2019a; Denyer and Tranfield, 2009; Durach *et al.*, 2017)**.

Following the recommendations outlined by Mayring (2004) and Denyer and Tranfield (2009), this review process was delineated into four phases: (1) material collection, (2) descriptive analysis, (3) category selection, and (4) material evaluation. In the context of this study, the C-I-M-O (context-intervention-mechanism-outcome) framework was employed (Briner and Denyer, 2012; Denyer and Tranfield, 2009), enabling the evaluation of the selected articles' relevance to the research questions using a specific set of criteria **(Xavier *et al.*, 2017)**.

Material collection

For research purposes, the electronic Scopus database was used. Scholars widely regard Scopus as one of the premier databases for conducting reliable bibliometric analyses **(Durán-Sánchez *et al.*, 2018)**. Scopus represents the largest scientific database, consisting of journals that have undergone rigorous quality criteria for indexing (Lim and Rasul, 2022). This distinguishes Scopus as a database capable of offering a high level of singularity and broad data coverage **(Salim *et al.*, 2019)**, making it one of the most comprehensive and authoritative scientific databases available **(Chadegani *et al.*, 2018)**.

The keywords, brainstormed and agreed upon by the authors, entered in the search strings in the criteria "Article title, abstract and keywords" are "Total quality management" OR "TQM" OR "Quality 4.0" AND "Industry 4.0" OR "I4.0". This analysis focused only on articles in peer-reviewed scientific journals in English **(Adjei-Bamfo *et al.*, 2019b; Alshqaqeeq *et al.*, 2020; Merli *et al.*, 2018; Seuring and Müller, 2008)**. The collection of articles ended on March 14, 2024, the article analysis and study process ended on March 15, 2024, and the article writing was completed on April 15, 2024.

The initial number of articles is 207. Applying the C-I-M-O framework, only articles from the following subject areas were selected: Business, Management and Accounting; engineering; Decision Sciences;

Computer Science; Materials Science; Social Sciences; economics, Econometrics and Finance; and engineering.

The aim of this research is, in fact, to analyse how the binomial TQM and I4.0 have been studied in management and social sciences. In particular, of the entire sample, only articles analysing this binomial and relating CSFs to I4.0 enabling technologies were extrapolated. The analysis of the abstracts reduced the sample to 111 articles, while the reading of the full paper reduced the final sample to 88 articles. Table 2 shows the article analysis and selection process.

Table 2 - Article selection process

Step	Number of Articles in Scopus
Step 1 - Keywords extraction	207
Step 2- Focus on specific subject areas	120
Step 3 - Analysis Abstract	111
Step 4 - Analysis of full paper	88

Source: our elaboration

Category selection

Based on Mayring (2004) model and considering the research question, two structural dimensions and related analytical categories were identified to evaluate the material. In particular, this approach was used to understand the main enabling technologies used for the implementation of CSFs. For this purpose, a deductive approach was adopted (Mayring 2004; Seuring and Muller 2008; Merli et al. 2020; Silvestri 2021), which made it possible to identify the most recurring CSFs as well as the enabling technologies and the existing relationships between CSFs and I4.0 enabling technologies.

For this purpose, the analytical categories of CSFs were based on the studies conducted by authors such as **(Dezi *et al.*, 2022; Hietschold *et al.*, 2014)** supplemented with more recent studies such as Sony et al. (2020), Sureshchandar, (2023) who analysed CSFs from Q4.0.

This study aims to identify the TQM CSFs that make the most use of I4.0 enabling technologies for their implementation. However, the literature review on Q4.0 CSFs revealed the lack of a universally accepted consensus among academics. For this reason, and to achieve the objective of this research, the authors reported on the TQM CSFs that summarise the most recurring Q4.0 CSFs (Tab.3).

The deductive approach was also used to identify enabling technologies. Their definition was based on the studies conducted by **(Bortolini *et al.*, 2018; Brunelli *et al.*, 2017; Büchi *et al.*, 2020; Forcina and Falcone, 2021; Martinelli *et al.*, 2021; Rüßmann *et al.*, 2015)**, according to which the enabling technologies of I4.0 can be summarised in nine main pillars: 1) Industrial Internet of Things (IoT); 2) Big Data; 3) Horizontal and vertical integration of systems; 4) Simulations; 5) Clouds; 6) Augmented Reality; 7) Autonomous Robots; 8) Additive Manufacturing and 9) Cyber Security. Table 3 summarises the Structural dimensions and related Analytical categories.

Table 3 - Approach, structural dimensions and analytical categories

Approach	**Structural dimensions**	**Analytical categories**
Deductive	CSFs of TQM	Continuous improvement Culture and Communication Customer focus HRM Information and analysis Leadership Process management Strategic planning Supplier patnership Training and learning
Deductive	Enabling technologies of I4.0	Additive manufacturing Augmented reality Autonomous robots Big Data & Analytics Cloud Computing Cybersecurity Horizontal/Vertical integration Internet of Things Simulation

Source: Authors' elaboration

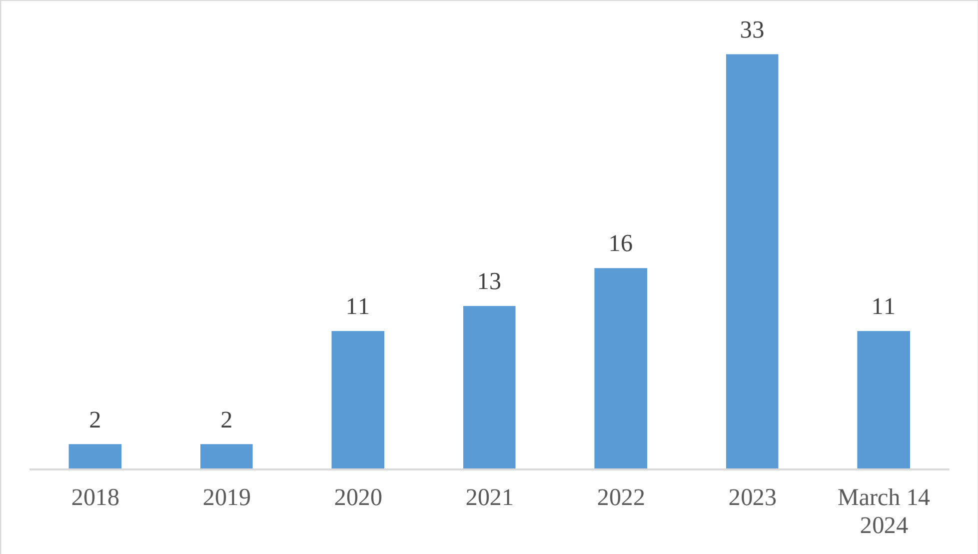
A general description of the sample was performed before analysing the relationship between CSFs and enabling technologies.

Results and Discussion

The descriptive analysis of the sample classifies articles according to the following criteria: (1) date of publication, (2) journal and (3) geographical origin of the first author.

As the topic is new and still evolving, the first two articles analysing the relationship between CSFs and enabling technologies are from 2018 and were published in the *International Journal of Production Research* and *Total Quality Management & Business Excellence.* Also, in 2019, the number of articles published on this topic is two, while from 2020 to 2023, there is a steady growth in publications, with a peak in 2023 with 33 articles. In 2024, 11 articles are published until March 14, 2024.

Figure 1- Temporal distribution of articles



Source: our elaborate

The journal with the most publications on the topic is "The TQM Journal" (42% of the sample), followed by "Total Quality Management & Business Excellence" (14% of the sample), "Sustainability" (6% of the sample), and "International Journal of Quality & Reliability Management" (6% of the sample) (Table 4). From the analysis, it emerges that it is mainly the journals that study the topics of total quality management that have delved most deeply into the topic of the relationship between TQM and I4.0, with the exception of the journal Sustainability, which is mainly oriented towards proposing studies relating to sustainability and sustainable development in general.

Table 4 - Journal

Journals	***f***	**%**
The TQM Journal	37	42%
Total Quality Management & Business Excellence	12	14%
International Journal Of Quality & Reliability Management	5	6%
Sustainability	5	6%
Quality Innovation Prosperity	4	5%
International Journal Of Computer Integrated Manufacturing	3	3%
International Journal Of Production Research	2	2%
Proceedings On Engineering Sciences	2	2%
Quality Engineering	2	2%
Advanced Engineering Informatics	1	1%
Advances In Production Engineering And Management	1	1%
American Journal Of Health Behavior	1	1%
Central European Management Journal	1	1%
Facta Universitatis, Series: Mechanical Engineering	1	1%
Global Journal Of Flexible Systems Management	1	1%
International Journal Of Lean Six Sigma	1	1%
International Journal Of Online And Biomedical Engineering	1	1%
International Journal Of Quality And Service Sciences	1	1%
Materials Today: Proceedings	1	1%

Operations Research Forum	1	1%
Production And Manufacturing Research	1	1%
Production Planning & Control	1	1%
Quality And Reliability Engineering International	1	1%
Sensors	1	1%
Technological Forecasting And Social Change	1	1%
Total	88	100%

Source: our elaboration

India has the largest number of publications (23% of the sample), followed by Brazil (7% of the sample), Italy (7% of the sample), and Portugal (6% of the sample) (Table 5).

Table 5 - Country of 1er Authors

Country	***f***	**%**
India	20	23%
Brazil	6	7%
Italy	6	7%
Portugal	5	6%
Arab Emirates	4	5%
Serbia	3	3%
Turkey	3	3%
Australia	2	2%
Czech Republic	2	2%
England	2	2%
Israel	2	2%
Malaysia	2	2%
Poland	2	2%
Slovakia	2	2%
South Africa	2	2%
Tanzania	2	2%
United Kindgom	2	2%
Argentina	1	1%
Bangladesh	1	1%
Egypt	1	1%
Finland	1	1%
Germany	1	1%
Greece	1	1%
Indonesia	1	1%
Iran	1	1%
Ireland	1	1%
Jordan	1	1%
Mexico	1	1%
Morocco	1	1%
Namibia	1	1%
Pakistan	1	1%
Russia	1	1%

Scotland	1	1%
Slovenia	1	1%
South Korea	1	1%
Sweden	1	1%
Thailand	1	1%
Vietnam	1	1%
Total	88	100%

Source: our elaboration

Category analysis: CSFs of TQM

The first research question this paper seeks to answer is:

RQ1 What are the main CSFs of TQM that recur most in I4.0?

Data analysis shows that the top three most studied CSFs about I4.0 enabling technologies are 'Process management' (24% of occurrences), 'Information and analysis' (22% of occurrences) and 'Continuous improvement' (19% of occurrences) (Table 6).

Table 6 - Most recurrent CSFs

CSFs	***f***	%
Process management	77	24%
Information and analysis	72	22%
Continuous improvement	62	19%
Customer focus	32	10%
Strategic Planning	20	6%
HRM	18	6%
Culture and Communication	18	6%
Supplier patnership	17	5%
Leadership	5	2%
Training and learning	2	1%
Total recurrences	323	100%

Source: our elaboration

CSF of TQM known as 'process management' focuses on several topics, including product and service design, production processes, process control, statistical quality control, flexible manufacturing, advanced production systems, use of Just-In-Time (JIT) principles, inventory reduction, use of technology, process quality and systems-based approach (Karuppusami and Gandhinathan, 2006; Sila and Ebrahimpour, 2005).

The importance of 'process management' as a CSF in TQM is based on the premise that a company is a system of interconnected processes and how these processes interact with each other determines the organisation's overall performance (Samson and Terziovski, 1999). Identifying key processes and ensuring continuous improvement is crucial to maintaining product and service quality (Hietschold *et al.*, 2014). Furthermore, in the context of TQM, the control of processes is paramount, as the goal is not only to ensure that these processes perform as expected but also to prevent potential problems from arising in the future. The focus, therefore, is on controlling the behaviour of the processes that generate the products rather than solely on controlling product conformity (Forza and Filippini, 1998). In a Q4.0 context, the company's ability to adapt to rapid market changes is one of the key factors for industry competitiveness (Benešová *et al.*, 2019). Integrating I4.0 concepts into existing process and product improvement methodologies requires state-of-the-art infrastructure and advanced skills (Longo *et al.*, 2017). I4.0 processes will be different from existing processes, not only in terms of using new technologies such as digitisation or augmented reality but also in terms of management and support processes (Benešová et al., 2019). According to Frank et al. (2019) the new technologies will transform production into a fully integrated, automated and optimised production flow, in which production processes will be linked from production planning to supply and customer processes.

Furthermore, 'process management' is closely related to the second most recurring CSF, 'information and analysis'. The timely analysis of data (as, for example, the use of big data) in production processes is crucial for resource planning, maintenance and flexible production management (Benešová et al., 2019). Data is the basis of modern factories, which are becoming smarter thanks to big data analytics, machine learning and cloud computing (Saldivar *et al.*, 2015). The term I4.0 refers to a new model of organising and controlling the value chain based on the product lifecycle supported by information technologies(Bazan and Estevez, 2022). For this reason, I4.0, which is characterised by the integration of technologies such as the Internet of Things (IoT), big data analytics and artificial intelligence, relies heavily on information and analytics to promote innovation and process/product efficiency(Frank *et al.*, 2019; Tortorella and Fettermann, 2018). Furthermore, the synergy between 'information and analysis' and I4.0 not only increases operational efficiency, but also opens up new opportunities for companies to adapt to market demands, improve customer satisfaction and promote sustainable business performance (Kovács and Kot, 2016).

Finally, 'continuous improvement' is the third most recurring CSF. The definitions most widely referred to explain 'continuous improvement' are provided by Bessant et al. (1994), Hyland et al. (2007) and Farrington et al. (2018), who defined it as "a companywide process of focused and continuous incremental innovation" (Vinodh *et al.*, 2021).

Continuous improvement programmes use information on production processes to achieve their objectives. For programme development to be efficient, information must be available throughout the company and the supply chain. New data management technologies have the potential to help programmes. Intelligent production systems can autonomously diagnose performance and propose continuous improvement projects towards success (Alavian and Tavakoli-Anbaran, 2020). I4.0 enabling technologies can, therefore, help improve quality parameters such as product and service quality (Foidl and Felderer, 2016).

Finally, 'continuous improvement' is a key component in process management, particularly in the context of lean manufacturing (Kolberg *et al.*, 2017; Peças *et al.*, 2021), which, in this context, is generally defined as a culture of sustained improvement aimed at eliminating waste in all systems and processes of an organization (Vinodh et al., 2021; Bhuiyan and Baghel, 2005).

The three most recurring TQM CSFs are therefore closely interrelated, and their synergy seems to create a virtuous circle for the entire enterprise system.

4.2 Category analysis: enabling technologies of I4.0

The second research question to be answered is:

RQ2 What are the main enabling technologies applied in connection with TQM?

The top three most recurring enabling technologies are Big Data and Analytics (25% of co-occurrences), the Internet of Things (22% of co-occurrences), and Autonomous robots (10% of co-occurrences).

Table 7 - Most co-occurrence enabling technologies of I4.0

Enabling technologies of I4.0	***f***	**%**
Big Data & Analytics	61	25%
Internet of Things (IoT)	52	22%
Autonomous robots	23	10%
Augmented reality	21	9%
Simulation	19	8%
Cloud Computing	18	7%
Cybersecurity	17	7%
Additive manufacturing	15	6%
Horizontal/Vertical integration	15	6%
Total Co-occurrence	241	100%

In the new business environment, the ability to transform information into usable knowledge and value plays a key role in the digital era, where big data and connectivity are a significant focus for companies seeking to improve their competitiveness (Watson, 2014). According to (Carvalho-Silva *et al.*, 2019a) big data is poised to become a ubiquitous presence within businesses, making it necessary for strategic decision-making to be supported by robust information and in-depth analysis.

The smart factory is an important feature of I4.0, and for it to be implemented, it should combine smart objects with big data analytics (Sony and Naik, 2020). Smart objects can dynamically reconfigure themselves to achieve high flexibility, while big data analytics can provide global feedback and coordination to achieve high efficiency. Therefore, the smart factory is mainly based on big data providing constant feedback and coordination to the system (Wang *et al.*, 2016).

IoT technology is closely related to big data, the second most recurring I4.0-enabling technology. The adoption of big data can have a great influence on data quality (Kwon *et al.*, 2014); thus, increased timeliness and huge volumes of data provided by the IoT can improve the performance of organisations, enhancing operational planning and the ability to react quickly to previously unforeseen events (Brous *et al.*, 2020). The IoT allows the physical world to be monitored and controlled remotely(Ramos *et al.*, 2008), providing a wide range of benefits for businesses, while the resulting big data offers organisations the potential to gain valuable insights(Dwivedi *et al.*, 2017; Hashem *et al.*, 2015).

Finally, the third most recurring enabling technology is Autonomous robots. Robotics stands as a technological foundation serving the IoT to develop an intelligent industry where products can find their way through production and establish alternatives in case of any disturbances (Goel and Gupta, 2020). The advancement of robotic technology has led to increasingly autonomous, flexible and cooperative robots (Vaidya *et al.*, 2018). It is foreseeable that eventually, robots will be able to interact with each other and safely operate alongside humans, thus facilitating mutual learning processes (Rüßmann et al., 2015). Autonomous robots are particularly employed in tasks requiring precision within production methodologies and in environments where human presence is limited. Such robots demonstrate skills in completing tasks within set timeframes, prioritising safety, flexibility, adaptability and collaboration (Bahrin *et al.*, 2016).**Conclusions**

This research aimed to understand the main enabling technologies used for the implementation of TQM CSFs. After an overview of the main studies analysing Q4.0 CSFs in the literature, the authors provided a list of TQM CSFs capable of synthesising the most recurring Q4.0 CSFs. The research showed that the most recurring TQM CSFs are 'Process management', 'Information and Analysis' and 'Continuous improvement', about which the most used enabling technologies are 'Big Data & Analytics', 'Cybersecurity' ', IoT'. Among the main findings is the perfect synergy between TQM and I4.0. Enabling technologies enable companies to increase productivity, improve customer relations, and enhance the effectiveness of human resource management (Bai *et al.*, 2019) through better implementation of CSFs. In the face of a new era, Quality emerges as a key factor in the I4.0 transition (Aldag and Eker, 2018; Küpper *et al.*, 2019; Radziwill, 2018; Zonnenshain and Kenett, 2020), as it is capable of integrating all the enabling technologies of I4.0 within it, in a complementary manner. Quality management thus constitutes a solid foundation for any organisation and, in the context of a transition, can function as a facilitator of change (Carvalho-Silva *et al.*, 2019b).

From a scientific point of view, this research aimed to provide an overview of the main studies that have analysed the relationship between TQM and I4.0. From a managerial point of view, the aim is to provide a tool for companies that want to understand which enabling technologies are best for implementing TQM CSFs and achieving operational excellence.

However, the article has some limitations. Although it represents the first systematic review in this field, the manual search method adopted may exclude or overlook other articles relevant to the analysis, as well as using only one database (Scopus) for the search. Therefore, the systematic review aims to catalyse attention to this topic and stimulate further studies to deepen understanding of the relationship between TQM CSFs and I4.0 enabling technologies. For this reason, the next steps of the research include the use of other databases such as WoS to expand the sample of articles, outline a framework that can integrate TQM CSFs with I4.0 enabling technologies and highlight in which contexts enabling technologies are applied for the implementation of key CSFs.

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Exploration and exploitation strategies influencing business performance. The Greek case

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Abstract

The pursuit of sustainable competitive advantage is a fundamental goal for companies operating in dynamic environments. Thus, companies should aim at both exploiting existing resources and exploring new resources that will differentiate them from competition. The objective of this study is to examine the relationship between the exploration and exploitation strategies and their influence on business performance. A questionnaire was developed including items with regard to the exploration and exploitation strategies and business performance. Based on this questionnaire, an empirical research study was conducted among 370 companies in Greece. Hierarchical regression was performed to test the research hypotheses. The findings indicate that the exploration and exploitation strategies are interrelated, and both enhance business performance. This study reveals the significance of striking a delicate balance between the exploration and exploitation strategies of companies to improve their performance and adapt to the changing market conditions while efficiently leveraging existing assets. The main limitation of this study is its exclusive reliance on data from Greek companies. Incorporating data from companies across various countries could offer a broader understanding of the subject under scrutiny. This the first study that adds to the upper echelon theory, identifying whether and how the exploration and exploitation strategies influence business performance of companies operating in Greece.

Keywords: Ambidexterity, Exploration, Exploitation, Business Performance

Introduction

A key objective of the strategic management research is to comprehend why certain firms achieve superior performance compared to others. In the continuously competitive environment, which is rapidly changing and characterized by intense competition, significant technological advancements and ongoing shifts in consumer preferences, organizations must not only ensure their current viability and competitive nature but also innovate and seek new ways to differentiate themselves. This persistent struggle has become a major concern for both business professionals and academics (Sayed and Dayan, 2024). Previous studies in management literature have demonstrated that companies across different industries must leverage existing knowledge and technologies to generate immediate profits, while also seeking new knowledge and technologies to adapt to changing conditions and capitalize on future demand (O'Reilly and Tushman, 2013; Farzaneh et al., 2022). The fundamental differences between exploration and exploitation, combined with their competition for limited resources and managerial focus, make the tension between these two activities challenging to manage (Lindskog et al., 2021). The organizational ability to manage this tension and to achieve both exploration and exploitation simultaneously is termed “organizational ambidexterity” (OA) (Taródy, 2016).

It is crucial to manage both exploration and exploitation simultaneously, as failing to do so can negatively impact overall performance (Alpkan et al., 2012). In the short term, exploitation and exploration activities support each other and are essential for an organization’s long-term survival. Therefore, we define ambidexterity as the balance between exploration and exploitation if it is to achieve sustainably superior performance (Fourne et al., 2019). A firm that fails to achieve this balance risks falling into a downward spiral of mediocrity. Nevertheless, several critical questions regarding ambidexterity remain unanswered. There are still gaps in the research on exploration and exploitation (Chakma et al., 2021). One of these gaps concerns the impact of exploration and exploitation on business performance (Jurksiene and Pundziene, 2016).

Given the significance of ambidexterity for modern multinational corporations, this research seeks to assess the impact of ambidexterity on business performance, especially within emerging economies. Previous studies examining the relationship between an ambidextrous strategy (encompassing both exploration and exploitation) and business performance have largely focused on traditional financial indicators and related metrics (such as revenue, sales growth, or return on assets) (Sarkees et al., 2010). Therefore, further research is necessary to explore the simultaneous influence of exploration and exploitation on business performance using various performance measures (Katou et al., 2023). The primary goal of this study is to enhance the management literature by analysing whether OA contributes to improved business performance. Little is known about the performance implications of OA (Hsu and Ziedonis, 2013), but our current empirical examination intends to shed some light on this research topic. Based on the ambidexterity perspective on business (Prange and Verdier, 2011), we expect a positive relationship of OA and business performance.

The rest of this article is organized as follows: Section 2 outlines the theoretical background and hypotheses. Section 3 details the methodology employed in this study. In Section 4, based on the theoretical framework, a research model is developed and tested through a large-scale empirical study. Section 5 presents a concluding discussion of the results. Additionally, Section 6 discusses the conclusions derived from the study, acknowledges its limitations, and offers suggestions for future research.

Theoretical Background

Organizational Ambidexterity (OA)

Organizational ambidexterity is an organization's ability to be aligned and efficient in managing current business demands while simultaneously being adaptive to changes in the environment (Gupta et al., 2006). It refers to a firm's capacity to develop and utilize new resources and skills (exploration of resources) while making efficient use of the resources already available (exploitation of resources) (Hafkesbrink and Schroll, 2014; Shamim et al., 2020). In order to survive and cope with the demands of the modern environment, firms must not only maintain their existing capabilities but also adapt to rapidly changing conditions. They need to compete in current markets by leveraging their skills to generate short-term profits while simultaneously seeking new opportunities to adapt to new markets for long-term gains. Exploitation is essential for competing in mature markets and technologies, whereas exploration is crucial for adapting to new markets and technologies.

Some authors argue that engaging in both exploration and exploitation concurrently not only is possible but also enhances organizational performance (Jansen et al., 2009). To effectively foster an ambidextrous approach (Fourne et al., 2019), companies must strike a nuanced equilibrium between their exploration and exploitation endeavours. A core principle for ambidextrous organizations is to uphold a balance between exploitation and exploration, acknowledging their interdependence and striving for harmony between the two. March (1991) highlighted that both exploitation and exploration are crucial for organizations, yet they vie for finite resources. However, they must be managed concurrently, as neglecting either can detrimentally impact overall performance.

Although exploration and exploitation may vie for resources in the short term, they synergistically bolster each other in ensuring the long-term viability of the organization. Placing excessive emphasis on exploitative capabilities can lead to monotony and impede the organization's capacity to innovate. Conversely, concentrating solely on exploratory capabilities may hinder companies from fully leveraging their existing resources and capabilities (Carmeli and Halevi, 2009). Adaptive firms acknowledge the necessity of achieving a balance between exploitation and exploration, sustaining a blend of established processes while venturing into new avenues, such as adopting novel products, entering fresh markets, and embracing emerging technology. The decision between exploitation and exploration profoundly shapes a firm's current and future path (Levinthal and March, 1993; March, 1991). Attaining this equilibrium is pivotal for maintaining enduring success and adaptability in a swiftly evolving business landscape.

From the above mentioned we can reach the following research hypothesis:

H1. Exploration and exploitation strategies are interrelated.

Business Performance (BP)

A key concern for many managers and business owners is the performance of their businesses in the marketplace (Gyedu et al., 2020). Managers and business owners consider business performance improvement to be a critical management strategy. A common metric for evaluating a company's success in meeting its objectives is business performance. This performance reflects the outcomes of business activities and serves as a benchmark for assessing quality work through specific evaluation techniques (Cho and Lee, 2018). Performance can also be understood as the accomplishments attained by the organization within a defined timeframe.

According to Neely et al. (2000), performance measures in any organization fall into two basic categories: those related to results (financial performance) and those that focus on the factors influencing these results. Several researchers have suggested various methods and tools to assess business performance, utilizing sub-dimensions such as financial performance and non-financial performance (Maestrini et al., 2017). Financial performance holds significant importance from a financial viewpoint, as it can be evaluated through metrics such as sales growth, sales transactions, achieved profits, return on investment, market share, return on assets, and overall profitability (Giantari et al., 2022). According to Agyabeng-Mensah and Tang (2021), financial performance can be assessed through various indicators including sales volume, profit level, profit growth, ROI (Return on Investment), ROS (Return on Sales), market share, and ROI growth. Conversely, non-financial performance is a type of performance measurement that is not based on monetary values. Non-financial measures can include various methods for assessing long-term objectives. Examples of non-financial performance measurement include market share, quality, customer satisfaction, innovation performance (encompassing product performance, digital performance, and service performance), employee performance (including employee commitment, satisfaction, and loyalty), operational performance, marketing performance (such as customer loyalty), and brand equity (Ayimey et al., 2020; Kyazze et al., 2020).

Exploration and Exploitation strategies - Business performance

The literature review on OA suggests that companies that are dedicated to specific goals maintain the agility to quickly adapt to changing environmental conditions and are likely to realize superior performance outcomes. Previous studies indicate that OA enhances business performance when companies successfully manage to balance exploration and exploitation concurrently (Voss and Voss, 2013; Cao et al., 2009; Lubatkin et al., 2006). As ambidexterity involves integrating high levels of both exploration and exploitation, it enables organizations to remain competitive over both short and long-term periods (Rosing and Zacher, 2017). Exploration and exploitation are mutually interactive in corporate activities, and there is evidence of a strong relationship between exploitation and business performance (Junni et al., 2013). Consequently, it can be assumed that the combination of exploration and exploitation positively impacts business performance. Numerous studies demonstrate that companies proficient in both exploitative and explorative skills (OA) tend to outperform their competitors and achieve greater competitive advantage **(**Hughes, 2018). Caspin-Wagner et al. (2012) identified a positive relationship between ambidextrous behaviour and both short-term business profitability and long-term performance, as measured by stock market value. In uncertain environments, OA is positively associated with enhanced innovation, increased economic efficiency, and greater survival rates. This adaptability allows organizations to effectively navigate the complexities and the rapid changes of such environments. Maintaining a balance between explorative and exploitative activities helps firms minimize costs and optimize the allocation and utilization of scarce resources, thereby enhancing organizational efficiency (Herzallah et al., 2017).

In conclusion, companies that adopt OA operate under the premise that balancing exploration and exploitation leads to superior performance outcomes compared to those that concentrate solely on one approach. Focusing predominantly on exploration can obstruct the development and enhancement of essential capabilities, risking outcomes fraught with uncertainty and danger (Bui et al., 2021). On the other hand, an overemphasis on exploitation may reduce a company's ability to adapt to environmental shifts, potentially trapping it in stagnant competencies (Clauss et al., 2021) and limiting its long-term growth opportunities (Mathias, 2014; Chakma and Dhir, 2023). Therefore, the prevailing view among researchers is that firms should achieve a balance between engaging in exploratory activities, which provide opportunities for growth, and exploitative activities, which strengthen core competencies and enable sustainable profitability. Thus, we can reach the following research hypotheses:

H2. Exploration strategies are positively related to business performance

H3. Exploitation strategies are positively related to business performance

OA is depicted as consisting of exploration and exploitation strategies. These strategies interact and may have both direct and indirect effects on business performance. The relationship between OA and business performance will be investigated to assess how balancing exploration and exploitation promotes strategic foresight within organizations. In considering the potential influence of firm size on ambidexterity and business performance, we factored in the number of full-time employees. This variable helps account for the resources available within a firm. Additionally, the years of experience of the respondents, measured by their tenure in the firm, were included in the analysis. It is hypothesized that greater cumulative experience can improve a manager's ability to lead or manage ambidextrous teams effectively. To account for alternative explanations, the educational level of respondents was also considered, following the methodology suggested by Pantouvakis and Vlachos (2020).

Research methodology

Sample and questionnaire development

The proposed model and hypotheses were evaluated using a questionnaire survey method. The questionnaire was crafted based on a thorough literature review and interviews with industry experts. Prior to administering the survey, a pretest was conducted with 15 individuals from Greek firms, followed by personal interviews with managers. Minor adjustments were made to the questionnaire based on specific feedback. A two-page survey instrument was created, consisting of 15 questions with regard to OA and BP.

The empirical analysis data source was the ICAP database, the largest business information and consulting firm in Greece. The ICAP database (www.findbiz.gr, accessed on 22 June 2022) initially provided a list of all companies operating within each prefecture. A web-based questionnaire was developed as the data collection tool and sent to 1,100 randomly selected Greek manufacturing and service firms. The questionnaires were distributed to practitioners via email, each accompanied by a cover letter explaining the survey's purpose and assuring respondents of privacy and confidentiality. Respondents were asked to answer the survey questions based on their experiences. This approach enabled the collection of firsthand and current information regarding the specific project-related challenges and quality issues faced by the respondents.

A seven-point Likert scale was used to measure all items in the questionnaire. Respondents indicated their level of agreement with each item, ranging from '1' (strongly disagree) to '7' (strongly agree). The survey period lasted six months, from March 2022 to August 2022. Responses were received in two waves: the first with 207 and the second with 163 questionnaires, totalling 370 responses. The sample characteristics are presented in Table 1.

The questionnaire was designed to be straightforward and relevant, featuring a clear scale and appropriately sequenced questions. It was divided into three sections: the first section gathered demographic information about the respondents; the second section included an index of nine variables assessing the OA divided into exploration and exploitation; and the third section contained six variables measuring the business performance in the Greek manufacturing and service firms (see Table 2).

Table 1. Sample characteristics

Demographic characteristics of sample companies	**Number**	**Percent**
Firm size (number of employees)		
11- 49	246	66
50 – 250	81	22
251 – 500	43	12
Agricultural Sector		
Manufacturing	260	70
Services	110	30
Demographic characteristics of respondents		
Gender		
Male	231	62
Female	139	38
Education		
High school	32	9
University	178	48
Msc/PhD	160	43
Job Position		
Senior executive	147	40
Manager	223	60
Experience (years)		
<5	110	30
5-10	86	23
>10	174	47

Table 2. Items of the questionnaire and factor loadings

Code	Latent constructs and respective items	Factor loading
	Exploration	
V01	Think "outside the box"	0.880
V02	Explore new technologies	0.866
V03	Products or services that are new to the firm	0.746
V04	Ventures into new market segments	0.751
	Exploitation	
V05	Improve quality and lower cost	0.753
V06	Improve the reliability of products and services	0.885
V07	Increase the levels of efficiency in operations	0.728
V08	Constantly survey existing customers' satisfaction	0.693
V09	Fine-tune what the firm offers to keep its current customers satisfied	0.790
	Business Performance	
V10	Company's profitability	0.696
V11	Company's financial results	0.723
V12	Company's net profit margin	0.783
V13	Company's sales growth during the last three years	0.813
V14	Company's market growth during the last three years	0.655
V15	Company's cash flow	0.674

Analyses

The preliminary data was analyzed using the SPSS version 24.0. The Exploratory Factor Analysis was applied to condense the initial set of the instrument variables into a more manageable set of scales and to identify whether the measured variables are loaded adequately to specific latent constructs. The reliability of the latent constructs was examined through calculating the Cronbach's alpha coefficient for each construct. The average score of each latent construct was calculated to gauge the perceived level of implementation by the respondents. Additionally, a correlation matrix was created to explore the relationships among the latent constructs of the present study. Finally, the hierarchical regression was applied between the two ambidextrous dimensions and business performance.

Results

The Exploratory Factor Analysis revealed three latent constructs in our model: exploration, exploitation, and business performance (see Table 2). Table 3 presents the descriptive statistics (mean values and standard deviations), the correlation between the latent constructs as well as their Cronbach's alpha coefficients. For each latent construct, the Cronbach's alpha value is above the acceptable threshold of 0.7 (Hair et al., 2006), indicating that the scales are internally consistent. According to Table 3, the correlation coefficients (r) range between 0.5 and 0.65 at $p < 0.01$, indicating the interdependence of all the latent constructs; therefore, collinearity and multicollinearity are not issues in this research (Hair et al., 2006). So, there are significant and positive correlations among the latent constructs. In other words, there is a strong correlation between exploration and exploitation strategies (H1 acceptance).

Table 3. Descriptive statistics and reliability analysis

Variables	1	2	3
Exploration	-		
Exploitation	0.647	-	
Business Performance	0.512	0.617	-
Mean	5.18	5.76	5.80
SD	1.14	0.86	0.81
Cronbach's alpha	0.885	0.869	0.881
Note(s): Remarks: S.D. 5 standard deviation; correlation is significant at the 0.01 level (two-tailed)			

Moreover, the hierarchical regression was applied between the two ambidextrous dimensions (exploration and exploitation) and business performance. Table 4 presents the summary of the two OA dimensions' effects on business performance. In all regressions, control variables were considered. The control variables were the experience level, the number of employees and employees' educational level. It was considered necessary to include these control variables in the regression equations since these variables may affect business performance directly. This analysis was also performed separately for both the service sector and the manufacturing sector. The results showed that all the correlations from control variables showed very small effects.

The 'employees' experience' found to lack a significant effect on the business performance, within any group of respondents (total sample, manufacturing and service sector). Concerning the construct of the 'number of employees' it was found that there is not a significant relationship with the business performance, within any group of respondents (total sample, manufacturing and service sector). As far as the educational level of the respondents is concerned, it also demonstrated a non-significant influence on the business performance, within any group of respondents (total sample, manufacturing and service sector). As regards the two dimensions of OA, meaning the latent constructs of exploration and exploitation, this study emphasizes that they are the sole factors exerting a significant influence on business performance across all groups of respondents. The standardized regression coefficients for exploration are 0.138, 0.131 and 0.141, whereas the standardized regression coefficients for exploitation are 0.468, 0.461 and 0.459 respectively, at a significant level of $p < 0.001$.

Table 4. Summary of motives and control variables effects on business performance

Variables	Total respondents (n=370)	Service sector (n=197)	Manufacturing sector (n=173)
Control variables			
Experience	-0.002 (ns)	-0.030 (ns)	0.017 (ns)
Employees' number	0.035 (ns)	0.025 (ns)	0.058 (ns)
Educational level	-0.030 (ns)	-0.146 (ns)	0.062 (ns)
Ambidexterity			
Exploration	0.138***	0.131***	0.141***
Exploitation	0.468***	0.461***	0.459***
F Value	49.773***	47.858***	32.452***
Adjusted R^2	0.400	0.374	0.437
ΔR^2	0.403***	0.390***	0.414***

Note: Depended variable: Business Performance;
Significance at: **p<0.01, ***p<0.001,
ns: non statistically significant

In sum, the statistical analysis results corroborate all the hypotheses. Specifically, the relationship between exploration and business performance is both positive and significant, thus, the H2 hypothesis is supported (H2: b = 0.138, p < 0.001). Similarly, H3 is supported, as exploitation has a positive and significant effect on business performance (H3: b = 0.468, p < 0.001).

Discussion and Conclusions

The present research highlights the relatively underexplored areas of OA (exploration and exploitation) and its impact on business performance in Greek firms. By presenting an extended model specifically designed for the Greek manufacturing and service industries, the study significantly contributes to the existing literature on firms' strategic orientations and ambidexterity theory.

Valuable insights can be gained from the demographic characteristics of the research participants. For example, 91% of the respondents had completed university education, with 43% holding postgraduate or doctoral degrees. This indicates that the participants are well-educated and capable of understanding the questions. Additionally, as shown in Table 1, 66% of the businesses that responded to the questionnaire are small and medium-sized enterprises (SMEs) with fewer than 49 employees. The research results show that the Greek organizations participating in the study conform to the European Commission's (2006) definitions of small and medium-sized enterprises (SMEs). Most Greek organizations are classified as small enterprises (11-50 employees), making up 66% of the total sample. Additionally, 22% of the sample consists of medium-sized enterprises (51-250 employees). The percentage of non-SMEs, including those with 251-500 employees and those with more than 500 employees, is 8% and 4%, respectively. It's important to note that data from the European Union indicates that 90% of businesses in the EU are categorized as SMEs. Most of the sample SMEs (70%) belong to the manufacturing sector. The theory and findings of this study suggest that SMEs are likely to adopt ambidextrous strategies, especially when facing challenging conditions. Specifically, SMEs demonstrate high levels of explorative behaviour, although this does not extend to emerging exploitation strategies.

In this study, key research questions were investigated based on a combination of theoretical assumptions and empirical evidence with regard to the relationship between exploration and exploitation, and the impact of exploration and exploitation on business performance. Due to previous research yielding inconclusive results about the connections between these variables, a new model was developed to further examine these relationships. While earlier studies have suggested that exploitation and exploration are sequential, the present study findings show that exploration and exploitation are strongly interrelated (supporting H1) and both enhance business performance (supporting H2-H3). From the analysis it is apparent that managers should focus on continuous, sequential enhancements to drive business performance. So, the findings indicate that superior business performance is achieved through practicing OA, which involves a blend of both explorative and exploitative activities. Balancing exploration and exploitation is challenging and requires significant flexibility to respond promptly and effectively to environmental changes. Moreover, the relationship between ambidexterity and business performance is complex. Although evidence suggests that ambidextrous firms tend to perform better, this relationship may be influenced by factors such as profitability, financial results, and cash flow. Additionally, achieving ambidexterity might not always result in immediate business success, requiring companies to be patient and persistent in their efforts.

This study makes theoretical contributions in two significant ways. First, it empirically connects research on the outcomes of OA, addressing the need for additional research on its impact on business performance. It provides the first empirical evidence of how the simultaneous implementation of exploration and exploitation can facilitate ambidexterity in two crucial business domains. Second, the study finds that OA (exploration and exploitation) positively impacts business performance, despite numerous empirical studies over the past two decades producing conflicting results regarding ambidexterity's effects on business performance. This study emphasizes the potential for integrating exploration and exploitation to mutually reinforce each other. It also demonstrates that managers should promote the right balance between exploration and exploitation, which requires careful consideration of the available resources and the levels of uncertainty and risk involved.

In addition to its theoretical contributions, this study provides significant managerial implications. First, organizations can gain valuable insights for executives aiming to improve their OA and performance through strategic decision-making and resource allocation. A key implication for managers is the necessity for allocating resources to achieve a harmonious balance between exploration and exploitation, underscoring the importance of pursuing both equally. Managers should recognize that exploration and exploitation are not competing issues but complementary ones that reinforce each other. It is crucial to consider both aspects in their decision-making processes to achieve a balanced and effective approach. Second, concurrently pursuing exploitation and exploration is a major driver of positive performance effects. The insights from our study can help managers adopt ambidexterity at various organizational levels, promoting a more structured approach to improve business performance. In other words, the present study can guide managers on effectively orchestrating ambidexterity by finding an optimal balance between exploration and exploitation, which results in improving business performance.

Limitations of the study and future research

Despite the efforts made during the research design and primary data analysis to enhance the reliability and validity of the results, this research is not without limitations. One limitation is that private manufacturing and service companies operating in Greece were included in the study. This means that the proposed model was not validated including companies from several sectors which operate all over the world. This limitation should be seriously considered when interpreting the results. Another limitation was the cost of conducting the research, which necessitated communication with companies primarily through email. The prohibitive cost of visiting companies across all regions of Greece excluded the possibility of direct contact with business representatives at their physical locations. Including organizations from all regions was essential for the research, but direct contact would have allowed for clearer, less biased, and more abundant information. Specific on-site observations could also have taken place, potentially providing additional evidence to support the responses received.

The business and economic performance of the companies was measured using specific qualitative variables. It is possible that other measurable variables could have influenced the relationships among the unobserved latent constructs and the degree of their co-variation. These limitations highlight the need for further research. It is recommended to conduct a similar study, but with adequate resources to enable the collection of primary data from a sufficient number of companies operating not only in Greece but in many other countries. This can be achieved through on-site visits and direct contact with business executives. Such an approach would allow for gathering more representative primary data from each company, not only from a single respondent such as the company's manager, but also from multiple administrative personnel within the organization.

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