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Sustainable Food Supply Chains in Maritime Ports: A Review Across Management, Economic, and Social Dimensions

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Abstract

The growing pressures on the global food supply chain highlight the challenges faced by maritime ports, which are responsible for 80% of global trade, emphasising the need for sustainable operations across management, economic, and social dimensions. This article analyses the research trends in this area within the Scopus database, which was researched on July 11, 2024. The PRISMA method (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) was applied. Based on the results of the systematic literature review, four main subjects were the focus of the researchers: i) smart port requirements and sustainable performance; ii) the technological innovations driving sustainable supply chain management; iii) circular economy and digital supply chain sustainability; iv) frameworks and models for integrating sustainable digital supply chain. Additionally it opens possibility for future research could cover the gaps identified in this article, such as analyzing the effects of Technologies like Artificial Intelligence, Blockchain, and the Internet of Things on the efficiency and environmental goals of ports, evaluating social sustainability in the supply chain through indicators like child labor, rural poverty traps, and standards of living, and food economy. The findings contribute to the academic understanding of sustainable

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development in maritime ports, considering the interconnections among business, economic, and social factors, establishing the groundwork for key performance indicators (KPIs) and opening perspectives for practical innovation.

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1. Introduction

The challenging complexity of modern global food trade, combined with evolving societal expectations, has brought significant challenges to traditional port operations and supply chains (Notteboom *et al.*, 2022). The response to them revealed the need for real-time data-driven decision-making solutions. In response, the concept of smart ports has emerged, integrating digital technologies, automation, and sustainability principles to increase the efficiency, transparency, and resilience of food supply chains in maritime Ports (Cacho *et al.*, 2021). The business environment and the new digital transformation era add their share on top of other pressures from the global supply chain to ports (Fainshtein *et al.*, 2024).

All in all, they need to be smarter, which means being open to adopting new technologies. Smart ports is a topic in this area that has led to the work of several researchers. Despite previous studies that have separately analysed the needs of smart ports, there is still no comprehensive vision on interconnections among business, economic, and social factors, describing various all-encompassing characteristics and a consequent sustainability performance outlook for commercially significant factors in port realms.

The central research question guiding this study is: What are the directions of the research, prospective and retrospective, in the field of Sustainable Supply Chain Management? The article is structured as follows: an introductory part, which sets the context and outlines the research question, followed by section 2, which presents a theoretical framework reflecting the main topics of the study. Section 3 presents the methodology used to produce the article. Section 4 presents and discusses the results. Finally, section 5 presents the conclusion, the limitations and suggestions for future research.

The main direction simultaneously improves desirable economic-social natural indicators, while the aim of this review is to synthesise existing knowledge on sustainable food supply chains in port environments, with a particular focus on management practices, economic feasibility, and social impacts, thereby contributing to both academic discourse and practical innovation.

2. Background

According to UNCTAD - United Nations Conference on Trade and Development (2023), more than 80% of global merchandise trade, including food, is carried out by sea. The maritime port sector represents a strategic industrial zone due to its significant role in modern society and the vast range of business activities it entails (González *et al*., 2020). For example, Batte *et al*. (2020) point out that small increases in profit in this sector can have a great impact due to the number of operations developed at maritime ports. A new integrated concept has arisen, namely that of smart ports, which is expected to support all active ports so they can evolve and be sustainable for existing and future User Ports (Botti *et al*., 2017). On the other hand, according to Yeo (2017), a smart port is defined as possessing automation and high productivity – which must be built on a green system of all port operations, structures, and different means for logistics equipment systems, as well as other logistic infrastructures (Buiza-Camacho-Camacho *et al*., 2016). More simply, a smart port is characterized by improvements in operations (efficiency), energy management, and environmental considerations. Port services will move forward, becoming more interactive and efficient through technologies such as artificial intelligence, blockchain, and the Internet of Things, which are fundamental to realising the sustainability goals for port development (Jun *et al*., 2018).

From a practical perspective, several ports worldwide already present very satisfactory levels of digitalisation – and hence, a sustainable supply chain. Ports such as Hamburg, Antwerp-Bruges, Singapore, Rotterdam, Shanghai, Los Angeles, and Long Beach are seen to incorporate the most advanced supply chains in the world. The NEXUS project aims to bring other ports connected to the Mediterranean region up to a similar level of sustainable supply chain. In this context, the NEXUS project addresses the urgent need for more sustainable food supply chains within maritime ports by promoting, among others, a systemic and multidisciplinary understanding of how economic, social, and management factors interact. This initiative, with a funding of approximately 92 million euros, aims to acquire new knowledge about the sustainability and digitalisation of maritime ports connected to the Portuguese deep-water Port of Sines, which is positioned as the "Atlantic gateway to Europe." The NEXUS project has laid the groundwork for this article, as it profoundly impacts sustainable supply chain management.

The project also seeks to elevate food supply chains in maritime ports to a higher level of competitiveness and global readiness. It aims to provide original products and services to other ports based on a predefined business model, allowing them to achieve similar advancements for a fee. The pressing need for new knowledge in sustainable supply chain management became

clear during project development, and this literature review directly responds to that necessity.

3. Materials and Methods

The article adopted a version of a systematic literature review method proposed by (Denyer and Tranfield, 2009), including a selection of articles. It followed the processes outlined by (Tranfield *et al*., 2003), which comprises three distinct stages:

- Stage 1: Definition of the research purpose and research question.
- Stage 2: Identification of relevant literature, according to established inclusion and exclusion criteria.
- Stage 3: Reporting and dissemination of results.

The definition of the research intention (Stage 1) was previously established in the Introduction section above, while this section aims to clarify the approach adopted in Stage 2. The next section of this article explores Stage 3, which refers to analysing and exploring the relevant data.

The research question was answered by selecting relevant studies significant to the topic. The search was conducted in one database, Scopus. Search terms were established according to the research topic and organised into a search sequence, which allows for greater interaction and reorganisation in the process (Pittaway *et al*., 2004). This resulted in the following sequence: "supply chain" AND "sustainability" AND "indicators" AND "digital*". These keywords were selected because of their relevance to the research topic and, as key performance indicators (KPIs) (especially for maritime ports), constitute a research gap in the literature, as the subsequent research also showed. Let it be noted that this study is being performed in conjunction with the NEXUS project, which involves the digitalisation of maritime ports and their supply chain for added sustainability. This digitalisation is also a question of survival, amidst intense competition for business, as well as for security reasons in an increasingly uncertain world. Maritime ports in times of peace and stability represent a major channel for goods to enter and exit a country. In other more turbulent times maritime ports take on an even stronger responsibility. The research was conducted in the Scopus database on July 11, 2024. Other reviews were also included in the analysis due to the dearth of articles and publications found in the original research effort.

Results were limited to the subject areas "Business, Management and Accounting,"; "Economics, Econometrics and Finance; and "Social Sciences" based on a preliminary analysis of the existing literature on sustainable supply chains in ports, as well as the multidisciplinary nature of the

subject. These three domains capture the key dimensions involved in port sustainability and are linked to the management of increasingly sustainable maritime ports identified in the NEXUS project (Au-Yong-Oliveira *et al.*, 2024):

- Business, Management and Accounting covers sustainable business practices and management strategies that directly influence supply chain performance (Chkoniya, 2021).
- Economics, Econometrics and Finance allows for the assessment of economic and financial impacts of sustainability in port operations, as well as performance evaluation and economic feasibility models (Cacho et al., 2021).
- Social Sciences provides essential perspectives on social impacts, governance, and public policy, which are increasingly relevant in sustainability assessments of logistics systems (International Association of Ports and Harbors, 2024).

The environmental aspect is not included in this paper, since it requires dedicated research, with a focus that goes beyond the management perspective. In the document type category, they were limited to articles and reviews. The language was limited to Portuguese and English. The type of source was limited to journals, which undergo a more rigorous and iterative review process than other types of publications (including, for example, book chapters and conference articles). Access was limited to all open access. The result compiled 36 articles.

The next step involves exporting the articles to an Excel spreadsheet. This enabled each author to identify potential studies for inclusion in the review, as well as track the selection and analysis process of the articles by reading their keywords and abstracts considering the following criteria:

- Does the abstract address the supply chain, mentioning sustainability assessment indicators or frameworks?

Articles were then equally distributed among the researchers and categorised. According to the independent analysis, all the articles were attributed colours to guide future analysis:

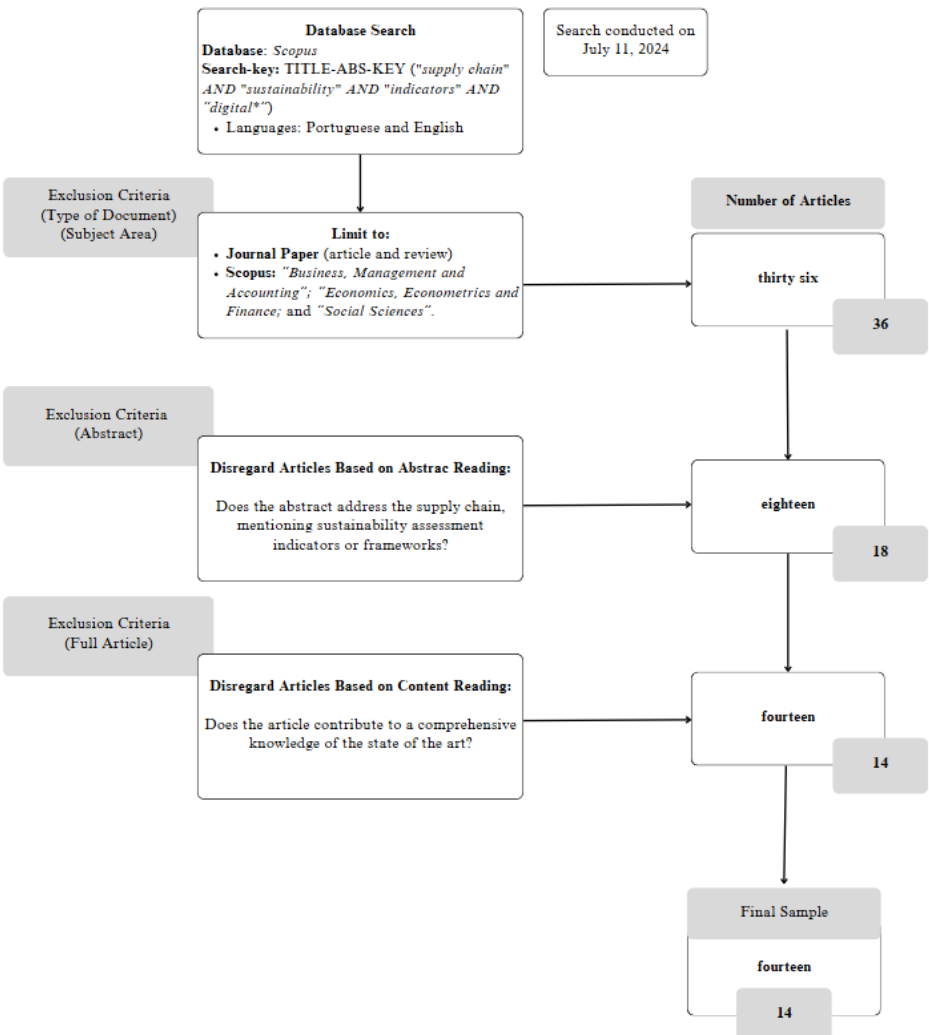
- Green: completely answered.
- Yellow: partially answered/could enrich the research.
- Red: Does not answer or contribute to the research topic.

Following this approach, 15 articles were categorized as green and selected for this study. This number was unanimously reached after joint discussion and analysis by the researchers (Xiao and Watson, 2019). One of the articles originally considered for the study was not used due to a lack of access to the full article on the date of writing. From the research, three articles were evaluated as yellow, and 18 articles were disregarded. The articles were fully read and, analysed and then selected whenever they met the following criteria:

- Does the article contribute to a comprehensive knowledge of the state of the art?

Hence, 14 articles were analysed. Figure 1 provides an overview of the selection process based on PRISMA. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) is a set of evidence-based guidelines designed to assist authors in conducting and presenting systematic reviews (Moher *et al.*, 2015). These guidelines offer specific recommendations for

Figure 1 - PRISMA-based Schema (own elaboration)



every stage of the systematic review process and involve thoroughly examining large volumes of text by several reviewers, which demands significant human effort (O'Connor *et al.*, 2014).

Table 1 shows the articles analysed in the systematic literature review. The main themes or categories identified are the following: Industry 4.0, Industry 5.0, circular economy, sustainability, competitiveness, performance (of ports / supply chain), business and territory management, digital technologies, digital transformation, and ethics, applied to different case scenarios. This preliminary analysis will be further simplified below (into four main thematic groups).

Table 1 - Articles analysed in the systematic literature review

N.	Document Title	Authors	Year	Journal
1	The paradigms of Industry 4.0 and circular economy as enabling drivers for the competitiveness of businesses and territories: The case of an Italian ceramic tiles manufacturing company	Garcia-Muiña F.E.; González-Sánchez R.; Ferrari A.M.; Settembre-Blundo D.	2018	*Social Sciences*
2	The effect of blockchain technology on supply chain sustainability performance	Park A.; Li H.	2021	*Sustainability (Switzerland)*
3	A Framework for Adopting a Sustainable Smart Sea Port Index	Othman A.; El-Gazzar S.; Knez M.	2022	*Sustainability (Switzerland)*
4	Developing and validating an instrument to measure the impact of digital supply chain activities on sustainable performance	Ahmad Amouei M.; Valmohammadi C.; Fathi K.	2023	*Journal of Enterprise Information Management*
5	To Align Technological Advancement and Ethical Conduct: An Analysis of the Relationship between Digital Technologies and Sustainable Decision-Making Processes	Riso T.; Morrone C.	2023	*Sustainability (Switzerland)*
6	Sustainable Supply Chain Management, Performance Measurement, and Management: A Review	Kumar A.; Shrivastav S.K.; Shrivastava A.K.; Panigrahi R.R.; Mardani A.; Cavallaro F.	2023	*Sustainability (Switzerland)*
7	Readiness and Maturity of Smart and Sustainable Supply Chains: A Model Proposal	Demir S.; Gunduz M.A.; Kayikci Y.; Paksoy T.	2023	*EMJ - Engineering Management Journal*
8	A cyclic and holistic methodology to exploit the Supply Chain Digital Twin concept towards a more resilient and sustainable future	Cimino A.; Longo F.; Mirabelli G.; Solina V.	2024	*Cleaner Logistics and Supply Chain*
9	Utilising Digital Twins to Bolster the Sustainability of Logistics Processes in Industry 4.0	Rigó L.; Fabianová J.; Lokšík M.; Mikušová N.	2024	*Sustainability (Switzerland)*

N.	Document Title	Authors	Year	Journal
10	Framework to supporting monitoring the circular economy in the context of industry 5.0: A proposal considering circularity indicators, digital transformation, and sustainability	Payer R.C.; Quelhas O.L.G.; Bergiante N.C.R.	2024	*Journal of Cleaner Production*
11	Digital transformation and corporate green supply chain efficiency: Evidence from China	Liao F.; Hu Y.; Chen M.; Xu S.	2024	*Economic Analysis and Policy*
12	Assessing sustainable supply chain transparency practices in Taiwan semiconductor industry: A hierarchical interdependence approach.	Bui T.-D.	2024	*International Journal of Production Economics*
13	Proposing a conceptual model of the sustainable digital supply chain in manufacturing companies: a qualitative approach	Ahmad Amouei M.; Valmohammadi C.; Fathi K.	2024	*Journal of Enterprise Information Management*
14	Industry 4.0 and Sustainability Integration in the Supply Chains of Micro, Small, and Medium Enterprises through People, Process, and Technology within the Triple Bottom Line Perspective	Machado E.A.; Scavarda L.F.; Caiado R.G.G.; Santos R.S.	2024	*Sustainability (Switzerland)*

The articles were analysed with the aim of identifying similar and dissimilar perspectives and restructuring the data from a different angle (Denyer and Tranfield, 2009). The key aspects of each selected article were then identified and summarized.

Finally, the articles were organized into four main thematic groups identified below, each with subtopics explained in the results section:

- Smart Port Requirements and Sustainable Performance;
- Technological Innovations Driving Sustainable Supply Chain Management;
- Circular Economy and Digital Supply Chain Sustainability;
- Frameworks and Models for Integrating Sustainable Digital Supply Chain.

Table 2 shows how the articles analysed correspond to the four main thematic areas identified.

Table 2 - Articles Analysed by Thematic Area (own elaboration)

Thematic Area	Document Title	Authors	Year
Smart Port Requirements and Sustainable Performance	Developing and validating an instrument to measure the impact of digital supply chain activities on sustainable performance	Ahmad Amouei M.; Valmohammadi C.; Fathi K.	2023
	Readiness and Maturity of Smart and Sustainable Supply Chains: A Model Proposal	Demir S.; Gunduz M.A.; Kayikci Y.; Paksoy T.	2023

Thematic Area	Document Title	Authors	Year
Technological Innovations Driving Sustainable Supply Chain Management	The effect of blockchain technology on supply chain sustainability performance	Park A.; Li H.	2021
	Sustainable Supply Chain Management, Performance Measurement, and Management: A Review	Kumar A.; Shrivastav S.K.; Shrivastava A.K.; Panigrahi R.R.; Mardani A.; Cavallaro F.	2023
	Utilising Digital Twins to Bolster the Sustainability of Logistics Processes in Industry 4.0	Rigó L.; Fabianová J.; Lokšík M.; Mikušová N.	2024
	Digital transformation and corporate green supply chain efficiency: Evidence from China	Liao F.; Hu Y.; Chen M.; Xu S.	2024
	Proposing a conceptual model of the sustainable digital supply chain in manufacturing companies: a qualitative approach	Ahmad Amouei M.; Valmohammadi C.; Fathi K.	2024
	To Align Technological Advancement and Ethical Conduct: An Analysis of the Relationship between Digital Technologies and Sustainable Decision-Making Processes	Riso T.; Morrone C.	2023
Circular Economy and Digital Supply Chain Sustainability	The paradigms of Industry 4.0 and circular economy as enabling drivers for the competitiveness of businesses and territories: The case of an Italian ceramic tiles manufacturing company	Garcia-Muiña F.E.; González-Sánchez R.; Ferrari A.M.; Settembre-Blundo D.	2018
	Framework to support monitoring the circular economy in the context of Industry 5.0: A proposal considering circularity indicators, digital transformation, and sustainability	Payer R.C.; Quelhas O.L.G.; Bergiante N.C.R.	2024
	Assessing sustainable supply chain transparency practices in the Taiwan semiconductor industry: A hierarchical interdependence approach.	Bui T.-D.	2024
Frameworks and Models for Integrating Sustainable Digital Supply Chain	A Framework for Adopting a Sustainable Smart Sea Port Index	Othman A.; El-Gazzar S.; Knez M.	2022
	A cyclic and holistic methodology to exploit the Supply Chain Digital Twin concept towards a more resilient and sustainable future	Cimino A.; Longo F.; Mirabelli G.; Solina V.	2024
	Industry 4.0 and Sustainability Integration in the Supply Chains of Micro, Small, and Medium Enterprises through People, Process, and Technology within the Triple Bottom Line Perspective	Machado E.A.; Scavarda L.F.; Caiado R.G.G.; Santos R.S.	2024

4. Results and Discussion

4.1. *Sample Characterization*

The sample analysed in this literature review includes articles published in various scientific journals, as shown in Figure 2. Most of the articles were published in the journal Sustainability (Switzerland), with six articles, followed by the Journal of Cleaner Production, which contributed three publications. The other journals, such as Business Strategy and the Environment, Energy Policy and Economic Analysis and Policy, contributed less, with one or two articles each. Concerning the year of publication, as shown in Figure 3, there is an upward trend in publications over time. Between 2018 and 2020, the number of articles published was relatively low, varying between one and two per year. However, from 2022 onwards, there was a significant increase, culminating in seven articles published in 2023 and a projection that this trend will continue in 2024. A significant increase can be observed from 2022 onwards, with a peak in 2023, indicating a growing interest in the topic in recent years. Furthermore, this recent increase suggests that the topic in question aligns with contemporary discussions, possibly reflecting the urgency of new research and solutions to emerging issues.

The business environment and the new digital transformation era are putting pressure on the global supply chain and, consequently, on ports. To cope with the new demands, ports must adapt to the new technologies and become smarter. Because of its relevance, there are several studies focusing on the requirements for smart ports.

Figure 2 - Source of Publication

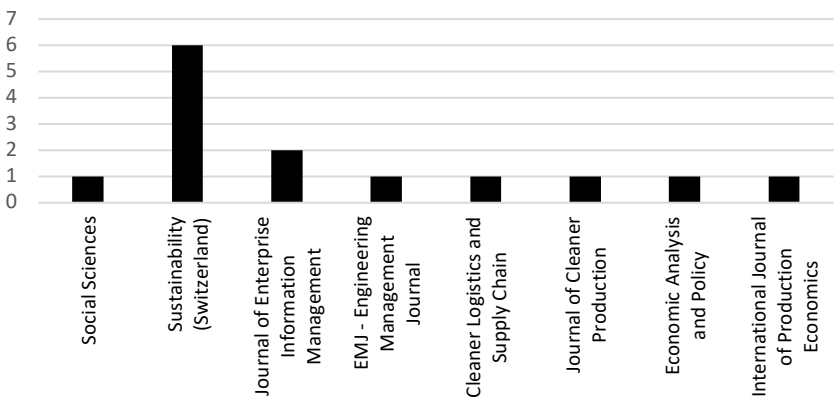
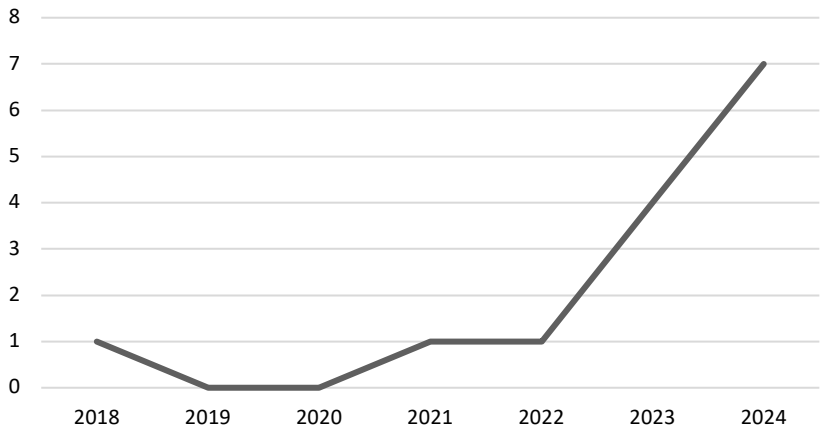


Figure 3 - Articles published during the period 2018-2024



4.2. *Smart Port Requirements and Sustainable Performance*

Although previous studies have already analysed the requirements of smart ports, there is still no integrated vision that captures the different overarching elements of a smart port and shows their impact on sustainable performance to improve the economic, social, and environmental factors of ports.

Given the significant role of the port sector in modern society and its extensive business activities, this sector is of critical importance. González *et al*. (2020) emphasise that even a slight increase in profitability within this sector can lead to substantial impacts due to the high volume of port operations. Integrating the smart concept into the port sector, leading to the emergence of the term smart port, has garnered significant attention across active ports as it supports the development and sustainability of future ports. According to Bott *et al*. (2017), a smart port is characterized by feature automation, high productivity, and eco-friendly services, including port operation structures, logistics equipment, and infrastructure. Similarly, Buiza-Camacho-Camacho *et al.* (2016) highlighted those advancements in operational efficiency, energy management, and environmental considerations that characterise a smart port. Technologies such as Artificial Intelligence, Blockchain, and the Internet of Things are key to transforming port services into more interactive and efficient offerings, aligning port development with environmental goals (Jun *et al*., 2018).

Park and Li (2021) highlight the role of blockchain technology in enhancing the social sustainability of supply chains. Social sustainability focuses on the impacts on employees, workers, customers, and local

communities. On the one hand, Blockchain technology offers transparency and traceability by ensuring that all parties involved in the supply chain can access and verify information about the origins, handling, and movement of products. This transparency reinforces trust among all stakeholders of the supply chain. On the other hand, Blockchain facilitates compliance with social and environmental regulations by providing a clear and auditable trail of information. This ease of compliance helps companies avoid legal and reputational risks associated with non-compliance. The authors also emphasise the importance of evaluating social sustainability in the supply chain through indicators like child labour, rural poverty traps, and standards of living.

The in-depth review by Kumar *et al.* (2023) reveals several significant results and directions for future Sustainable Supply Chain Management (SSCM) research. Firstly, the research confirms a positive correlation between sustainable development and SSCM, emphasising that a collaborative approach between the various stakeholders in the supply chain, such as employees, suppliers, buyers, governments, and society, can improve sustainability objectives. The study introduces a comprehensive framework for integrating sustainability indicators into supply chains, which helps to achieve the United Nations' Sustainable Development Goals (SDGs). In addition, it presents the 'House of Sustainability' framework as a method for effectively implementing sustainability practices in all three dimensions of sustainability. The discussion revolves around different dimensions of sustainability – economic, environmental, and social – and various tools and technologies that can aid in achieving these goals.

4.3. *Technological Innovations Driving Sustainable Supply Chain Management*

Based on an analysis of previous studies, Othman *et al.* (2022) conclude that the five domains associated with smart ports (operations, environment, energy, safety and security, and human resources) are independently incorporated into ports. Consequently, the authors suggest an integrated smart port index related to sustainability performance, which can be adapted to enhance sustainable smart port performance by utilizing outcome measures, identifying weaknesses and adaptation challenges, and finding ways to overcome, manage, and improve these obstacles. Additionally, ports can use this index to evaluate their standing relative to other ports.

Demir *et al.* (2023) propose a model that offers a robust framework for assessing the readiness and maturity of supply chains in the context of smart and sustainable practices. This model is valuable in guiding organisations

through the complex transition towards more sustainable and technologically advanced supply chains. A significant strength of the proposed model is its emphasis on technological capabilities. The integration of advanced technologies such as the Internet of Things (IoT), big data analytics, and artificial intelligence (AI) is crucial for developing smart supply chains. These technologies enable real-time monitoring, predictive analytics, and enhanced decision-making, which are essential for optimizing supply chain operations and achieving sustainability goals. By incorporating these technological aspects into the readiness and maturity assessment, the model ensures that organisations are not only aware of but also prepared to leverage technological advancements for sustainable supply chain management. The model's incorporation of sustainability practices is comprehensive, covering environmental, social, and economic dimensions. This holistic approach ensures that all aspects of sustainability are considered. Environmental sustainability is addressed through measures such as carbon footprint reduction, waste management, and resource conservation. Social sustainability is evaluated by examining labour practices, community impact, and stakeholder engagement. Economic sustainability is assessed by analysing cost efficiency, financial performance, and long-term viability.

Beyond Othman *et al.* (2022), Amouei *et al.* (2023) also focus their study on sustainable performance, creating and verifying a tool through a questionnaire to assess how digital supply chain operations affect the sustainable performance of Iranian manufacturing firms. The motivation of the authors to do this study is based on evidence that digital technologies and their use in supply chain operations have significantly increased in the era of Industry 4.0, and the demand for corporate social responsibility in the sustainable manufacture of goods is also growing on a global scale. The authors identify three constructs: i) main activities, which include digital supplier, manufacturing, logistics, and customer, as well as innovation; ii) support activities, made up of digital performance and technologies and human resources; iii) sustainable performance, which includes social, environmental, and economic sustainability. The results show that the digital supply chain and its support activities have a positive and significant influence on sustainable performance. Moreover, support activities have a significant effect on the core actions of the digital supply chain. Based on the questionnaire results, Amouei *et al.* (2023) conclude that, regrettably, many of the concepts associated with this problem remain unclear and unknown to those working in the supply chain. The low level of knowledge and lack of mastery of this subject might be one of the main obstacles to adopting a digital supply chain. However, for a business to survive in today's competitive and evolving business world, it is imperative to have staff with adequate skills, competencies, and experience.

4.4. *Circular Economy and Digital Supply Chain Sustainability*

Cimino *et al.* (2024) emphasise the growing need for supply chain resilience and sustainability, especially considering recent global disruptions such as natural disasters, geopolitical tensions, and the COVID-19 pandemic. The potential of new digital technologies, particularly the Supply Chain Digital Twin (SCDT), can transform supply chain management by providing dynamic, real-time information. The authors argue that one of the main advantages of supply chain modelling through digitalisation is improved visibility and real-time monitoring capabilities. SCDT provides a dynamic and comprehensive view of the supply chain, capturing data from various sources and updating the digital model in real-time. This capability allows organisations to monitor their supply chain operations continuously, identify potential disruptions early on, and respond quickly. The results of the case study conducted by the authors indicate that implementing SCDT significantly improves situational awareness, leading to more informed decision-making and proactive risk management. Using scenario analysis and predictive analytics within the SCDT framework allows organisations to simulate various disruption scenarios and assess their potential impacts on supply chain performance.

Rigó *et al.* (2024) focus on evaluating the effectiveness and applicability of the digital twin (DT) concept in strengthening supply chain sustainability. The research presented aims to integrate digital twin technology into production logistics to meet sustainability challenges. The study provides a detailed methodology for creating and implementing a digital twin using specific technologies, including SIEMENS PLC SIMATIC S7-1200, Siemens Tecnomatix Plant Simulation, OPC UA, KEPServerEX, and TIA Portal. Key findings highlight the capacity of digital twins to offer real-time insights into production processes, which facilitates prompt responses to operational disruptions and optimises resource utilisation. By simulating various scenarios, digital twins enable the identification of inefficiencies and opportunities for improvement, thereby contributing to sustainability goals such as resource conservation and reduction of environmental impact. However, the study also acknowledges certain limitations. The primary focus on specific technologies may restrict the generalizability of the findings to other contexts where different systems are employed. Additionally, the empirical examination was conducted on a hypothetical production line, which might not fully represent the complexities of real-world manufacturing environments.

Some of the publications in the sample focus on digitalisation and sustainability, such as the ones by Garcia-Muiña *et al.* (2018), Riso and Morrone (2023), Payer *et al.* (2024), Liao *et al.* (2024) and Amouei *et al.* (2024).

Garcia-Muiña *et al.* (2018) analyze the transition from a linear to a circular economy, proposing a procedure for introducing the principles of sustainability (environmental, economic, and social) into a manufacturing environment in Italy. According to the authors, sustainable development and the circular economy are key company competitiveness issues. To achieve satisfactory levels of sustainability, production processes need to be reconfigured to develop eco-sustainable products. This requires the participation and commitment of different stakeholder groups, so the industry must redesign supply chains with a view toward resource efficiency and circularity. Adopting a circular economy implies the need to review the implementation of the entire supply chain contained in each cycle of production (Tantau *et al.*, 2018). The evolution of technology, such as the Internet of Things, contributes to this systemic transition.

Riso and Morrone (2023) conducted a structured literature review focusing on the relationship between digitalization and sustainability and on publications between 2019 and 2023. Some of the papers analyzed focus on green supply chains and logistics. However, a few studies explore how business strategy professionals might use sustainable decision-making processes to help develop sustainable goals. Some of the studies they examine pay attention to the theme of green supply chain, logistics, and digital management. This trend has been developed in recent years by resilience and agility in supply chains due to digital technologies, particularly during the COVID-19 pandemic (Riso and Morrone, 2023). Supply chain 4.0, a transformational strategic development, effectively triggers resilience, playing a crucial role in facing COVID-19 (Frederico, 2021). According to Dwivedi and Paul (2022), eliminating barriers to digital supply chain progress is crucial for transforming traditional supply chains into sustainable digital ones. Moreover, the authors argue that the modification of supply chains is a determinant of adopting circular economy values. However, supply chain finance is a challenge, needing the adoption of finance and supply-chain perspectives and connecting several stakeholders, such as buyers, sellers, and banks, to create a sustainable supply chain for firms' success (Alsmadi *et al.*, 2022). Based on the literature review, Riso and Morrone (2023) suggest some topics for future research, such as the examination of crucial circular supply chain management and associated metrics, with the aim of illuminating the optimal functioning in sustainable circular supply networks that may be discerned through measures (Saraji and Streimikiene, 2022) and examine how the digital revolution affects sustainable supply chains and how cooperation between various actors is essential to the success of sustainable supply chain management (Tseng *et al.*, 2019).

Payer *et al.* (2024) elaborate a framework to address the topics of digital transformation, the Industry 5.0 paradigm, and the Environment, Social, and

Governance (ESG) components of sustainability that will help companies adopt a circular economy. The authors find seven dimensions that must be considered to hit the circularity, one of them being the circular and non-circular supply chain integration. Regarding the supply chain, the authors highlight the necessity to include circularity and sustainability (mainly the social and environmental pillars) topics and to have real-time information. In the same vein, Varriale *et al.* (2023) also emphasise the relevance of these topics to increase supply chain transparency, as stakeholders become more aware of the manufacturing processes of goods, and industries can be aware of the more efficient resources and cut costs and waste to enhance the circular practices. The integration of supply chains requires principles of Industry 5.0 (Camarinha-Matos *et al.*, 2024) and optimisation, which can be achieved through new technologies, such as digital transformation (Payer *et al.*, 2024). Although there are several advantages of digital transformation for the integration of circular and non-circular supply chains, some authors draw attention to various challenges, such as the need to apply digital transformation throughout the chain (Karmaker *et al.*, 2023), enabling them to obtain interconnected smart and decentralized chains (Belhadi *et al.*, 2021). On the other hand, it is necessary to obtain, develop, and use appropriate information and knowledge to implement the desired changes in business operations (Ghobakhloo *et al.*, 2023) to be efficient.

In the context of the growing use of digital technology by businesses to promote sustainability in the age of the digital economy, and when it is crucial to optimize the green supply chain, Liao *et al.* (2024) analyze data from Chinese manufacturing companies registered on the A-share market, for the period from 2011 to 2020. The authors explore their relationship by extracting digital transformation indicators and evaluating the effectiveness of eco-friendly supply chains. The results demonstrate that digital transformation enhances green supply chains' overall efficiency by fostering innovation in green technologies, lowering transaction costs, and easing finance limitations. The positive impact of digital transformation on green supply chains is in line with previous studies, such as the ones by Agyabeng-Mensah *et al.* (2023), Qin *et al.* (2023), and Su *et al.* (2023). Furthermore, the evidence shows that government-owned businesses, big firms, and those with lower per-capita production values are especially affected by digital transformation's ability to increase efficiency in green supply chains.

4.5. *Frameworks and Models for Integrating Sustainable Digital Supply Chain*

Bui (2024) identifies valid attributes of sustainable supply chain transparency, examining causal relationships, assessing hierarchical

interdependencies, and indicating priority practices in the context of Taiwan's semiconductor industry, contributing to detecting sustainable supply chain transparency structures, particularly when transparency extends beyond the actual operation of the supply chain, which involves various uncertain and complex factors. Sustainable supply chain transparency is established to improve the disclosure and visibility of sustainability information inside and outside the supply chain. The findings suggest that efforts of transparency made by stakeholders, digital expertise, and information management are causal characteristics that must be highlighted to enhance sustainable supply chain transparency. In addition, the author argues that digital competencies significantly enhance sustainable supply chain transparency by leveraging technologies such as Blockchain, the Internet of Things, and Artificial Intelligence, which agrees with previous arguments (Jun *et al*., 2018; Karmaker *et al*., 2023; Riso and Morrone, 2023).

Amouei *et al*. (2024), after creating a tool to analyze the impact of digital supply chain operations on sustainable performance (Amouei *et al*., 2023), now propose a conceptual model for a sustainable digital supply chain management in manufacturing companies, given the significance of the sustainable supply chain management and the industry 4.0 in supply chain management. According to the authors, emerging technologies have impacted every industry in the digital age. Digital, information, and communications technologies have made traditional supply chains more innovative and more resilient, allowing for better handling of risks. To carry out the study, Amouei *et al*. (2024) performed a literature review of many publications and ran some interviews with manufacturing specialists. Considering the suggested model, the digital supply chain management is composed of four sections: i) the digital supplier, which includes the "supplier evaluation and selection", "supplier segmentation", "duration of the relationship with the supplier", and "quality of relationship with the supplier"; ii) digital manufacturing, that incorporates the "supply chain transparency", the "digital customization", the "digital processes" and the "digital strategies"; iii) digital logistics and innovation, including the subjects of "digital logistics", "digital business model", "digital research and development" and "open innovation"; iv) digital customer, which comprises the issues of "customer relations", "digital delivery service", "customer feedback", "customer experience" and "customer training". Based on the study's findings, the authors conclude that support actions impact the primary activities of the digital supply chain. Digital performance, for instance, can lessen any current supply and demand mismatch and boost transparency throughout the supply chain, which eventually improves the company's competitive edge. The performance of the primary operations will be enhanced using digital technology through process integration, increased information availability, real-time inventory

monitoring, customer interaction, and cost savings. Finally, by utilizing cutting-edge technology in recruiting, training, and developing staff members, digital human resources can impact digital innovation and other key tasks. These conclusions are in accordance with previous studies (e.g., Agrawal and Narain, 2018).

Considering the suggested conceptual model, the consequences of digital technology use on supply chain management sustainability, and their findings, Amouei *et al.* (2024, p. 562-563) suggest three propositions: P1) "The use of digital technologies in supply chain support activities has a positive and significant effect on the supply chain main activities"; P2) "The use of digital technologies in supply chain main activities has a positive and significant effect on supply chain management sustainability"; P3) "The use of digital technologies in supply chain support activities has a positive and significant effect on supply chain management sustainability".

Machado *et al.* (2024) propose a framework to support the integration of Industry 4.0 and sustainability into supply chains, focusing on micro, small, and medium-sized enterprises. Based on a literature review, focus groups, and a survey of experts, the authors identified 32 key indicators associated with the main barriers and the main facilitators of Industry 4.0 and sustainability integration in these companies' supply chains. Some of the barriers are the lack of technical expertise, cybersecurity issues, resistance to change management practices, and adoption of innovation, and some of the factors are the internal innovation process, data-centred solutions, consistent data flow, and customer and supplier integration. Some barriers can be mitigated by facilitators, which is very important that firms are aware of. The results were also synthesized into a new framework, applied separately to Micro and Small Enterprises (MSEs) and Medium Enterprises (MEs) due to the companies' size differences, concluding that there is a need to treat MSEs and MEs differently when it comes to integrating Industry 4.0 and sustainability into their supply chains, allowing this process to be accelerated. MSE managers, for example, ought to concentrate on obstacles since they have a greater impact than MEs. However, in their quest for a bigger business impact, MEs managers must pay more attention to facilitators. For example, the barrier of the cost of improvement and economic state of operations and supply chain management is more relevant and influential to MSEs than it is to MEs. The facilitator related to top management commitment and strategic alignment must be paid attention to both in MSEs and MEs contexts. The authors conclude that if sustainability has gained importance in the case of Industry 4.0 implementation in MSME (Micro, Small & Medium Enterprises) supply chains, this may have an even greater effect on Industry 5.0 or Society 5.0 visions.

The model proposed by Lahane *et al.* (2023) to evaluate and rank solutions for overcoming barriers to adopting Industry 4.0 technologies in sustainable

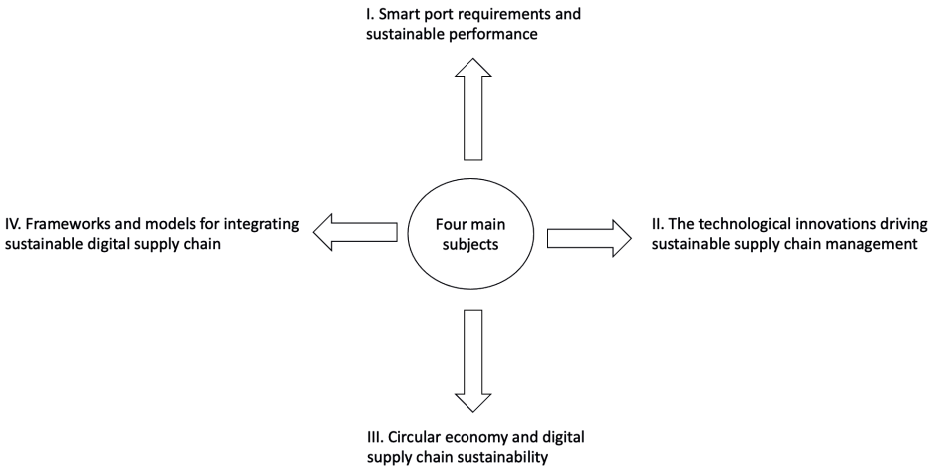
food supply chains is a comprehensive framework that addresses the multifaceted nature of this challenge. By employing multi-criteria decision-making methods (MCDM), the model provides a structured approach to decision-making that incorporates a wide range of factors relevant to sustainability and technological adoption. The identification of barriers is a critical first step in the model. The categorisation into technological, economic, organisational, regulatory, and social domains ensures that all potential obstacles are considered. This holistic approach is essential because the successful implementation of Industry 4.0 technologies in the supply chain is contingent on addressing challenges across these diverse areas. The application of MCDM methods such as the Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and Decision-Making Trial and Evaluation Laboratory (DEMATEL) is a significant strength of the model. These methods facilitate a rigorous and systematic evaluation of solutions, allowing for nuanced decision-making. AHP, for instance, enables the decomposition of complex decisions into simpler, more manageable components, facilitating a thorough analysis of each criterion. TOPSIS, on the other hand, helps identify solutions closest to the ideal and farthest from the negative ideal, providing a clear preference order. DEMATEL visualises the structure of complex causal relationships, aiding in identifying key factors and their interrelationships.

The model proposed by Lahane *et al.* (2023) offers a rigorous and comprehensive approach to evaluating and overcoming barriers to adopting Industry 4.0 technologies in sustainable food supply chains. By integrating MCDM methods with a holistic consideration of barriers and solutions, the model provides a valuable tool for stakeholders seeking to enhance the sustainability of their supply chains.

4.6. *Discussion*

Based on the results of the 14 publications, the main subjects that researchers focused on were identified: i) smart port requirements and sustainable performance (e.g., González *et al.*, 2020; Park and Li, 2021; Othman *et al.*, 2022); ii) the technological innovations driving sustainable supply chain management (Othman *et al.,* 2022; Amouei *et al.*, 2023; Demir *et al.*, 2023); iii) circular economy and digital supply chain sustainability, such as the studies by Garcia-Muiña *et al.* (2018), Riso and Morrone (2023), Payer *et al.* (2024), Liao *et al.* (2024) and Amouei *et al.* (2024) and; iv) frameworks and models for integrating sustainable digital supply chain (Amouei *et al.*, 2023, 2024; Machado *et al.*, 2024) (Figure 4).

Figure 4 - The four main subjects highlighted by literature

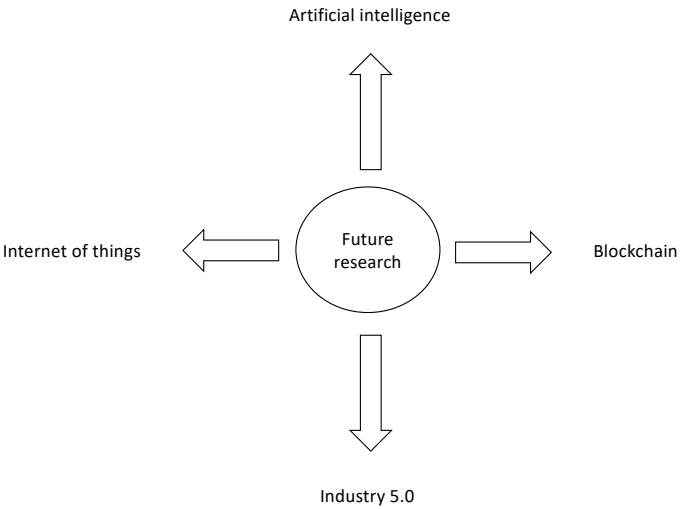


Note the presence of elements such as sustainable performance (no other type of performance should matter), technological innovations (innovation is indissociable from technology), digital supply chain (a natural evolution free of human intervention), and frameworks and models (for theorists to pursue further their applied research).

Several gaps identified in this work present opportunities for future research (see Figure 5). As Industry 5.0 gains traction, it is increasingly important to assess the additional value it offers beyond the capabilities of Industry 4.0, particularly in fostering human-centric, resilient, and sustainable systems. Moreover, there is a need to analyse the impact of advanced technologies, such as Artificial Intelligence, Blockchain, and the Internet of Things, on port operations, with a particular focus on their contributions to efficiency improvements and the achievement of environmental objectives.

Finally, it is essential to place greater emphasis on social sustainability in the supply chain, particularly through the development and application of indicators that evaluate critical social issues such as child labour, rural poverty traps, standards of living, and the role of the food economy in promoting equitable development. Tackling these dimensions is crucial to building more inclusive, intelligent, and sustainable port and supply chain systems, aligned with the broader objectives of Industry 5.0 and global sustainability agendas.

Figure 5 - The gaps identified in this study



5. Conclusion, Limitations and Future Research

This study analyses the research trends in sustainable supply chains in the Scopus database, which was researched on July 11, 2024. Considering the sample selection process, 14 documents were obtained. To the best of the authors' knowledge, few studies have addressed this subject. The most influential works were identified, and an integrated analysis was performed. The increase in publications after 2022 reflects the recognition of the benefits of sustainable practices and digitalisation to improve supply chain efficiency. The relevance of sustainable practices is reinforced by the evidence that a major part of the papers was published in the Sustainability journal.

This study is important for managers because it identifies practices that can improve supply chain management, and it is important to realise that the staff need adequate skills, competencies, and experience. Moreover, this study shows some findings that can lead researchers to new avenues for further research on this subject.

The limitation is that it considers only the Scopus database, which can bias the sampling method. Thus, in the future, it would be valuable to use another bibliometric source, such as the Web of Science (WoS) database.

Future research could cover the gaps identified in this work (Figure 5), such as analyzing the effects of Technologies like Artificial Intelligence, Blockchain, and the Internet of Things on the efficiency and environmental goals of ports, evaluating social sustainability in the supply chain through

indicators like child labor, rural poverty traps, and standards of living. Other research opportunities can focus on the examination of crucial circular supply chain management and associated metrics to illuminate the optimal functioning in sustainable circular supply networks, as well as to examine how the digital revolution affects sustainable supply chains and how cooperation between various actors is essential to the success of sustainable supply chain management.

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