Journal of
Marine Science and Engineering

MDPI

Review

The Adoption of Technological Innovations in the Maritime Industry: A Bibliometric Review

Armand Djoumessi , Alessio Tei and Claudio Ferrari *

Italian Centre of Excellence on Logistics, Transport and Infrastructures (CIELI), University of Genoa, Via Vivaldi 5, 16126 Genoa, Italy; thedjoumessima@gmail.com (A.D.); alessio.tei@unige.it (A.T.)
* Correspondence: claudio.ferrari@unige.it

Abstract

The adoption of technological innovations in the maritime industry is of interest to business, policy, and academic communities. In the last group, this interest has translated into the publication of a large but scattered literature, making it difficult to compare findings and identify the dynamics, structures, and patterns that might inform future research. A comprehensive review of past research on this topic might help achieve this. To date, no such review has been carried out, which is an important gap in the literature that this paper contributes to bridging. Two bibliometric review techniques—co-citation analysis of cited references and bibliographic coupling of documents—are applied to 171 journal articles published between 1999 and February 2025 to answer the following questions: 1. What is the knowledge base of this literature? 2. What are the recent research trends (research fronts) in this literature? The analysis reveals that research on "shore power" dominates both the knowledge base and research fronts. Other key research themes centre on "autonomous shipping", "blockchain", and "alternative fuels". Based on these results, implications for future research are drawn.

Keywords: technological innovations; innovation adoption; maritime industry; knowledge base; research fronts; bibliometrics

check for updates

Academic Editors: Jiaguo Liu and Jun Ye

Received: 23 June 2025
Revised: 27 July 2025
Accepted: 30 July 2025
Published: 31 July 2025

Citation: Djoumessi, A.; Tei, A.; Ferrari, C. The Adoption of Technological Innovations in the Maritime Industry: A Bibliometric Review. *J. Mar. Sci. Eng.* **2025**, *13*, 1484. https://doi.org/10.3390/jmse13081484

1. Introduction

As the maritime industry faces mounting pressure to meet the International Maritime Organization's 2050 decarbonisation targets, shipowners and port operators are rapidly exploring technological innovations such as shore power, alternative fuels, and artificial intelligence [1,2]. The introduction of technological innovations has always led to significant changes in the structure and organisation of the shipping industry [3].

For example, the introduction of the steam engine and later of diesel propulsion into the industry ensured faster delivery of goods [4]. Similarly, the adoption of the container ensured that more goods could be transported efficiently [5,6], and the adoption of larger ships ensured that the final customer could pay a lower price [7,8]. Some technological innovations have also been adopted into the industry for safety and environmental purposes—for example, the adoption of double-hull oil tankers to reduce their negative environmental impact in terms of oil spills [9,10].

In general, as more technologies that could be applied to the maritime industry have become available, operators have been faced with the challenge of selecting the right one for their specific case, especially as some of these technologies could be substitutes for each other. From a research point of view, this has resulted in a surge of publications, as authors from various disciplines have approached this issue from different perspectives. For example, the application of smart technologies [11,12], blockchain technologies [13–16], autonomous technologies [17–19], and environmentally friendly technologies [20–22] in the maritime industry has been explored.

Depending on the technology studied, the perspective taken, and the goal of the research, studies on this topic have been published beyond maritime- and transport-focused journals—for example, in behaviour-focused journals (e.g., [12]), energy-focused journals (e.g., [21,23]), environment-focused journals [24,25], and strategic management-focused journals [10,26], just to name a few. Although this has enriched the body of knowledge on the topic, it has also resulted in a very scattered literature, making it difficult to compare findings and identify the dynamics, structures, and patterns. A comprehensive review of past research on this topic might help identify such patterns. To date, no such review has been carried out, which is an important gap in the literature that this paper contributes to bridging.

The purpose of this study is thus to bring together and provide a comprehensive review of the growing literature on the adoption of technological innovations in the maritime industry. Though there are many types of reviews (e.g., systematic, narrative, critical, scoping, bibliometric, etc.), we are particularly interested in this first attempt to bring this literature together to provide a macroscopic perspective. As such, a bibliometric literature approach seems appropriate. A core benefit of bibliometric studies is that they allow the identification of influential authors, documents, sources, etc. in a field of studies as well as associations and similarities between them, which in turn provide researchers with a solid foundation for positioning their contribution and identifying new lines of research [27,28]. As argued by Ref. [29], in the context of maritime research, carrying out bibliometric reviews is important because they bridge the gap between researchers and practitioners, especially in the current context of sustainability transitions in the maritime industry.

In line with bibliometric studies in other fields [30–32], the following research questions will guide this study:

- Q1. What is the knowledge base of this literature?
- Q2. What are the recent research trends (research fronts) in this literature?

Two bibliometric techniques—co-citation analysis and bibliographic coupling (further explained in Section 3.4)—are used to answer the above questions. The dataset consists of peer-reviewed journal articles on the adoption of technological innovations in the maritime industry published between 1999 and February 2025. Of note, 1999 represents the year the earliest article relevant on the topic was identified, while February 2025 (the dataset was downloaded on 2 December 2025) represents the month and year the data used in this article were downloaded.

By carrying out a literature review on the adoption of technological innovations, this paper contributes to the increasing literature on maritime bibliometric studies in the following ways. First, it explores an important but rather unexplored topic in the context of maritime bibliometric studies. In their recent review of maritime bibliometric studies, Ref. [29] has called for such studies. In the current context of maritime decarbonisation, it is anticipated that more technological innovations will be adopted as shipowners and charterers strive to meet the International Maritime Organization (IMO) regulation requirements and that more research will be conducted [33–36]. Taking stock of past research on the adoption of technological innovations in the maritime industry is necessary, as it will lay a strong foundation upon which future research on the topic can be built. Second, it demonstrates that the knowledge base of this literature is composed of seven thematic areas at various stages of development. Third, by capturing the seven research fronts on the different technologies discussed in the extant literature, the paper will benefit researchers wanting to orientate themselves in this field. Finally, the paper also contributes to increasing the number of maritime bibliometric studies using co-citation analysis and bibliographic coupling, whose use has so far been limited [29].

The remainder of this paper is structured as follows. Section 2 lays the theoretical foundation of this study. Section 3 presents the research design and methodology, followed by the findings in Section 4. Finally, Section 5 concludes and provides some trajectories for future research.

2. Theoretical Background: Technological Innovations and Their Adoption Process

2.1. How Should Technological Innovation Be Understood in This Paper?

According to Ref. [37], the term "technological innovation" might be characterised as an inclusive concept (in the sense that it can be used to mean different things depending on the context) whose meaning has evolved over the years. In essence, it has served and continues to serve different purposes in the literature. It has often been used as a theoretical concept, process, good, or service. As an example, in their review article on the literature on technological innovation, Ref. [38] defines technological innovation as "a procedure that contains the interplay of multiple sources, a multidimensional concept difficult to measure". This rather broad definition leaves the interpretation to the reader. In fact, many authors using the phrase shy away from defining it, choosing rather to give examples. For example, in the chapter titled "Defining technological innovation", Ref. [39] fails to provide a definition of the term, demonstrating the difficulty that might be associated with doing so. It is therefore critical to clarify how this phrase/term is used in this paper.

It can be argued that the difficulty to define technological innovation stems from the fact that it is composed of two words, "technological" and "innovation" [37]. It is therefore useful to clarify what each of these words means in the context of this research before providing an understanding of how the two combined should be understood in this research. Starting with "technological", there seems to be a consensus in the literature that it relates to or involves technology [37,39]. The Cambridge online dictionary defines technology as "a method by which science is used for practical purposes, new machinery and equipment that has been developed using scientific knowledge or processes" [40]. It can be inferred that a technology is a scientific method (e.g., automated container terminal), a tangible tool (e.g., electric tugboat), or an intangible tool (e.g., blockchain). This is how technology will be understood in this paper.

Turning now to "innovation", the other word in the phrase "technological innovation", Ref. [37] refers to it as a "buzzword, a magic word that seeps into almost every sentence, a panacea for every socio-economic problem". Although multitudes of definitions of "innovation" have been provided [41,42], there is a consensus in the literature that it includes an element of newness to the world, industry, organisation, etc. [43]. This paper focuses on maritime industry, and thus on innovations that are new to organisations involved in this industry. As for what is new, various typologies of innovations have been provided [44,45]. In this paper, the focus is on technology, and thus technological innovation as type of innovation. The degree of newness of an innovation (radical, incremental) is also often discussed in the literature (e.g., [46,47]). In this paper, both will be considered without distinction in the literature explored.

In this paper, therefore, technological innovation refers to a new scientific method, or a tangible or intangible tool. They are adopted by users to either achieve competitiveness or compliance with sustainability regulations. For an in-depth discussion on this term, refer to Refs. [37,38]. Various theories of technological innovations have been developed, but a discussion of them is beyond the scope of this paper (see Refs. [48,49] for details on these).

Since our focus is on technology adoption, we will focus in the next section on the most used theory to explain the adoption of technological innovation.

2.2. Adoption Lifecycle of Technological Innovations

Ref. [50] provides a review of the major models and theories related to users' adoption of technology. Their findings show that the most important of these theories as per the number of cited documents is the Innovation Diffusion theory (also called the Diffusion of Innovation (DOI) theory by Ref. [51]), which will be briefly discussed in this paper because it has recently been applied in the maritime context by Ref. [52] to study the adoption of LNG and electric batteries by ferries in Norway. The DOI theory distinguishes five end-user categories in the technology adoption lifecycle spread over a normally distributed bell curve [51,53,54].

Innovators are generally more eager to experiment with a new technology as soon as possible to learn about its potential monetary returns. Motivated by profits they can capture by adopting the technology before their competitors, early adopters are willing to take the risk of investing in an immature technology [55]. According to Refs. [54,56], there are chasms or cracks in the bell curve representing adoption barriers (in form of various types of uncertainties and risks) between different groups of adopters, the most significant of which is between early adopters and the early majority, preventing the new technology from taking off. It should be noted, however, that the absence of chasms in the curve between other groups is not synonymous with their non-existence but rather with the fact that they are of lower magnitude, and thus crossed by adopters [57]. The early majority group (nearly a third of the market) is risk averse and conservative, and adopts technological innovation only when it has been proven. The late majority (also a third of the market) is much more risk averse and will only be committed after most technological and economic uncertainties associated with the new technology have been resolved. Finally, the laggards resist new technologies and only adopt them when compelled to.

3. Research Design and Methods

We relied on the literature review approach proposed by Ref. [58] (p. 102). According to these authors, despite their differences, all reviews can be conducted following eight steps: (1) formulating the research problem, (2) developing and validating the review protocol, (3) searching the literature, (4) screening for inclusion, (5) assessing quality, (6) extracting data, (7) analysing and synthesising data, and (8) reporting the findings. For the purpose of this review, some of these steps are combined, as shown in Figure 1. Steps 1, 2, 3, and 4 are elaborated upon in Section 3 of the paper, and Step 5 is in Section 4 of this paper.

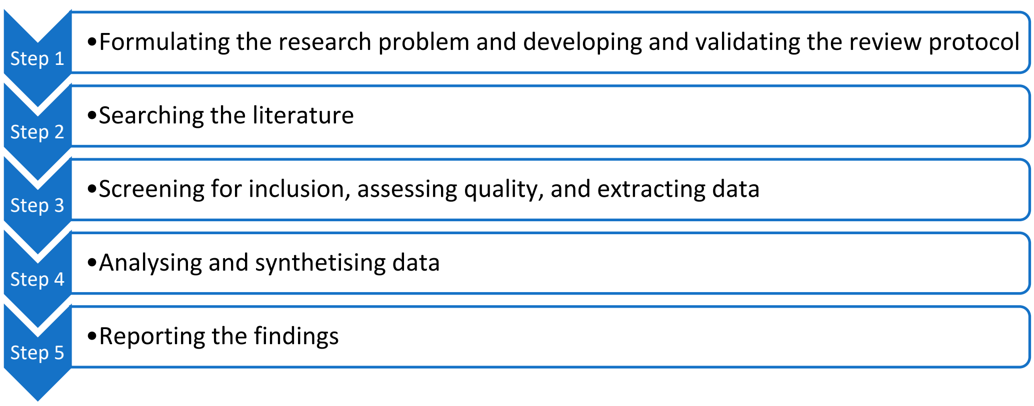

Figure 1. Research framework.

3.1. Formulating the Research Problem and Developing and Validating the Review Protocol

In this step, the topic investigated is defined and justified, and the type of review that will be conducted is chosen. In this paper, the topic of interest is the adoption of technological innovations in the maritime industry. This topic is especially relevant with the current push toward the decarbonisation and digitalisation of the industry, which will necessitate the adoption of many technologies and potentially drive more research on this topic. To the best of our knowledge, there has been no attempt to bring together the extant literature on the topic. Doing so is critical and will lay a strong foundation on which future research on the topic will build and identify issues requiring further investigations. According to Ref. [58], a question modelled on the topic can be used to define keywords and relevant synonyms that will be used for identifying relevant articles on the topic. Here, it is important to stress that the sole purpose of the question framed in this step is to retrieve the relevant literature. As such, it is not to be confused with the main research questions (Q1 and Q2, mentioned in the introduction, which this paper attempts to answer).

The use of synonyms in the question that is modelled on the topic to retrieve the data is particularly relevant in the context of the maritime industry, where several terminologies are often used to refer to the same concept (i.e., the maritime industry is often just referred to as shipping, and ships can also be referred to as vessels). Accordingly, the following question was used to identify relevant articles on the topic:

- What are the drivers and barriers to the adoption of technological innovations in the maritime industry?

Various technological innovations in the maritime industry have been analysed through the lens of their drivers and barriers in the literature (e.g., [21,22,59–62]. This justifies why "barriers" and "drivers" were included in the question. After defining the question used to retrieve the literature, Refs. [58,63] recommend dissecting it into concept domains that will be used to search the literature. Accordingly, the domains of the research questions are "drivers", "barriers", "adoption", "technological innovations", and "maritime industry".

As pointed out by Ref. [58], the domains can be extended by synonyms, abbreviations, other alternative spelling, or related terms, or even broken down into other words. We argue that in addition to this, the researcher's knowledge of the language/terms/vocabulary commonly used in their discipline for the industry addressed in the study and of previous known studies on the topic can also direct the selection of alternative keyword domains [63]. For example, although the word "factors" does not appear in the research question, it is often used in the maritime industry/shipping literature as a generic term encompassing both drivers and barriers (e.g., [19,64–66]). Therefore, it will be used as a domain during the search process in combination with other domains. The same reasoning goes for the selection of the words "challenges" and "constraints", which often are associated with the barriers [67].

Regarding the domain "technological innovations", since "technological" is a qualifier for innovations, it is more appropriate in the context of this research to break this domain into the related terms "technology" and "innovations", which are widely used in the maritime literature (e.g., [4,17,68,69]. Table 1 shows the results of the extended domains.

Table 1. Domains and their extensions used in the data selection search.

Domains Derived from the Research Questions	Synonyms Provided by the Cambridge Thesaurus (Online)	Synonyms Potentially Relevant to this Research	Relevant Related Terms
Drivers	Chauffeurs, jockeys, motorists, operators Trainers	-	Factors Triggers Enablers
Barriers	Hindrances, checks, difficulties Restrictions, hurdles, obstacles Limitations, hazards, stumbling blocks Impediments	Obstacles Impediments Hindrances Limitations	Challenges Constraints
Adoption	Acceptance, approval, enactment Endorsement, maintenance Ratification, selection	Acceptance	Deployment Implementation
Technological innovations	High-tech, industrial, mechanical Professional, scholarly, scientific Special, specialised, vocational	-	Technology AND innovations
Maritime industry	-	Shipping industry	Shipping, port, ship

3.2. Searching the Literature

The different domains combinations were used as inputs in the “Advanced search TITLE-ABS-KEY” function of the Scopus database. It was selected because it covers most peer-reviewed academic research data in the fields relevant to this research (science, technology, and social sciences) and has also been used for conducting reviews in maritime research [17,70]. Separate search combinations were carried out depending on whether the retrieved documents focus on drivers or barriers. An example combination with drivers is [TITLE-ABS-KEY ((“Drivers” OR “factors” OR “triggers” OR “enablers”) AND “technology*” AND (“adoption” OR “deployment” OR “implementation” OR “acceptance”) AND (innovation) AND (“shipping” OR “port” OR (“maritime industry”) OR “ship”)). An example with barriers is [TITLE-ABS-KEY ((“Barriers” OR “obstacles” OR “challenges” OR “impediments” OR “hindrances” OR “constraints” OR “limitations”) AND (“adoption” OR “deployment” OR “implementation” OR “acceptance”) AND (“technology*”) AND innovation* AND (“shipping” OR “port” OR “ship” OR “maritime industry”))]. The search results for all combinations led to the identification of 2207 documents, while the keywords combinations used for searching papers are shown in Appendix A.

3.3. Screening for Inclusion, Assessing Quality, and Extracting Data

The documents selected for further analysis were limited to academic journal articles (916), and those published prior to 2023 (612) had to have been cited at least once. In total, 519 articles were selected, whose abstracts were read to ascertain their aims, the questions they were attempting to answer, and the main findings. When these were not very clear, the articles were read in full, as recommended by Ref. [70]. A total of 348 articles unrelated to research questions were deleted, leaving 171 journal articles deemed relevant for analysis. The data are analysed next.

3.4. Analysing and Synthetising Data

This paper adopts a bibliometric approach. Compared with traditional reviews (most often qualitative), bibliometric reviews enable researchers to replicate their review results. The advantage of bibliometric methods when used correctly is their quantitative rigour and ability to provide succent visualisations of large quantities of data [71]. Given the relatively large quantity of data to analyse (171 articles), they are suitable for this study.

They are increasingly being used to carry out reviews on topics and journals in social sciences [30,71–73] and are increasingly being applied in maritime transport research [29,74].

The choice of the software was based on its ability to provide clarity for the question being answered and its ability to support data imported from Scopus and Microsoft Excel. The software VOSviewer 1.6.20 was used to perform the analysis [75]. A key strength of this software is its ability to show network, overlay, and density visualisations.

In general, bibliometric techniques are used for performance assessment and science mapping [76,77]. The former is used when the purpose is to describe the performance of individual/groups of articles, authors, institutions, countries, etc. in a body of knowledge. The latter is performed when the aim is to identify dynamics, structures, and patterns in the data analysed. There are various types of science mapping techniques suitable for specific questions (see Refs. [71,78] for a detailed account of these techniques). Given the questions this paper attempts to answer, two bibliometric techniques will be used: co-citation analysis and bibliographic coupling.

Both techniques are centred on intertextual relationships among published documents, which are established based on the referencing behaviour of authors under the assumption that these relationships are an indication of textual similarity between the coupled or co-cited documents [28]. Two documents are said to be bibliographically coupled if they have at least one reference in common and co-cited if they appear on the same reference list [79]. Each of these techniques has some strengths and weaknesses, as shown in Table 2. It can be inferred from Table 2 that the two techniques are complementary. This justifies why both are used in this paper.

Table 2. Summary of bibliographic coupling and co-citation analysis.

Bibliometric Techniques	**Occurs When**	**Key Features**	**Merits**	**Critique**
Bibliographic coupling	Two documents have at least one reference in common	(i) Overlapping bibliographies (ii) Measure of association between two citing documents	(a) Forward looking (b) Best suited for mapping current trends and future priorities (research fronts)	(a) Static because number of references shared by two documents does not change over time (b) Two articles may reference a completely unrelated subject matter in the third
Co-citation	Two documents are included in the same reference list	(a) Similarity relationship between two cited documents (b) Applied to references of documents rather than the document itself	(i) Dynamic approach given that co-citation frequencies increase over time (ii) Best indicator of subject similarity (iii) Best suited for mapping the intellectual heritage on the basis of highly cited documents	(1) Not suitable for clustering smaller niche specialties formed by less cited documents (2) Biased towards the past (backward looking)

Given the goal of the paper and the research questions of interest, bibliographic coupling in this paper will only use documents as units of analysis (to answer question Q2), though sources, authors, organisations, and countries could also be used. In the same vein, though sources and authors can also be used as units of analysis, co-citation in this paper will only be applied to references (to answer Q1). A graphical representation of co-citation and bibliographic coupling as applied in this paper is shown in Figure 2.

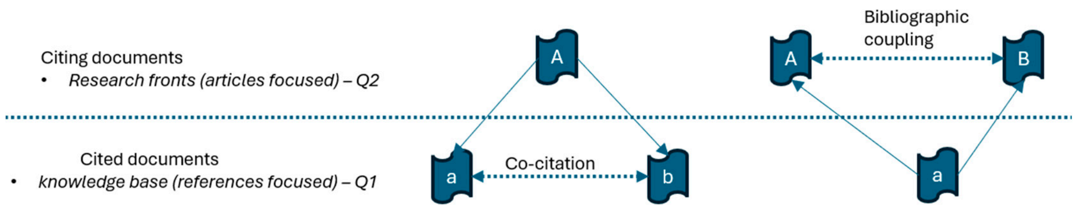

Figure 2. A graphic illustration of co-citation and bibliographic coupling. Adapted from Ref. [28] (p. 429).

4. Reporting the Findings

4.1. Descriptive Analysis

In this section, the annual scientific production, the most influential documents, and the authors and countries involved in research on the adoption of technological innovations in the maritime industry are discussed.

As can be seen in Figure 3, interest in the adoption of technological innovations in the maritime industry picked up in 2019 and has been increasing ever since, with 2024 being the most productive year. The 171 articles analysed were authored by 544 authors, with an average value of 3.68 authors per paper. Out of these, only 19 were single authored, reflecting a high level of collaboration. It can be seen from the corresponding author data in Figure 4 that authors from China dominate this research, both in terms of national collaboration, expressed as single-country production (SCP), and international collaboration, expressed as multiple-country production (MCP), followed by the UK, the USA, Norway, Italy, Sweden, Australia, Germany, and Hong Kong. For Germany, Italy, and Sweden, multiple-country collaborations overtake single-country productions.

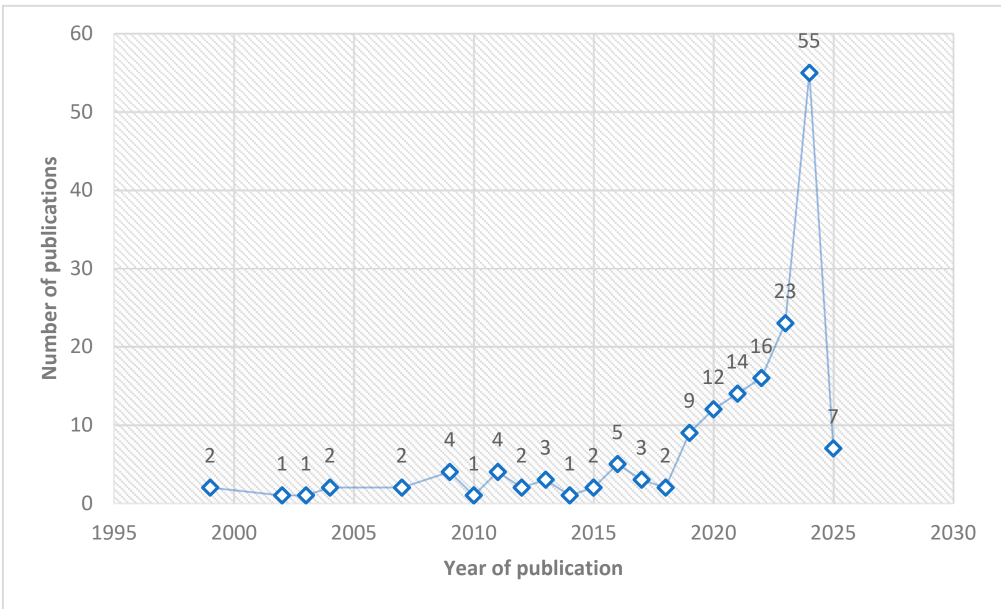

Figure 3. Annual scientific production between 1999 and 2025.

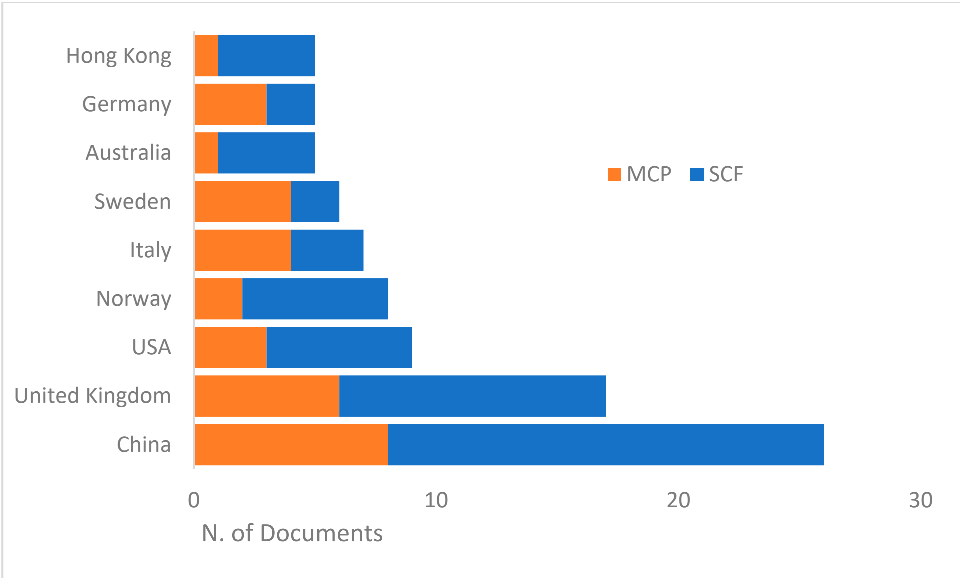

Figure 4. Countries of the authors.

A snapshot linking the top 15 authors (AU) that have contributed the most to this research, the sources in which they have published (SO), and the keywords (DE) used is shown in the three-field plot in Figure 5. The three-field plot was built based on the concept of Sankey diagrams. The keywords shown in Figure 5 reflect the topic being explored. Of note, when considering all 544 authors, a total 632 keywords were used, with those that were used at least five (5) times shown in Table 3. The sources in which the examined articles are published, shown in Figure 5, cover maritime business- and transportation-related issues in their scope. The 171 articles were published in 105 different sources covering various disciplines and topics related to the adoption of technological innovation, with a focus on the maritime industry, including technology, innovation, pollution, the environment, etc. Sources in which there were at least three (3) articles on the topic are shown in Table 4. The diversity of sources and keywords used reflects the multidisciplinary nature of the topic under consideration in this paper.

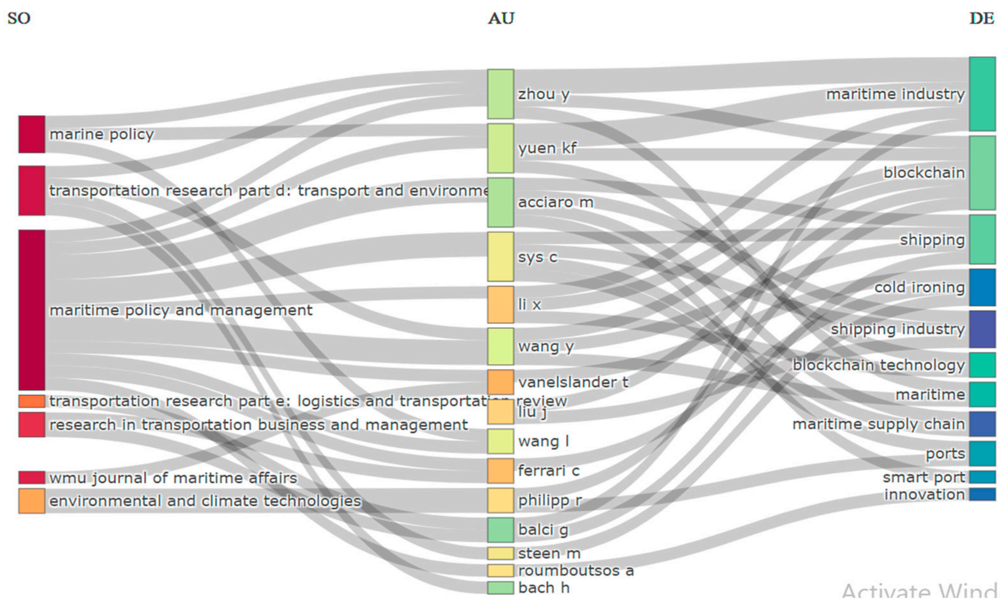

Figure 5. Three-field plot connecting sources, authors, and keywords.

Table 3. Author keywords occurring at least five times.

Keywords	Frequency
Blockchain (or blockchain technology)	25
Shipping	17
Maritime industry	15
Seaports	13
Shore power	10
Digital transformation	9
Autonomous ships	9
Supply chain management	8
Decarbonisation	7
Container	7
Sustainability	6
Smart port	6
Innovation	5
Maritime supply chain	5
Maritime transportation	5

Table 4. Sources contributing at least 3 articles.

Rank	Sources	2024 Impact Factor	Nr. of Documents
1	Maritime Policy & Management	3.6	11
2	Marine Policy	3.7	9
3	Sustainability	3.3	6
4	Transportation Research Part D: Transport and Environment	7.7	6
5	WMU Journal of Maritime Affairs	2.4	6
6	Research in Transportation Business and Management	4.4	5
7	Technological Forecasting and Social Change	13.3	4
8	Journal of Marine Science and Engineering	2.8	4
9	Maritime Business Review	2.79	4
10	Transport Policy	5.3	3
11	Transportation Research Part E: Logistics and Transportation Review	8.8	3

The most cited articles (with a citation count greater than 90) among the 171 selected articles are shown in Table 5. Ref. [80] is by far the most cited and also the oldest. Though published just two years ago, Ref. [81] has the highest number of citations per year (54). In the majority of the titles of these top cited papers, the technological innovation(s) they deal with are mentioned. Though it is beyond the scope of this paper to discuss the many technological innovations discussed in the 171 articles individually, they can be broadly grouped into seven categories: digital, autonomous, energy-efficient ships, information and communication, machinery and equipment, tracing and tracking, and industrial production. Examples of each category are given in Table 6.

Table 5. Top cited articles (citation ≥ 90).

Authors	Title	Cited by	Citations per Year
Giannopoulos (2004) [80]	The application of information and communication technologies in transport	201	9.57
Zis (2019) [52]	Prospects of cold ironing as an emissions reduction option	167	27.83
Schinas and Butler (2016) [82]	Feasibility and commercial considerations of LNG-fueled ships	161	17.89
Lu et al. (2007) [83]	Application of structural equation modeling to evaluate the intention of shippers to use Internet services in liner shipping	135	7.5
Ahmad et al. (2021) [84]	Blockchain applications and architectures for port operations and logistics management	130	32.5
Tan and Sidhu (2022) [85]	Review of RFID and IoT integration in supply chain management	129	43
Greve (2009) [10]	Bigger and safer: The diffusion of competitive advantage	125	7.81
Zhou et al. (2020) [86]	The key challenges and critical success factors of blockchain implementation: Policy implications for Singapore's maritime industry	121	24.20
Gausdal et al. (2018) [60]	Applying blockchain technology: Evidence from Norwegian companies	119	17
Baldi et al. (2020) [87]	The role of solid oxide fuel cells in future ship energy systems	113	22.60
Liu et al. (2023) [81]	Blockchain technology in maritime supply chains: applications, architecture and challenges	108	54
Balci and Surucu-Balci (2021) [88]	Blockchain adoption in the maritime supply chain: Examining barriers and salient stakeholders in containerized international trade	101	25.25
Bach et al. (2020) [20]	Implementing maritime battery-electric and hydrogen solutions: A technological innovation systems analysis	93	18.60
Hogg and Ghosh (2016) [85]	Autonomous merchant vessels: examination of factors that impact the effective implementation of unmanned ships	93	10.33

Table 6. Examples of technological innovations discussed in the 171 papers.

Group of Technologies	Examples of Types of Technologies	Example of References per Type
Digital	Blockchain, digital twins, digital platforms	[84–90]
Autonomous	Autonomous ships, automated container terminals, remote automated vehicles	[91–93]
Energy efficient ships	Shore power, alternative fuels, electric tugboats, scrubber, wind-assisted propulsion technologies	[23,94–96]
Information and communication	Internet, Internet of Things (IOT), 5G, augmented reality	[97–100]
Machinery and equipment	Wearable safety devices, ship bridge, simulator, stack train, diesel engine, air compressor, dehumidifier, inverter welding machine, PV, welding machine, fast ferries, steel hull, double-hull tankers, post-Panamax container ship, indented berth	[10,12,26,101–105]
Tracing and tracking	RFID, X-ray scanning, asset tracking system	[106–108]
Industrial production	Advanced manufacturing technology, additive manufacturing	[109,110]

Regarding the institutions that contributed the most (see Table 7), universities in Asia dominate, followed by European universities, with Shanghai Maritime University as the institution that contributed the most. Regarding the most productive authors, European and Asian share dominance, as reflected in Table 8, with Vanelslander, Thierry, being the most productive author, affiliated with the University of Antwerp.

Table 7. Institutions that contributed the most (≥4 articles).

Affiliation	Articles
Shanghai Maritime University	10
University of Antwerp	8
Dalian Maritime University	7
The Hong Kong Polytechnic University	7
University of the Aegean	6
National Taiwan University	5
Norwegian University of Science and Technology	5
Delft University of Technology	4
Nanyang Technological University	4
University of Genoa	4

Table 8. Most productive authors (≥3 articles).

Authors	Articles
Vanelslander, T.	4
Ferrari, C.	3
Li, X.	3
Liu, J.	3
Philipp, R.	3
Roumboutsos, A.	3
Steen, M.	3
Sys, C.	3
Wang, L.	3
Wang, Y.	3
Yuen, K.F.	3

Overall, the descriptive analysis has provided the following insights regarding this literature: the increased interest reflected in the number of papers published in recent years (since 2019), the high number of technological innovations studied, the dominance of Asian institutions in terms of the number of documents they have contributed, and the dominance of Asian and European authors in terms of productivity. The global nature of this literature is evidenced by the number of multiple-country collaborations. Furthermore, the variety of journals in which this literature is published also demonstrates that this research is approached from different perspectives and is multidisciplinary.

4.2. Knowledge Base of the Literature on the Adoption of Technological Innovations in the Maritime Industry (Q1)

As already explained in Section 3.4 a reference co-citation analysis was carried out to identify the knowledge base of this literature. In line with the principles of co-citation also explained above, a key assumption of this method is that the content of two documents frequently cited together (i.e., frequently appearing together in the reference list of other documents) is related in the sense that they share some textual similarities [28,111]. Of note, the analysis was conducted on the 9119 references of the 171 journal articles identified. The analysis was carried out using the VOSviewer 1.6.20 software with the purpose of identifying networks of documents often co-cited together. The mathematical underpinnings of co-citation analysis are beyond the scope of this paper and can be found in Ref. [75]. In a nutshell, the software uses normalising, mapping, and clustering algorithms to build networks of interconnected documents based on intertextual similarities and (manually) defined citation of cited reference thresholds. As a general rule, the higher the threshold set for a citation of a cited reference, the fewer documents are connected.

The best results obtained in the context of this paper after running the analysis are based on a minimum citation threshold of 3 of a cited reference, with 44 out the 9119 references interconnected and organised into seven clusters, as shown in Figures 6 and 7.

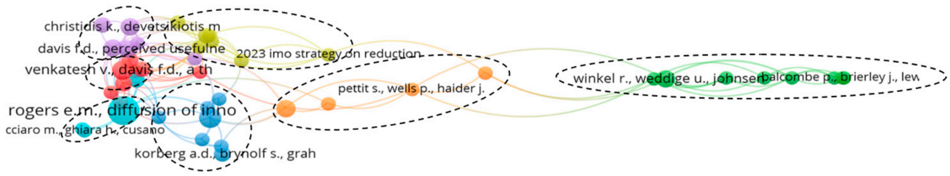

Figure 6. Network visualization of reference co-citation analysis.

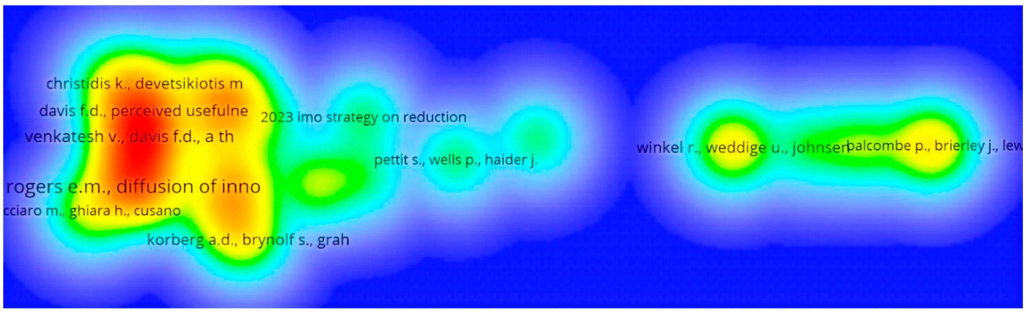

Figure 7. Density visualisation of reference co-citation analysis.

Each sphere in Figure 6 represents a cited reference. The size of the sphere is proportional to the number of citations of a cited reference. The lines between the spheres represent the strength of the interconnection link between the cited references. Finally, spheres of the same colour clustered together represent cited references with the highest levels of similarities between them (and are assumed to be dealing with similar themes or topics). As can be seen in Figure 7, the stronger the link between two cited references, the denser the visualisation. Documents with stronger links are represented in different colours (the strongest links are shown in red and in green the weakest ones), as shown in Figure 7.

Given these results, an attempt is made to name the different clusters of the knowledge base of this literature based on the documents they contain (Figure 6). It is important to note that an in-depth analysis of the content of each of the documents in each of the clusters will necessitate a different type of literature review (e.g., systematic review) and is therefore beyond the scope of this paper. In this first attempt to bring together this rather scattered literature on the adoption of technological innovations in the maritime industry, our aim was to use a robust and objective approach to organise this literature and provide a macro perspective. This is why we opted for a bibliometric approach. The only criteria used for naming the clusters was therefore limited to the titles of the documents since the software clusters together based on intertextual similarities. As also argued by Refs. [112,113], authors choose the titles of their research carefully, and they are indicative of the content of the articles. It is also worth noting that the names proposed were derived based on the data and could be considered as "ideal types" rather than rigid categorizations.

- Cluster 1 (green cluster): Shore power as technological innovation for maritime decarbonisation

The documents belonging to this cluster are shown in Table 9. It can be inferred from the titles of these documents that the broadest topic in this cluster is maritime decarbonisation, with a focus on shore power (or cold ironing) as a technological innovation solution. This cluster is therefore named "shore power as technological innovation for maritime decarbonisation". Issues related to cost, design, regulations, policies, and environmental and economic benefits are addressed by the references in this cluster. These documents are the main documents currently informing research on the adoption of shore power as a decarbonisation solution.

Table 9. Documents in the green cluster.

Documents	Titles
[114]	How to decarbonise international shipping: Options for fuels, technologies and policies
[115]	Cost benefit calculation tool onshore power supply, (2016)
[116]	Technical design aspects of harbour area grid for shore to ship power: State of the art and future solutions
[117]	Environmental assessment and regulatory aspects of cold ironing planning for a maritime route in the Adriatic Sea
[118]	Shore power management for maritime transportation: status and perspectives
[119]	Shore side electricity in Europe: potential and environmental benefits
[94]	Policy implementation barriers and economic analysis of shore power promotion in China
[120]	Is cold ironing hot enough? An actor focus perspective of on shore power supply (ops) at Copenhagen's harbour

- Cluster 2 (red cluster): Autonomous shipping and digital technologies

The documents belonging to this cluster are shown in Table 10. This is a rather heterogeneous cluster in the sense that the focus is on autonomous shipping and digital technologies. As such, it is named "autonomous shipping and digital technologies"; the issues analysed relate to their implementation and their impact in the industry. The main theoretical perspective informing these studies is the technology acceptance model.

Table 10. Documents in the red cluster.

Documents	Titles
[121]	Digitization in maritime logistics—What is there and what is missing?
[91]	Autonomous merchant vessels: examination of factors that impact the effective implementation of unmanned ships
[122]	Technological trajectories and scenarios in seaport digitalization
[123]	Analyzing the economic benefit of unmanned autonomous ships: an exploratory cost-comparison between an autonomous and a conventional bulk carrier
[124]	A theoretical extension of the technology acceptance model: four longitudinal field studies
[125]	User acceptance of information technology: Toward a unified view
[126]	Shipping innovation
[127]	Towards the assessment of potential impact of unmanned vessels on maritime transportation safety

- Cluster 3 (blue cluster): Alternative fuels as a decarbonisation solution

The documents in this cluster are shown in Table 11. This is another heterogeneous cluster that nonetheless can be named "alternative fuels as a decarbonisation solution" given that two documents deal with the topic. The presence of a blockchain-related paper in the cluster could be due to the fact two documents dealing with unrelated topics can both appear in the reference list of more than one document. This is a weakness of the bibliometric approach issued, though it remains a valid and robust review method.

Table 11. Documents in the blue cluster.

Documents	Titles
[128]	Agency theory: An assessment and review
[129]	Alternative marine fuels: Prospects based on multi-criteria decision analysis involving Swedish stakeholders
[130]	Techno-economic assessment of advanced fuels and propulsion systems in future fossil-free ships
[131]	Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers

- Cluster 4 (yellow cluster): Blockchain technology applications in maritime supply chains and logistics

The documents included in this cluster are shown in Table 12. Blockchain is undoubtedly the technological innovation at the centre, with a focus on applications in maritime supply chains and logistics. This justifies why it is named "blockchain technologies applications in maritime supply chains and logistics".

Table 12. Documents in the yellow cluster.

Documents	Titles
[132]	Blockchain in global supply chains and cross border trade: a critical synthesis of the state-of-the-art, challenges and opportunities
[133]	The architectural design requirements of a blockchain-based port community system
[13]	Blockchain adoption from the Shipping industry: An empirical study
[134]	Blockchain's roles in meeting key supply chain management objectives
[135]	Blockchain technology implementation in logistics

- Cluster 5 (light purple cluster): Blockchain technology applications to information communication technologies and transport sustainability.

The documents in this cluster are included in Table 13. Blockchain is the technological innovation addressed, with a focus on applications in information and communication technologies, and transport sustainability, which justifies the chosen name. Research on this thematic area appears to be informed by the user acceptance theory.

Table 13. Documents in the light purple cluster.

Documents	Titles
[136]	Blockchains and smart contracts for the internet of things
[137]	User acceptance of computer technology: A comparison of two theoretical models
[138]	Perceived usefulness, perceived ease of use, and user acceptance of information technology
[60]	Applying blockchain technology: Evidence from Norwegian companies
[139]	Improving maritime transport sustainability using blockchain-based information exchange

- Cluster 6 (deep sky blue): Blockchain applications in maritime digitalisation

The documents included in this cluster are shown in Table 14. Blockchain is also at the centre stage, with a focus on applications in maritime shipping digitalisation, as reflected in the chosen name. This technology appears to be discussed in the context of innovation diffusion.

Table 14. Documents in the deep sky-blue cluster.

Documents	Titles
[140]	Energy management in seaports: A new role for port authorities
[51]	Diffusion of innovations
[141]	Markets and hierarchies: analysis and antitrust implications
[142]	Maritime shipping digitalization: Blockchain-based technology applications, future improvements, and intention to use

- Cluster 7 (orange cluster): Shipping sustainability transitions

The documents included in this cluster are shown in Table 15. The context of these papers is the broader topic of shipping sustainability, with some documents focusing on liquefied natural gas (LNG), regulations, and the conditions for a second socio-technical transition in shipping to occur.

Table 15. Documents in the orange cluster.

Documents	Titles
[143]	Improving sustainability of maritime transport through utilization of liquefied natural gas (LNG) for propulsion
[144]	Revisiting history: Can shipping achieve a second socio-technical transition for carbon emissions reduction?
[145]	Sustainability transitions in Baltic Sea shipping: Exploring the responses of firms to regulatory changes
[146]	Third IMO GHG study

The results of the co-citation analysis of the cited references revealed that the knowledge base of this literature is still relatively recent and is still being built. This is evidenced by the limited number of citations of a cited reference (3) that had to be applied for the network of 44 articles to be built. Of note, a citation threshold of 4 resulted in only 9 of the 9119 references being interconnected and a citation threshold of 5 resulting in only 5 interconnected references. This justifies why the threshold of 3 was selected.

The decrease in the number of interconnected cited references as the threshold of citation of cited reference increases reveals the following about the reviewed papers. First, the knowledge base of the literature on the studied topic constitutes non-influential documents (in the sense of not being very highly cited). A close look at the documents constituting the knowledge base reveals that the quasi-totality of them were published between 2014 and 2021. Given that citations take time to accumulate and depend on the popularity of the topic in the research community, this is understandable. With such a "recent" knowledge base, it can also be inferred that the adoption of technological innovations in the maritime industry is a recent topic, and thus worth exploring, as is being carried out in this paper. Second, the knowledge base of this literature is still in development and will be consolidated and partitioned into distinctive areas, forming the foundation of future research in these areas in the coming years.

In addition, the results also reveal that academic research on the adoption of technological innovations in the maritime industry has predominantly focused on two main technologies: shore power and blockchain. These two thematic areas are well delineated in the knowledge base. Furthermore, they also reveal that though shore power and blockchain technologies currently dominate, there are emerging thematic areas for autonomous ships, alternative fuels, digitalisation, and sustainability transitions that will be consolidated as more research is carried out in these areas. This research is accumulating and serving as the foundation for future research on these topics.

4.3. Research Fronts on the Adoption of Technological Innovations in the Maritime Industry (Q3)

The results of bibliographic coupling are reported and discussed in this section. They are based on a citation threshold of at least 15 citations. As can be seen in Figures 8–10, there are seven (7) research fronts in this literature. Each sphere in Figure 8 represents a published article. The size of each sphere is proportional to the number of citations of the article. The lines between the spheres represent the strength of the interconnection link between the coupled articles. Finally, spheres of the same colour clustered together represent coupled documents with the highest levels of similarities between them (with overlapping bibliographies). As can be seen in Figure 9, the stronger the link between the coupled documents, the denser the visualisation. The period within which the coupled documents were published is shown in Figure 10.

Similar to what has been carried out with the clusters, hereafter an attempt is made to name the different clustered research fronts based on their constituting documents (Figure 8). As for the knowledge base, the naming is based on the titles of the documents, with a focus on the technological innovation examined. Also, the names proposed are based on the data and could be considered "ideal types" rather than rigid categorisations.

- Research front 1 (red cluster): Adoption of shore power as a technological innovation for maritime decarbonisation

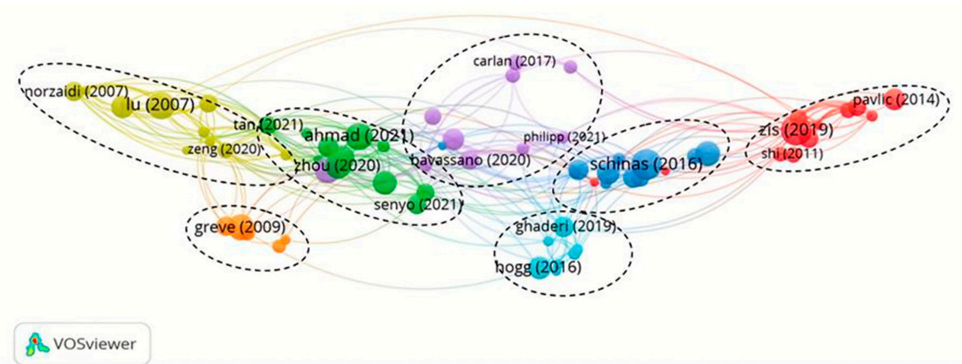

Figure 8. Network visualisation of bibliographic coupling results (based on a citation threshold of at least 15) In red are the strongest link.

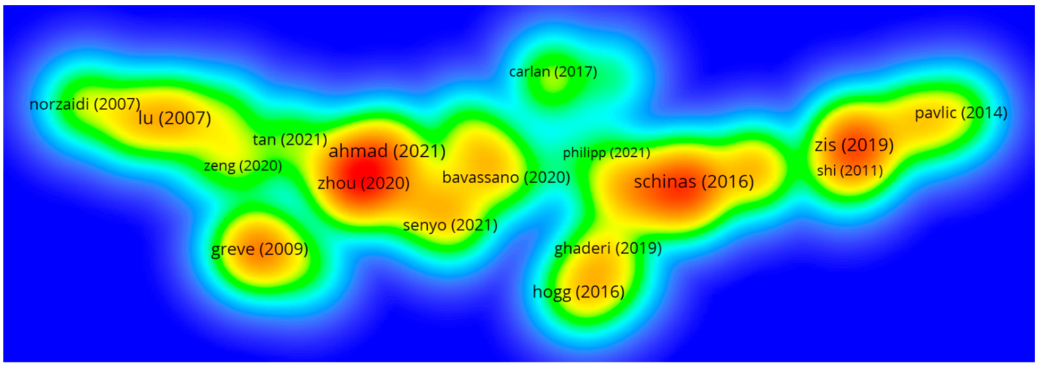

Figure 9. Density visualisation of bibliographic coupling results.

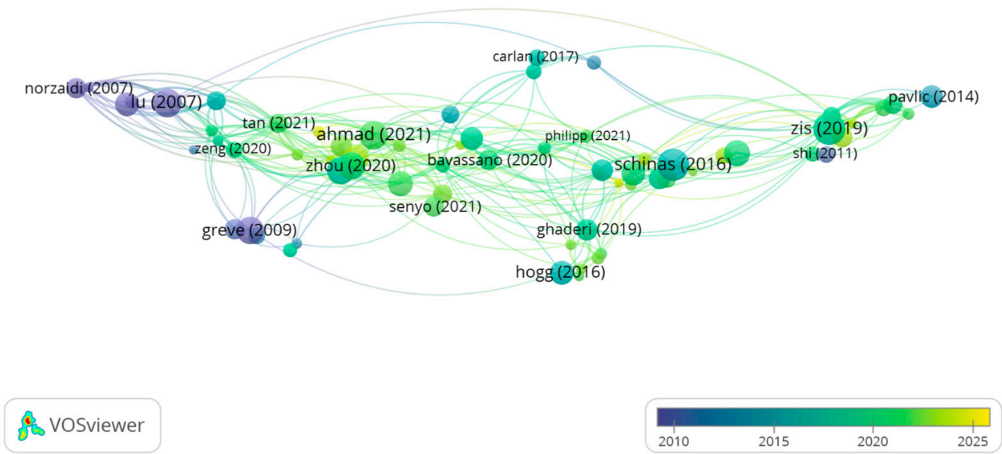

Figure 10. Overlay visualisation of bibliographic coupling results.

The documents included in this cluster are shown in Table 16, in which it can be seen that the main topic for shore power is decarbonisation, with a focus on shore power/cold ironing (7 of the 12 documents dealt with this topic). The adoption of shore power is thus a core trend in this literature and justifies the name chosen. Issues explored in relation to shore power include the role of government subsidies, barriers to adoption, industry-related opinions, emissions reduction potential, and policies that facilitate implementation. The appearance of other decarbonisation technological solutions such as green ammonia, biofuels, and sustainable port infrastructure is understandable, as the authors might have referred to them as examples of other solutions when discussing shore power. On the other hand, the appearance of RFID and automated container terminals in the table is a limitation of bibliographic coupling. As explained by Ref. [147], the bibliographies of two articles can overlap regarding unrelated subject matters.

Table 16. Documents in the red cluster.

Documents	Titles
[148]	Electrification of onshore power systems in maritime transportation towards decarbonization of ports: A review of the cold ironing technology
[149]	A roadmap to alternative fuels for decarbonising shipping: The case of green ammonia
[150]	The global trends of automated container terminal: a systematic literature review
[151]	Optimization of shore power deployment in green ports considering government subsidies
[152]	Sustainable port infrastructure, practical implementation of the green port concept
[61]	Critical barriers to the introduction of shore power supply for green port development: case of Djibouti container terminals
[106]	RFID technology and its application to port-based container logistics
[85]	Adoption of biofuels for marine shipping decarbonization: A long-term price and scalability assessment
[153]	Identifying industry-related opinions on shore power from a survey in China
[154]	A bilevel hybrid economic approach for optimal deployment of onshore power supply in maritime ports
[94]	Policy implementation barriers and economic analysis of shore power promotion in China
[155]	Prospects of cold ironing as an emissions reduction option

- Research front 2 (green cluster): Blockchain technology applications in maritime supply chains and logistics

The documents included in this cluster are shown in Table 17, which highlights how blockchain is the main technological innovation discussed, with an emphasis on its application in maritime supply chains and logistics.

Table 17. Documents in the green cluster.

Documents	Titles
[84]	Blockchain applications and architectures for port operations and logistics management
[88]	Blockchain adoption in the maritime supply chain: Examining barriers and salient stakeholders in containerized international trade
[156]	Technological drivers of seaports' business model innovation: An exploratory case study on the port of Barcelona
[157]	Managing a blockchain-based platform ecosystem for industry-wide adoption: The case of TradeLens
[81]	Blockchain technology in maritime supply chains: applications, architecture and challenges
[158]	Blockchain Adoption for Sustainable Supply Chain Management: Economic, Environmental, and Social Perspectives
[159]	Blockchain Technology for tracking and tracing containers: model and conception
[160]	Blockchain adoption in container shipping: An empirical study on barriers, approaches, and recommendations
[90]	Digital platformisation as public sector transformation strategy: A case of Ghana's paperless port
[161]	Assessing Blockchain Technology application for freight booking business: a case study from Technology Acceptance Model perspective
[86]	The key challenges and critical success factors of blockchain implementation: Policy implications for Singapore's maritime industry

- Research front 3 (blue cluster): Adoption of energy efficient ship technologies

Documents belonging to this research front are shown in Table 18. As evidenced in the titles of the documents, the focus is on energy efficient ship technologies. Examples of technologies analysed from an adoption perspective include hydrogen, electric batteries, biofuels, biogas, LNG, and solid oxide fuel cells. This is a rather homogeneous front, with all documents dealing with the same topic.

Table 18. Documents in the blue cluster.

Documents	Titles
[20]	Implementing maritime battery-electric and hydrogen solutions: A technological innovation systems analysis
[162]	Blending new and old in sustainability transitions: Technological alignment between fossil fuels and biofuels in Norwegian coastal shipping
[87]	The role of solid oxide fuel cells in future ship energy systems
[163]	Adopting different wind-assisted ship propulsion technologies as fleet retrofit: An agent-based modeling approach
[59]	Drivers for and barriers to biogas use in manufacturing, road transport and shipping: a demand-side perspective
[164]	Fuel cell and hydrogen in maritime application: A review on aspects of technology, cost and regulations
[165]	Biofuel as an alternative shipping fuel: technological, environmental and economic assessment
[21]	Drivers and barriers for the large-scale adoption of hydrogen fuel cells by Nordic shipping companies
[22]	Wind technologies: Opportunities and barriers to a low carbon shipping industry
[166]	The impact of split incentives on energy efficiency technology investments in maritime transport
[82]	Feasibility and commercial considerations of LNG-fueled ships

- Research front 4 (yellow cluster): Adoption of ICT and tracking technologies

Documents belonging to this research front are shown in Table 19, the majority of which deal with the adoption of ICTs, followed by tracing and tracking technologies. This justifies the name chosen: "adoption of ICT and tracking technologies".

Table 19. Documents in the yellow cluster.

Documents	Titles
[167]	Critical factors affecting the adoption of container security service: The shippers' perspective
[168]	The facilitating role of IT systems for legal compliance: the case of port community systems and container Verified Gross Mass (VGM)
[13]	Blockchain adoption from the Shipping industry: An empirical study
[12]	Development and validation of a technology acceptance model for safety-enhancing, wearable locating systems
[83]	Application of structural equation modeling to evaluate the intention of shippers to use Internet services in liner shipping
[169]	Intranet usage and managers' performance in the port industry
[170]	A study of RFID adoption for vehicle tracking in a container terminal
[171]	RFID benefits, costs, and possibilities: The economical analysis of RFID deployment in a cruise corporation global service supply chain
[172]	Factors that affect acceptance and use of information systems within the Maritime industry in developing countries: The case of Ghana
[173]	The adoption of open platform for container bookings in the maritime supply chain

- Research front 5 (light purple cluster): Innovation adoption in seaports

Documents in this cluster are shown in Table 20. The emphasis is on innovation adoption in seaports, with blockchain, liquefied biogas, and LNG being discussed. As such, the cluster is named "innovation adoption in seaports".

Table 20. Documents in the light purple cluster.

Documents	Titles
[174]	Are the innovation processes in seaport terminal operations successful?
[175]	Innovation in the maritime sector: aligning strategy with outcomes
[105]	How to turn an innovative concept into a success? An application to seaport-related innovation
[176]	Blockchain: How shipping industry is dealing with the ultimate technological leap
[177]	Digital innovation in the port sector: Barriers and facilitators
[60]	Applying Blockchain technology: Evidence from Norwegian companies
[178]	Blockchain for LBG Maritime Energy Contracting and Value Chain Management: A Green Shipping Business Model for Seaports
[179]	Blockchain and Smart Contracts for Entrepreneurial Collaboration in Maritime Supply Chains
[180]	Towards Green and Smart Seaports: Renewable Energy and Automation Technologies for Bulk Cargo Loading Operations
[181]	The role of port authorities in the development of LNG bunkering facilities in North European ports

- Research front 6 (deep sky-blue cluster): Adoption of maritime autonomous ships

Documents in this cluster are shown in Table 21 below, and all deal with autonomous surface ships. Aspects explored concern public perception, implementation factors, challenges, and regulations.

Table 21. Documents in the deep sky-blue cluster.

Documents	Titles
[17]	Assessing innovation in transport: An application of the Technology Adoption (TechAdo) model to Maritime Autonomous Surface Ships (MASS)
[182]	Autonomous technologies in short sea shipping: trends, feasibility and implications
[183]	An exploratory investigation of public perceptions towards autonomous urban ferries
[91]	Autonomous merchant vessels: examination of factors that impact the effective implementation of unmanned ships
[184]	Maritime Autonomous Surface Ships: Problems and Challenges Facing the Regulatory Process
[18]	Autonomous ships: A study of critical success factors
[185]	Regulatory framework analysis for the unmanned inland waterway vessel

- Research front 7 (orange cluster): Adoption of machinery and equipment

Documents in this cluster are shown in Table 22, with the adoption of machinery and equipment being a core topic. As such, it is named "adoption of machinery and equipment".

Table 22. Documents in the orange cluster.

Documents	Titles
[109]	Digitalizing the maritime industry: A case study of technology acquisition and enabling advanced manufacturing technology
[10]	Bigger and safer: The diffusion of competitive advantage
[26]	Fast and expensive: The diffusion of a disappointing innovation
[186]	Environmental innovation and the role of stakeholder collaboration in West Coast port gateways
[187]	'Information communication technology' innovation in a non-high technology sector: achieving competitive advantage in the shipping industry

The bibliographic coupling analysis revealed that the extant literature on the adoption of technology comprises seven (7) research fronts: adoption of shore power as a technological innovation for maritime decarbonisation, blockchain technology applications in maritime supply chains and logistics, adoption of energy efficient ship technologies, adoption of ICT and tracking technologies, innovation adoption in seaports, and adoption of machinery and equipment. Energy efficient ship technologies (among which shore power is the most studied technology), blockchain, and autonomous ships are of most interest to researchers. This can be explained by the drive towards a cleaner maritime industry. Indeed, though maritime autonomous surface ships and blockchain technologies do not directly contribute to decarbonisation, their adoption has the potential to contribute to more sustainable maritime shipping [188,189].

4.4. Linking the Knowledge Base to Research Fronts

As explained in Section 3.4, co-citation of references and bibliographic coupling were chosen because they are two complementary techniques. The former allowed us to identify seven thematic areas that constitute the knowledge base of the literature under consideration, while the latter allowed us to identify seven research fronts. It was observed that shore power is a well-delineated thematic area of the knowledge base, as well as a key research front. Second, though still a nascent thematic area of the knowledge base, the adoption of autonomous surface ships is a well-delineated research front. Third, blockchain applications in maritime supply chains and logistics is also both a thematic knowledge base area and a research front. Fourth, the knowledge base of the research fronts adoption of ship energy efficient technologies, adoption of ICT and tracking technologies, innovation adoption in seaports, and adoption of machinery and equipment expansion (i.e., as research continues to investigate these areas) will develop in the future.

Given the period covered (1999–2025), the dominance of the knowledge base and of the research fronts based on recent technological popularity trends such as shore power, blockchain, autonomous shipping, and alternative fuels could appear intriguing at first sight. However, a look at Figure 3 reveals that publications on the topic explored pick up in 2016, when these technologies were becoming popular in the maritime domain. In the face of tightening environmental regulations by the IMO, these technologies are the main ones being considered by the industry as solutions for emissions reduction. They have thus attracted much interest from researchers, shifting the balance in the 171 articles towards these recent trends.

5. Conclusions and Trajectories for Future Research

Research on the adoption of technological innovations in the maritime industry has grown considerably in the last five years, and this trend is expected to continue in the current context of maritime decarbonisation. The purpose of this paper was to bring together and synthesise this growing literature. Using performance analysis and science mapping, we analysed 171 journal articles published on the topic. The results of the performance analysis showed the dominance of Asian institutions in terms of the number of documents they have contributed, and the dominance of Asian and European authors in terms of productivity. The global nature of this literature was evidenced by the number of multiple-country collaborations. Through a co-citation analysis of 9119 cited references, it was shown that the extant literature on the adoption of technological innovations in the maritime industry is built on seven thematic knowledge base areas in different stages of development. Finally, through bibliographic coupling of 171 journal articles, it was shown that seven research fronts dominate in this literature. The link between the knowledge base and the research fronts was also established.

The main contributions of this paper are fourfold. First, being the first attempt to bring together this scattered and transdisciplinary literature, it brings clarity and highlights the knowledge base and the research fronts. As such, it lays a strong foundation upon which researchers looking to orientate themselves on the topic can build [28]. Second, by using two objective approaches (co-citation of cited references and bibliographic coupling) to identify the knowledge base and the research fronts of this literature, it contributes to theoretical advancement [190]. Third, its practical contribution relates to the objective assessment and reporting productivity, and impact-related indicators. Fourth, having identified thematic areas of the knowledge base and the research fronts of this literature, it provides editors with a tool they can rely upon to call for special issues to increase the representativeness of themes identified in this paper in their journals. Moreover, the paper also sheds light on the technological innovation adopted in the maritime industry. It has been shown that though many technological innovations have been adopted, the focus of the academic community has been on just a few of these, namely blockchain, shore power, and alternative fuels. More research on other technologies is needed.

This research has the following limitations. The first relates to the bibliometric techniques used. Though bibliometric studies involve rigorous and replicable quantitative approaches, some studies (e.g., [191,192]) have argued that they only provide a macro perspective and miss key insights that can only be revealed through in-depth qualitative approaches. Though this is true to some extent, for the purpose of this paper, the methods used are justified given the large number of documents (171) and cited references analysed (9119). Since the techniques used cannot identify keys issues related to the settings, methods, and types of data used in the analysed papers, they have nonetheless allowed the identification of documents forming the backbone of research on the topic examined, which is an important step for future research. Traditional review approaches might thus be used in future research to complement our results. Such studies might look into the methodology used in the papers constituting the knowledge base and the research fronts of the literature identified in this paper. Another limitation of the techniques used in this paper is that they are citation- and trend-driven. As explained in Section 3.4, while bibliographic coupling favours recent publications, reference co-citation analysis favours older works. The implication is that some relevant research that had not accumulated enough citations might have been missed, given that citation thresholds had to be set. Other studies might also replicate our study using alternative citation thresholds. A further limitation is that the documents analysed were limited to journal articles. Though important documents in the form of conference papers, book chapters, industry reports, or others might have been missed, the choice of focusing only on peer-reviewed journal articles ensured the documents analysed were vetted by the relevant academic community and that the analysis was conducted on documents of high quality.

Author Contributions: Conceptualisation, A.D.; methodology, A.D.; validation, A.T. and C.F.; formal analysis, A.D.; investigation, A.D.; resources, A.T. and C.F.; data curation, A.D., A.T. and C.F.; writing—original draft preparation, A.D. and A.T.; writing—review and editing, A.D., A.T. and C.F.; visualisation, A.D.; supervision, A.T. and C.F.; project administration, A.T.; funding acquisition, A.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research was carried out during the European project Optiwise, funded by HORIZON EUROPE (Climate, Energy & Mobility) with grant agreement No. 101056769.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Appendix A

Keywords combinations used to retrieve articles from Scopus.

Keywords Combinations in Title, Abstract, and Keyword	Articles Retrieved from Scopus
Drivers	
TITLE-ABS-KEY ((“Drivers” OR “factors” OR “triggers” OR “enablers”) AND (“technology*”) AND (“adoption” OR “deployment” OR “implementation” OR “acceptance”) AND (innovation) AND (“shipping” OR “port” OR “maritime industry” OR “ship”)) AND (LIMIT-TO (SRCTYPE, “j”)) AND (LIMIT-TO (LANGUAGE, “English”)) AND (LIMIT-TO (DOCTYPE, “ar”))	29
TITLE-ABS-KEY ((“Drivers” OR “factors” OR “triggers” OR “enablers”) AND “technology*” AND (“adoption” OR “deployment” OR “implementation” OR “acceptance”) AND (“shipping” OR “port” OR (“maritime industry”) OR “ship”)) AND (LIMIT-TO (SRCTYPE, “j”)) AND (LIMIT-TO (DOCTYPE, “ar”) AND (LIMIT-TO (LANGUAGE, “English”))	271
TITLE-ABS-KEY ((drivers OR factors OR triggers OR enablers) AND innovation AND (adoption OR deployment OR implementation OR acceptance) AND (shipping OR port OR (“maritime industry”) OR ship) AND (LIMIT-TO (DOCTYPE, “ar”)) AND (LIMIT-TO (SRCTYPE, “j”)) AND (LIMIT-TO (LANGUAGE, “English”))	55

Keywords Combinations in Title, Abstract, and Keyword	Articles Retrieved from Scopus
TITLE-ABS-KEY ((drivers OR factors OR triggers OR enablers) AND (technology OR innovation) AND (adoption OR deployment OR implementation OR acceptance) AND (shipping OR port OR ("maritime industry") OR ship) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (SRCTYPE, "j"))	297
Barriers	
TITLE-ABS-KEY (("Barriers" OR "obstacles" OR "challenges" OR "impediments" OR "hindrances" OR "constraints" OR "limitations") AND ("adoption" OR "deployment" OR "implementation" OR "acceptance") AND ("technology*") AND innovation* AND ("shipping" OR "port" OR "ship" OR "maritime industry") AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j"))	47
TITLE-ABS-KEY ((barriers OR obstacles OR challenges OR impediments OR hindrances OR constraints OR limitations) AND technology AND (adoption OR deployment OR implementation OR acceptance) AND (shipping OR port OR ship OR ("maritime industry"))) AND (LIMIT-TO (DOCTYPE, "ar") AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (LANGUAGE, "English"))	457
TITLE-ABS-KEY ((barriers OR obstacles OR challenges OR impediments OR hindrances OR constraints OR limitations) AND innovation AND (adoption OR deployment OR implementation OR acceptance) AND (shipping OR port OR ship OR ("maritime industry"))) AND (LIMIT-TO (DOCTYPE, "ar") AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j"))	87
TITLE-ABS-KEY ((barriers OR obstacles OR challenges OR impediments OR hindrances OR constraints OR limitations) AND (innovation OR technology) AND (adoption OR deployment OR implementation OR acceptance) AND (shipping OR port OR ship OR ("maritime industry"))) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English"))	497

References

1. Chalfant, J.; Kite-Powell, H.; Bonfiglio, L.; Chryssostomidis, C. Decarbonization of the Cargo Shipping Fleet. *J. Ship Prod. Des.* **2022**, *38*, 199–214. [CrossRef]
2. Romano, A.; Yang, Z. Decarbonisation of shipping: A state of the art survey for 2000–2020. *Ocean Coast. Manag.* **2021**, *214*, 105936. [CrossRef]
3. King, J. Technology and the course of shipping. *Ocean Coast. Manag.* **2001**, *44*, 567–577. [CrossRef]
4. Strez, C. The dynamics of propulsion technology adoption in the maritime industry: A systems dynamics model of technology transition. In Proceedings of the 16th Annual General Assembly and Conference of the International Association of Maritime Universities, Rijeka, Croatia, 7–10 October 2015.
5. Coşar, A.K.; Demir, B. Shipping inside the box: Containerization and trade. *J. Int. Econ.* **2018**, *114*, 331–345. [CrossRef]
6. Notteboom, T.; Rodrigue, J.-P. The future of containerization: Perspectives from maritime and inland freight distribution. *GeoJournal* **2009**, *74*, 7–22. [CrossRef]
7. Haralambides, H.E. Gigantism in container shipping, ports and global logistics: A time-lapse into the future. *Marit. Econ. Logist.* **2019**, *21*, 1–60. [CrossRef]
8. Tran, N.K.; Haasis, H.-D. An empirical study of fleet expansion and growth of ship size in container liner shipping. *Int. J. Prod. Econ.* **2015**, *159*, 241–253. [CrossRef]
9. Glen, D. Modelling the impact of double hull technology on oil spill numbers. *Marit. Policy Manag.* **2010**, *37*, 475–487. [CrossRef]
10. Greve, H.R. Bigger and safer: The diffusion of competitive advantage. *Strateg. Manag. J.* **2009**, *30*, 1–23. [CrossRef]
11. Buhalis, D.; Papathanassis, A.; Vafeidou, M. Smart cruising: Smart technology applications and their diffusion in cruise tourism. *J. Hosp. Tour. Technol.* **2022**, *13*, 626–649. [CrossRef]
12. Kwee-Meier, S.T.; Bützler, J.E.; Schlick, C. Development and validation of a technology acceptance model for safety-enhancing, wearable locating systems. *Behav. Inform. Technol.* **2016**, *35*, 394–409. [CrossRef]
13. Kapnissis, G.; Vaggelas, G.K.; Leligou, H.C.; Panos, A.; Doumi, M. Blockchain adoption from the Shipping industry: An empirical study. *Marit. Transp. Res.* **2022**, *3*, 100058. [CrossRef]
14. Lin, H.-F. Blockchain adoption in the maritime industry: Empirical evidence from the technological-organizational-environmental framework. *Marit. Policy Manag.* **2023**, *51*, 1474–1496. [CrossRef]

15. Orji, I.J.; Kusi-Sarpong, S.; Huang, S.; Vazquez-Brust, D. Evaluating the factors that influence blockchain adoption in the freight logistics industry. *Transp. Res. Part E Logist. Transp. Rev.* **2020**, *141*, 102025. [CrossRef]
16. Todd, P. Electronic bills of lading, blockchains and smart contracts. *Int. J. Law Inf. Technol.* **2019**, *27*, 339–371. [CrossRef]
17. Fonseca, T.; Lagdami, K.; Schröder-Hinrichs, J.-U. Assessing innovation in transport: An application of the Technology Adoption (TechAdo) model to Maritime Autonomous Surface Ships (MASS). *Transp. Policy* **2021**, *114*, 182–195. [CrossRef]
18. Li, X.; Yuen, K.F. Autonomous ships: A study of critical success factors. *Marit. Econ. Logist.* **2022**, *24*, 228–254. [CrossRef]
19. Park, Y.-J.; Jeong, Y.-J.; An, Y.-S.; Ahn, J.-K. Analyzing the Factors Influencing the Intention to Adopt Autonomous Ships Using the TOE Framework and DOI Theory. *J. Navig. Port. Res.* **2022**, *46*, 134–144.
20. Bach, H.; Bergek, A.; Bjørgum, Ø.; Hansen, T.; Kenzhegaliyeva, A.; Steen, M. Implementing maritime battery-electric and hydrogen solutions: A technological innovation systems analysis. *Transp. Res. Part D Transp. Environ.* **2020**, *87*, 102492. [CrossRef]
21. Latapí, M.; Davíðsdóttir, B.; Jóhannsdóttir, L. Drivers and barriers for the large-scale adoption of hydrogen fuel cells by Nordic shipping companies. *Int. J. Hydrogen Energy* **2023**, *48*, 6099–6119. [CrossRef]
22. Rehmatulla, N.; Parker, S.; Smith, T.; Stulgis, V. Wind technologies: Opportunities and barriers to a low carbon shipping industry. *Mar. Policy* **2017**, *75*, 217–226. [CrossRef]
23. Rojon, I.; Dieperink, C. Blowin' in the wind? Drivers and barriers for the uptake of wind propulsion in international shipping. *Energy Policy* **2014**, *67*, 394–402. [CrossRef]
24. Schwartz, H.; Gustafsson, M.; Spohr, J. Emission abatement in shipping-is it possible to reduce carbon dioxide emissions profitably? *J. Clean. Prod.* **2020**, *254*, 120069. [CrossRef]
25. Shi, J.; Zhu, Y.; Feng, Y.; Yang, J.; Xia, C. A Prompt Decarbonization Pathway for Shipping: Green Hydrogen, Ammonia, and Methanol Production and Utilization in Marine Engines. *Atmosphere* **2023**, *14*, 584. [CrossRef]
26. Greve, H.R. Fast and expensive: The diffusion of a disappointing innovation. *Strateg. Manag. J.* **2011**, *32*, 949–968. [CrossRef]
27. Ferreira, F.A. Mapping the field of arts-based management: Bibliographic coupling and co-citation analyses. *J. Bus. Res.* **2018**, *85*, 348–357. [CrossRef]
28. Vogel, R.; Güttel, W.H. The dynamic capability view in strategic management: A bibliometric review. *Int. J. Manag. Rev.* **2013**, *15*, 426–446. [CrossRef]
29. Dragović, A.; Zrnić, N.; Dragović, B.; Dulebenets, M.A. A comprehensive review of Maritime Bibliometric Studies (2014–2024). *Ocean Eng.* **2024**, *311*, 118917. [CrossRef]
30. Ferrigno, G.; Crupi, A.; Di Minin, A.; Ritala, P. 50+ years of R&D Management: A retrospective synthesis and new research trajectories. *R&D Manag.* **2023**, *53*, 900–926.
31. Faraji, O.; Asiaei, K.; Rezaee, Z.; Bontis, N.; Dolatzarei, E. Mapping the conceptual structure of intellectual capital research: A co-word analysis. *J. Innov. Knowl.* **2022**, *7*, 100202. [CrossRef]
32. Xu, Z.; Ge, Z.; Wang, X.; Skare, M. Bibliometric analysis of technology adoption literature published from 1997 to 2020. *Technol. Forecast. Soc. Change* **2021**, *170*, 120896. [CrossRef]
33. Bai, X.; Hou, Y.; Yang, D. Choose clean energy or green technology? Empirical evidence from global ships. *Transp. Res. Part E Logist. Transp. Rev.* **2021**, *151*, 102364. [CrossRef]
34. IMO. *IMO Approves Net-Zero Regulations for Global Shipping*; International Maritime Organization (IMO): London, UK, 2025; Available online: https://www.imo.org/en/mediacentre/pressbriefings/pages/imo-approves-netzero-regulations.aspx (accessed on 1 May 2025).
35. Sheng, D.; Jiang, J.; Wang, H.; Tan, Z.; Wang, Y. Optimal compliance choices for ocean carriers under the sulphur regulation. *Transp. Res. Part D Transp. Environ.* **2023**, *116*, 103639. [CrossRef]
36. Zhang, X.; Bao, Z.; Ge, Y.-E. Investigating the determinants of shipowners' emission abatement solutions for newbuilding vessels. *Transp. Res. Part D Transp. Environ.* **2021**, *99*, 102989. [CrossRef]
37. Godin, B. Technological innovation: On the origins and development of an inclusive concept. *Technol. Cult.* **2016**, *57*, 527–556. [CrossRef]
38. Akbari, M.; Khodayari, M.; Khaleghi, A.; Danesh, M.; Padash, H. Technological innovation research in the last six decades: A bibliometric analysis. *Eur. J. Innov. Manag.* **2021**, *24*, 1806–1831. [CrossRef]
39. Vaughan, J. Defining technological innovation. *Lib. Technol. Rep.* **2013**, *49*, 10–46.
40. Cambridge Dictionary. Technology. 2005. Available online: https://dictionary.cambridge.org/dictionary/english/technology (accessed on 4 May 2025).
41. Baregheh, A.; Rowley, J.; Sambrook, S. Towards a multidisciplinary definition of innovation. *Manag. Decis.* **2009**, *47*, 1323–1339. [CrossRef]
42. Edison, H.; Bin Ali, N.; Torkar, R. Towards innovation measurement in the software industry. *J. Syst. Softw.* **2013**, *86*, 1390–1407. [CrossRef]
43. Johannessen, J.A.; Olsen, B.; Lumpkin, G.T. Innovation as newness: What is new, how new, and new to whom? *Eur. J. Innov. Manag.* **2001**, *4*, 20–31. [CrossRef]

44. OECD. *The Oslo Manual*; OECD/Euro-Stat: Paris, France, 2005.
45. Varis, M.; Littunen, H. Types of innovation, sources of information and performance in entrepreneurial SMEs. *Eur. J. Innov. Manag.* **2010**, *13*, 128–154. [CrossRef]
46. Du Plessis, M. The role of knowledge management in innovation. *J. Know Manag.* **2007**, *11*, 20–29. [CrossRef]
47. Ettlie, J.E.; Bridges, W.P.; O'keefe, R.D. Organization strategy and structural differences for radical versus incremental innovation. *Manag. Sci.* **1984**, *30*, 682–695. [CrossRef]
48. Butler, J.E. Theories of Technological Innovation as Useful Tools for Corporate Strategy. *Strateg. Manag. J.* **1988**, *9*, 15–29. [CrossRef]
49. Wei, X.; Liu, R.; Chen, W. Meta theories of technological innovation based on the analysis of classic texts. *Heliyon* **2023**, *9*, e16779. [CrossRef]
50. Yadegari, M.; Mohammadi, S.; Masoumi, A.H. Technology adoption: An analysis of the major models and theories. *Technol. Anal. Strateg.* **2022**, 1096–1110. [CrossRef]
51. Rogers, E. *Diffusions of Innovations*; Free Press: New York, NY, USA, 1995.
52. Laribi, S.; Guy, E. Marine energy transition with LNG and electric batteries: A technological adoption analysis of Norwegian ferries. *Marit. Bus. Rev.* **2023**, *8*, 80–96. [CrossRef]
53. Mansfield, E. Technical change and the rate of imitation. *Econometrica* **1961**, *29*, 741–766. [CrossRef]
54. Moore, G. *Crossing the Chasm: Marketing and Selling Technology Products to Mainstream Customers*; HarperCollins: New York, NY, USA, 1999.
55. Frattini, F.; Bianchi, M.; De Massis, A.; Sikimic, U. The role of early adopters in the diffusion of new products: Differences between platform and nonplatform innovations. *J. Prod. Innov. Manag.* **2014**, *31*, 466–488. [CrossRef]
56. Park, S.; Yoon, S.-H. Separating early-adopters from the majority: The case of Broadband Internet access in Korea. *Technol. Forecast. Soc. Change* **2005**, *72*, 301–325. [CrossRef]
57. Rycroft, R.W. Time and technological innovation: Implications for public policy. *Technol. Soc.* **2006**, *28*, 281–301. [CrossRef]
58. Xiao, Y.; Watson, M. Guidance on conducting a systematic literature review. *J. Plan. Educ. Res.* **2019**, *39*, 93–112. [CrossRef]
59. Dahlgren, S.; Kanda, W.; Anderberg, S. Drivers for and barriers to biogas use in manufacturing, road transport and shipping: A demand-side perspective. *Biofuels* **2022**, *13*, 177–188. [CrossRef]
60. Gausdal, A.H.; Czachorowski, K.V.; Solesvik, M.Z. Applying blockchain technology: Evidence from Norwegian companies. *Sustainability* **2018**, *10*, 1985. [CrossRef]
61. Radwan, M.E.; Chen, J.; Wan, Z.; Zheng, T.; Hua, C.; Huang, X. Critical barriers to the introduction of shore power supply for green port development: Case of Djibouti container terminals. *Clean. Technol. Environ.* **2019**, *21*, 1293–1306. [CrossRef]
62. Zhang, X.; Lam, J.S.L. A fuzzy Delphi-AHP-TOPSIS framework to identify barriers in big data analytics adoption: Case of maritime organizations. *Marit. Policy Manag.* **2019**, *46*, 781–801. [CrossRef]
63. Kitchenham, B.; Brereton, O.P.; Budgen, D.; Turner, M.; Bailey, J.; Linkman, S. Systematic literature reviews in software engineering–a systematic literature review. *Inform. Softw. Technol.* **2009**, *51*, 7–15. [CrossRef]
64. Li, X.; Zhou, Y.; Yuen, K.F. Blockchain implementation in the maritime industry: Critical success factors and strategy formulation. *Marit. Policy Manag.* **2022**, *51*, 304–322. [CrossRef]
65. Prussi, M.; Scarlat, N.; Acciaro, M.; Kosmas, V. Potential and limiting factors in the use of alternative fuels in the European maritime sector. *J. Clean. Prod.* **2021**, *291*, 125849. [CrossRef]
66. Wan, C.; Yan, X.; Zhang, D.; Yang, Z. Analysis of risk factors influencing the safety of maritime container supply chains. *Int. J. Ship Trans. Log.* **2019**, *11*, 476–507. [CrossRef]
67. Damian, S.E.; Wong, L.A.; Shareef, H.; Ramachandaramurthy, V.K.; Chan, C.K.; Moh, T.S.Y.; Tiong, M.C. Review on the challenges of hybrid propulsion system in marine transport system. *J. Energy Storage* **2022**, *56*, 105983. [CrossRef]
68. Searcy, T. Harnessing the wind: A case study of applying Flettner rotor technology to achieve fuel and cost savings for Fiji's domestic shipping industry. *Mar. Policy* **2017**, *86*, 164–172. [CrossRef]
69. Wiśnicki, B.; Wagner, N.; Wołejsza, P. Critical areas for successful adoption of technological innovations in sea shipping–the autonomous ship case study. *Innovation* **2021**, *37*, 582–608. [CrossRef]
70. Okoli, C.; Schabram, K. A Guide to Conducting a Systematic Literature Review of Information Systems Research. Available online: https://ssrn.com/abstract=1954824 (accessed on 10 January 2025).
71. Zupic, I.; Čater, T. Bibliometric Methods in Management and Organization. *Organ. Res. Methods* **2015**, *18*, 429–472. [CrossRef]
72. Dabić, M.; Marzi, G.; Vlačić, B.; Daim, T.U.; Vanhaverbeke, W. 40 years of excellence: An overview of Technovation and a roadmap for future research. *Technovation* **2021**, *106*, 102303. [CrossRef]
73. Nesari, M.; Naghizadeh, M.; Ghazinoori, S.; Manteghi, M. The evolution of socio-technical transition studies: A scientometric analysis. *Technol. Soc.* **2022**, *68*, 101834. [CrossRef]
74. Li, K.X.; Li, M.; Zhu, Y.; Yuen, K.F.; Tong, H.; Zhou, H. Smart port: A bibliometric review and future research directions. *Transp. Res. Part E Logist. Transp. Rev.* **2023**, *174*, 103098. [CrossRef]

75. van Eck, N.J.; Waltman, L. Visualizing Bibliometric Networks. In *Measuring Scholarly Impact: Methods and Practice*; Ding, Y., Rousseau, R., Wolfram, D., Eds.; Springer International Publishing: Basel, Switzerland, 2014; pp. 285–320.
76. Aria, M.; Cuccurullo, C. Bibliometrix: An R-tool for comprehensive science mapping analysis. *J. Informetr.* **2017**, *11*, 959–975. [CrossRef]
77. Cobo, M.J.; López-Herrera, A.G.; Herrera-Viedma, E.; Herrera, F. An approach for detecting, quantifying, and visualizing the evolution of a research field: A practical application to the Fuzzy Sets Theory field. *J. Informetr.* **2011**, *5*, 146–166. [CrossRef]
78. Donthu, N.; Kumar, S.; Mukherjee, D.; Pandey, N.; Lim, W.M. How to conduct a bibliometric analysis: An overview and guidelines. *J. Bus. Res.* **2021**, *133*, 285–296. [CrossRef]
79. Boyack, K.W.; Klavans, R. Co-citation analysis, bibliographic coupling, and direct citation: Which citation approach represents the research front most accurately? *J. Am. Soc. Inf. Sci. Tec.* **2010**, *61*, 2389–2404. [CrossRef]
80. Giannopoulos, G.A. The application of information and communication technologies in transport. *Eur. J. Oper. Res.* **2004**, *152*, 302–320. [CrossRef]
81. Liu, J.; Zhang, H.; Zhen, L. Blockchain technology in maritime supply chains: Applications, architecture and challenges. *Int. J. Prod. Res.* **2023**, *61*, 3547–3563. [CrossRef]
82. Schinas, O.; Butler, M. Feasibility and commercial considerations of LNG-fueled ships. *Ocean Eng.* **2016**, *122*, 84–96. [CrossRef]
83. Lu, C.-S.; Lai, K.-h.; Cheng, T.C.E. Application of structural equation modeling to evaluate the intention of shippers to use Internet services in liner shipping. *Eur. J. Oper. Res.* **2007**, *180*, 845–867. [CrossRef]
84. Ahmad, R.W.; Hasan, H.; Jayaraman, R.; Salah, K.; Omar, M. Blockchain applications and architectures for port operations and logistics management. *Res. Transp. Bus. Manag.* **2021**, *41*, 100620. [CrossRef]
85. Tan, W.C.; Sidhu, M.S. Review of RFID and IoT integration in supply chain management. *Oper. Res. Perspect.* **2022**, *9*, 100229. [CrossRef]
86. Zhou, Y.; Soh, Y.S.; Loh, H.S.; Yuen, K.F. The key challenges and critical success factors of blockchain implementation: Policy implications for Singapore's maritime industry. *Mar. Policy* **2020**, *122*, 104265. [CrossRef]
87. Baldi, F.; Moret, S.; Tammi, K.; Maréchal, F. The role of solid oxide fuel cells in future ship energy systems. *Energy* **2020**, *194*, 116811. [CrossRef]
88. Balci, G.; Surucu-Balci, E. Blockchain adoption in the maritime supply chain: Examining barriers and salient stakeholders in containerized international trade. *Transp. Res. Part E Logist. Transp. Rev.* **2021**, *156*, 102539. [CrossRef]
89. Koilo, V. Unlocking the sustainable value with digitalization: Views of maritime stakeholders on business opportunities. *Probl. Perspect. Manag.* **2024**, *22*, 401–417. [CrossRef]
90. Senyo, P.K.; Effah, J.; Osabutey, E.L.C. Digital platformisation as public sector transformation strategy: A case of Ghana's paperless port. *Technol. Forecast. Soc. Change* **2021**, *162*, 120387. [CrossRef]
91. Hogg, T.; Ghosh, S. Autonomous merchant vessels: Examination of factors that impact the effective implementation of unmanned ships. *Aust. J. Marit. Ocean Aff.* **2016**, *8*, 206–222. [CrossRef]
92. Majoral, G.; Reyes, A.; Saurí, S. Lessons from Reality on Automated Container Terminals: What Can Be Expected from Future Technological Developments? *Transp. Res. Rec.* **2023**, *2678*, 401–415. [CrossRef]
93. Hadley, M.; Pourzanjani, M. How remote is remote pilotage? *WMU J. Marit. Aff.* **2003**, *2*, 181–197. [CrossRef]
94. Yin, M.; Wang, Y.; Zhang, Q. Policy implementation barriers and economic analysis of shore power promotion in China. *Transp. Res. Part D Transp. Environ.* **2020**, *87*, 102506. [CrossRef]
95. Devarapali, S.; Manske, A.; Khayamim, R.; Jacobs, E.; Li, B.; Elmi, Z.; Dulebenets, M.A. Electric tugboat deployment in maritime transportation: Detailed analysis of advantages and disadvantages. *Marit. Bus. Rev.* **2024**, *9*, 263–291. [CrossRef]
96. Ho, T.C.; Lee, H.S. An Analysis of the Technology, Service Quality, and Relevance for CSBC Corporation: Taiwan's Installation of Scrubber Systems. *Sustainability* **2023**, *15*, 5641. [CrossRef]
97. Pisanias, N.; Willcocks, L. Understanding slow Internet adoption: 'Infomediation'; in ship-broking markets. *J. Inf. Technol.* **1999**, *14*, 399–413. [CrossRef]
98. Singh, S.; Lakshay; Pratap, S.; Jauhar, S.K. Unveiling barriers to IoT adoption in the maritime freight industry. *Int. J. Syst. Assur. Eng. Manag.* **2024**, *15*, 1–11.
99. Potter, A.; Wang, Y.; Naim, M. Scaling-up 5G adoption in smart ports: Barriers and enablers. *Marit. Policy Manag.* **2024**, *52*, 517–534. [CrossRef]
100. O'Keeffe, V.; Jang, R.; Manning, K.; Trott, R.; Howard, S.; Hordacre, A.-L.; Spoehr, J. Forming a view: A human factors case study of augmented reality collaboration in assembly. *Ergonomics* **2024**, *67*, 1828–1844. [CrossRef]
101. Danielsen, B.-E.; Lützhöft, M.; Haavik, T.K.; Johnsen, S.O.; Porathe, T. "Seafarers should be navigating by the stars": Barriers to usability in ship bridge design. *Cogn. Technol. Work* **2022**, *24*, 675–691. [CrossRef]
102. Kim, T.E.; Sharma, A.; Bustgaard, M.; Gyldensten, W.C.; Nymoen, O.K.; Tusher, H.M.; Nazir, S. The continuum of simulator-based maritime training and education. *WMU J. Marit. Aff.* **2021**, *20*, 135–150. [CrossRef]

103. Stapleton, A.; Hanna, J.B. Technological Innovation Adoption: An Empirical Investigation of Steamship Line Sales Force Integration. *Transp. J.* **2002**, *41*, 5–22.
104. Liu, J.; Liao, R.; Dong, F.; Huang, C.; Li, H.; Liu, J.; Zhao, T. Low-carbon technology selection and carbon reduction potential assessment in the shipbuilding industry with dynamically changing grid emission factors. *J. Clean. Prod.* **2024**, *441*, 140707. [CrossRef]
105. Arduino, G.; Aronietis, R.; Crozet, Y.; Frouws, K.; Ferrari, C.; Guihéry, L.; Kapros, S.; Kourounioti, I.; Laroche, F.; Lambrou; et al. How to turn an innovative concept into a success? An application to seaport-related innovation. *Res. Transp. Econ.* **2013**, *42*, 97–107. [CrossRef]
106. Shi, X.; Tao, D.; Voß, S. RFID Technology and its Application to Port-Based Container Logistics. *J. Org. Comp. Elect. Com.* **2011**, *21*, 332–347. [CrossRef]
107. Min, H.; Park, J.-W.; Lim, Y.-K.; So, A.; Cho, Y.K. Challenges and opportunities for implementing X-ray scanning technology at the Korean hub ports. *Int. J. Logist. Syst. Manag.* **2016**, *25*, 513–531. [CrossRef]
108. Choi, H.; Baek, Y.; Lee, B. Design and implementation of practical asset tracking system in container terminals. *Int. J. Precis. Eng. Man.* **2012**, *13*, 1955–1964. [CrossRef]
109. Ellingsen, O.; Aasland, K.E. Digitalizing the maritime industry: A case study of technology acquisition and enabling advanced manufacturing technology. *J. Eng. Technol. Manag.* **2019**, *54*, 12–27. [CrossRef]
110. Kostidi, E.; Nikitakos, N.; Progoulakis, I. Additive manufacturing and maritime spare parts: Benefits and obstacles for the end-users. *J. Mar. Sci. Eng.* **2021**, *9*, 895. [CrossRef]
111. Small, H. Co-citation in the scientific literature: A new measure of the relationship between two documents. *J. Am. Soc. Inform. Sci.* **1973**, *24*, 265–269. [CrossRef]
112. Bowman, D.; Kinnan, S. Creating effective titles for your scientific publications. *VideoGIE* **2018**, *3*, 260–261. [CrossRef]
113. Tullu, M.S. Writing the title and abstract for a research paper: Being concise, precise, and meticulous is the key. *Saudi J. Anaesth.* **2019**, *13* (Suppl. S1), S12–S17. [CrossRef]
114. Balcombe, P.; Brierley, J.; Lewis, C.; Skatvedt, L.; Speirs, J.; Hawkes, A.; Staffell, I. How to decarbonise international shipping: Options for fuels, technologies and policies. *Energy Convers. Manag.* **2019**, *182*, 72–88. [CrossRef]
115. 'T Hoen, M.; den Boer, E. *Cost Benefit Calculation Tool Onshore Power Supply*; C. Delft: Valle de los Molinos, Mexico, 2016.
116. Kumar, J.; Kumpulainen, L.; Kauhaniemi, K. Technical design aspects of harbour area grid for shore to ship power: State of the art and future solutions. *Int. J. Electr. Power* **2019**, *104*, 840–852. [CrossRef]
117. Piccoli, T.; Fermeglia, M.; Bosich, D.; Bevilacqua, P.; Sulligoi, G. Environmental assessment and regulatory aspects of cold ironing planning for a maritime route in the Adriatic Sea. *Energies* **2021**, *14*, 5836. [CrossRef]
118. Qi, J.; Wang, S.; Peng, C. Shore power management for maritime transportation: Status and perspectives. *Marit. Transp. Res.* **2020**, *1*, 100004. [CrossRef]
119. Winkel, R.; Weddige, U.; Johnsen, D.; Hoen, V.; Papaefthimiou, S. Shore side electricity in Europe: Potential and environmental benefits. *Energy Policy* **2016**, *88*, 584–593. [CrossRef]
120. Zanetti, S.L. Is Cold Ironing Hot Enough? An Actor Focus Perspective of on Shore Power Supply (OPS) at Copenhagen's Harbour. Master's Thesis, Lund University, Lund, Sweden, 2013.
121. Fruth, M.; Teuteberg, F. Digitization in maritime logistics-What is there and what is missing? *Cogent Bus. Manag.* **2017**, *4*, 1411066. [CrossRef]
122. Inkinen, T.; Helminen, R.; Saarikoski, J. Technological trajectories and scenarios in seaport digitalization. *Res. Transp. Bus. Manag.* **2021**, *41*, 100633. [CrossRef]
123. Kretschmann, L.; Burmeister, H.-C.; Jahn, C. Analyzing the economic benefit of unmanned autonomous ships: An exploratory cost-comparison between an autonomous and a conventional bulk carrier. *Res. Transp. Bus. Manag.* **2017**, *25*, 76–86. [CrossRef]
124. Venkatesh, V.; Davis, F.D. A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Manag. Sci.* **2000**, *46*, 186–204. [CrossRef]
125. Venkatesh, V.; Morris, M.G.; Davis, G.B.; Davis, F.D. User acceptance of information technology: Toward a unified view. *MIS Q.* **2003**, *27*, 425–478. [CrossRef]
126. Wijnolst, N.; Wergeland, T.; Levander, K. *Shipping Innovation*; IOS Press: Amsterdam, The Netherlands, 2009.
127. Wróbel, K.; Montewka, J.; Kujala, P. Towards the assessment of potential impact of unmanned vessels on maritime transportation safety. *Reliab. Eng. Syst. Safe* **2017**, *165*, 155–169. [CrossRef]
128. Eisenhardt, K.M. Agency theory: An assessment and review. *Acad. Manag. Rev.* **1989**, *14*, 57–74. [CrossRef]
129. Hansson, J.; Månsson, S.; Brynolf, S.; Grahn, M. Alternative marine fuels: Prospects based on multi-criteria decision analysis involving Swedish stakeholders. *Biomass Bioenergy* **2019**, *126*, 159–173. [CrossRef]
130. Korberg, A.D.; Brynolf, S.; Grahn, M.; Skov, I.R. Techno-economic assessment of advanced fuels and propulsion systems in future fossil-free ships. *Renew. Sust. Energy Rev.* **2021**, *142*, 110861. [CrossRef]

131. Kouhizadeh, M.; Saberi, S.; Sarkis, J. Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers. *Int. J. Prod. Econ.* **2021**, *231*, 107831. [CrossRef]
132. Chang, Y.; Iakovou, E.; Shi, W. Blockchain in global supply chains and cross border trade: A critical synthesis of the state-of-the-art, challenges and opportunities. *Int. J. Prod. Res.* **2020**, *58*, 2082–2099. [CrossRef]
133. Irannezhad, E. The architectural design requirements of a blockchain-based port community system. *Logistics* **2020**, *4*, 30. [CrossRef]
134. Kshetri, N. Blockchain's roles in meeting key supply chain management objectives. *Int. J. Inform. Manag.* **2018**, *39*, 80–89. [CrossRef]
135. Tijan, E.; Aksentijević, S.; Ivanić, K.; Jardas, M. Blockchain technology implementation in logistics. *Sustainability* **2019**, *11*, 1185. [CrossRef]
136. Christidis, K.; Devetsikiotis, M. Blockchains and smart contracts for the internet of things. *IEEE Access* **2016**, *4*, 2292–2303. [CrossRef]
137. Davis, F.D.; Bagozzi, R.P.; Warshaw, P.R. User acceptance of computer technology: A comparison of two theoretical models. *Manag. Sci.* **1989**, *35*, 982–1003. [CrossRef]
138. Davis, F.D. Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Q.* **1989**, *13*, 319–340. [CrossRef]
139. Jović, M.; Tijan, E.; Žgaljić, D.; Aksentijević, S. Improving maritime transport sustainability using blockchain-based information exchange. *Sustainability* **2020**, *12*, 8866. [CrossRef]
140. Acciaro, M.; Ghiara, H.; Cusano, M.I. Energy management in seaports: A new role for port authorities. *Energy Policy* **2014**, *71*, 4–12. [CrossRef]
141. Williamson, O.E. *Markets and Hierarchies: Analysis and Antitrust Implications: A Study in the Economics of Internal Organization*; Free Press: New York, NY, USA, 1975.
142. Yang, C.-S. Maritime shipping digitalization: Blockchain-based technology applications, future improvements, and intention to use. *Transp. Res. Part E Logist. Transp. Rev.* **2019**, *131*, 108–117. [CrossRef]
143. Burel, F.; Taccani, R.; Zuliani, N. Improving sustainability of maritime transport through utilization of Liquefied Natural Gas (LNG) for propulsion. *Energy* **2013**, *57*, 412–420. [CrossRef]
144. Pettit, S.; Wells, P.; Haider, J.; Abouarghoub, W. Revisiting history: Can shipping achieve a second socio-technical transition for carbon emissions reduction? *Transp. Res. Part D Transp. Environ.* **2018**, *58*, 292–307. [CrossRef]
145. Stalmokaitė, I.; Yliskylä-Peuralahti, J. Sustainability transitions in Baltic Sea shipping: Exploring the responses of firms to regulatory changes. *Sustainability* **2019**, *11*, 1916. [CrossRef]
146. Smith, T.; Jalkanen, J.; Anderson, B.; Corbett, J.; Faber, J.; Hanayama, S.; O'keeffe, E.; Parker, S.; Johansson, L.; Aldous, L. *Third IMO Greenhouse Gas Study*; International Maritime Organization: London, UK, 2014.
147. Garfield, E. From bibliographic coupling to co-citation analysis via algorithmic. In *A Citationist's Tribute to Belver C. Griffith*; Lazerow Lecture presented at Drexel University: Philadelphia, PA, USA, 2001.
148. Abu Bakar, N.N.; Bazmohammadi, N.; Vasquez, J.C.; Guerrero, J.M. Electrification of onshore power systems in maritime transportation towards decarbonization of ports: A review of the cold ironing technology. *Renew. Sustain. Energy Rev.* **2023**, *178*, 113243. [CrossRef]
149. Balci, G.; Phan, T.T.N.; Surucu-Balci, E.; Iris, Ç. A roadmap to alternative fuels for decarbonising shipping: The case of green ammonia. *Res. Transp. Bus. Manag.* **2024**, *53*, 101100. [CrossRef]
150. Kon, W.K.; Abdul Rahman, N.S.F.; Md Hanafiah, R.; Abdul Hamid, S. The global trends of automated container terminal: A systematic literature review. *Marit. Bus. Rev.* **2021**, *6*, 206–233. [CrossRef]
151. Lu, H.; Huang, L. Optimization of shore power deployment in green ports considering government subsidies. *Sustainability* **2021**, *13*, 1640. [CrossRef]
152. Pavlic, B.; Cepak, F.; Sucic, B.; Peckaj, M.; Kandus, B. Sustainable port infrastructure, practical implementation of the green port concept. *Therm. Sci.* **2014**, *18*, 935–948. [CrossRef]
153. Wang, J.; Zhong, M.; Wang, T.; Ge, Y.E. Identifying industry-related opinions on shore power from a survey in China. *Transp. Policy* **2023**, *134*, 65–81. [CrossRef]
154. Wang, L.; Liang, C.; Shi, J.; Molavi, A.; Lim, G.; Zhang, Y. A bilevel hybrid economic approach for optimal deployment of onshore power supply in maritime ports. *Appl. Energy* **2021**, *292*, 116892. [CrossRef]
155. Zis, T.P.V. Prospects of cold ironing as an emissions reduction option. *Transp. Res. Part A Pol. Pract.* **2019**, *119*, 82–95. [CrossRef]
156. Henríquez, R.; Martínez de Osés, F.X.; Martínez Marín, J.E. Technological drivers of seaports' business model innovation: An exploratory case study on the port of Barcelona. *Res. Transp. Bus. Manag.* **2022**, *43*, 100803. [CrossRef]
157. Jovanovic, M.; Kostić, N.; Sebastian, I.M.; Sedej, T. Managing a blockchain-based platform ecosystem for industry-wide adoption: The case of TradeLens. *Technol. Forecast. Soc. Change* **2022**, *184*, 121981. [CrossRef]

158. Munir, M.A.; Habib, M.S.; Hussain, A.; Shahbaz, M.A.; Qamar, A.; Masood, T.; Sultan, M.; Mujtaba, M.A.; Imran, S.; Hasan, M.; et al. Blockchain Adoption for Sustainable Supply Chain Management: Economic, Environmental, and Social Perspectives. *Front. Energy Res.* **2022**, *10*, 899632. [CrossRef]
159. Nasih, S.; Arezki, S.; Gadi, T. Blockchain Technology for tracking and tracing containers: Model and conception. *Data Metadata* **2024**, *3*, 373. [CrossRef]
160. Nguyen, S.; Chen, P.S.L.; Du, Y. Blockchain adoption in container shipping: An empirical study on barriers, approaches, and recommendations. *Mar. Policy* **2023**, *155*, 105724. [CrossRef]
161. Tan, W.K.A.; Sundarakani, B. Assessing Blockchain Technology application for freight booking business: A case study from Technology Acceptance Model perspective. *J. Glob. Oper. Strateg. Sourc.* **2021**, *14*, 202–223. [CrossRef]
162. Bach, H.; Mäkitie, T.; Hansen, T.; Steen, M. Blending new and old in sustainability transitions: Technological alignment between fossil fuels and biofuels in Norwegian coastal shipping. *Energy Res. Soc. Sci.* **2021**, *74*, 101957. [CrossRef]
163. Chica, M.; Hermann, R.R.; Lin, N. Adopting different wind-assisted ship propulsion technologies as fleet retrofit: An agent-based modeling approach. *Technol. Forecast. Soc. Change* **2023**, *192*, 122559. [CrossRef]
164. Fu, Z.; Lu, L.; Zhang, C.; Xu, Q.; Zhang, X.; Gao, Z.; Li, J. Fuel cell and hydrogen in maritime application: A review on aspects of technology, cost and regulations. *Sustain. Energy Technol. Assess.* **2023**, *57*, 103181. [CrossRef]
165. Kesieme, U.; Pazouki, K.; Murphy, A.; Chrysanthou, A. Biofuel as an alternative shipping fuel: Technological, environmental and economic assessment. *Sustain. Energy Fuels* **2019**, *3*, 899–909. [CrossRef]
166. Rehmatulla, N.; Smith, T. The impact of split incentives on energy efficiency technology investments in maritime transport. *Energy Policy* **2020**, *147*, 111721. [CrossRef]
167. Chao, S.L.; Lin, P.S. Critical factors affecting the adoption of container security service: The shippers' perspective. *Int. J. Prod. Econ.* **2009**, *122*, 67–77. [CrossRef]
168. Fedi, L.; Lavissiere, A.; Russell, D.; Swanson, D. The facilitating role of IT systems for legal compliance: The case of port community systems and container Verified Gross Mass (VGM). *Supply Chain Forum* **2019**, *20*, 29–42. [CrossRef]
169. Norzaidi, M.D.; Chong, S.C.; Murali, R.; Salwani, M.I. Intranet usage and managers' performance in the port industry. *Ind. Manag. Data Syst.* **2007**, *107*, 1227–1250. [CrossRef]
170. Ting, S.L.; Wang, L.X.; Ip, W. A study on RFID adoption for vehicle tracking in container terminal. *J. Ind. Eng. Manag.* **2012**, *5*, 22–52. [CrossRef]
171. Véronneau, S.; Roy, J. RFID benefits, costs, and possibilities: The economical analysis of RFID deployment in a cruise corporation global service supply chain. *Int. J. Prod. Econ.* **2009**, *122*, 692–702. [CrossRef]
172. Wiafe, I.; Koranteng, F.N.; Tettey, T.; Kastriku, F.A.; Abdulai, J.-D. Factors that affect acceptance and use of information systems within the Maritime industry in developing countries: The case of Ghana. *J. Syst. Inf. Technol.* **2020**, *22*, 21–45. [CrossRef]
173. Zeng, F.; Chan, H.K.; Pawar, K. The adoption of open platform for container bookings in the maritime supply chain. *Transp. Res. Part E Logist. Transp. Rev.* **2020**, *141*, 102019. [CrossRef]
174. Acciaro, M.; Ferrari, C.; Lam, J.S.L.; Macario, R.; Roumboutsos, A.; Sys, C.; Tei, A.; Vanelslander, T. Are the innovation processes in seaport terminal operations successful? *Marit. Policy Manag.* **2018**, *45*, 787–802. [CrossRef]
175. Acciaro, M.; Sys, C. Innovation in the maritime sector: Aligning strategy with outcomes. *Marit. Policy Manag.* **2020**, *47*, 1045–1063. [CrossRef]
176. Bavassano, G.; Ferrari, C.; Tei, A. Blockchain: How shipping industry is dealing with the ultimate technological leap. *Res. Transp. Bus. Manag.* **2020**, *34*, 100428. [CrossRef]
177. Carlan, V.; Sys, C.; Vanelslander, T.; Roumboutsos, A. Digital innovation in the port sector: Barriers and facilitators. *Compet. Regul. Netw. Ind.* **2017**, *18*, 71–93. [CrossRef]
178. Philipp, R. Blockchain for LBG Maritime Energy Contracting and Value Chain Management: A Green Shipping Business Model for Seaports. *Environ. Clim. Technol.* **2020**, *24*, 329–349. [CrossRef]
179. Philipp, R.; Prause, G.; Gerlitz, L. Blockchain and Smart Contracts for Entrepreneurial Collaboration in Maritime Supply Chains. *Transp. Telecommun.* **2019**, *20*, 365–378. [CrossRef]
180. Philipp, R.; Prause, G.; Olaniyi, E.O.; Lemke, F. Towards Green and Smart Seaports: Renewable Energy and Automation Technologies for Bulk Cargo Loading Operations. *Environ. Clim. Technol.* **2021**, *25*, 650–665. [CrossRef]
181. Wang, S.; Notteboom, T. The role of port authorities in the development of LNG bunkering facilities in North European ports. *WMU J. Marit. Aff.* **2015**, *14*, 61–92. [CrossRef]
182. Ghaderi, H. Autonomous technologies in short sea shipping: Trends, feasibility and implications. *Transp. Rev.* **2019**, *39*, 152–173. [CrossRef]
183. Goerlandt, F.; Pulsifer, K. An exploratory investigation of public perceptions towards autonomous urban ferries. *Safety Sci.* **2022**, *145*, 105496. [CrossRef]
184. Issa, M.; Ilinca, A.; Ibrahim, H.; Rizk, P. Maritime Autonomous Surface Ships: Problems and Challenges Facing the Regulatory Process. *Sustainability* **2022**, *14*, 15630. [CrossRef]

185. Nzengu, W.; Faivre, J.; Pauwelyn, A.-S.; Bolbot, V.; Lien Wennersberg, L.A.; Theotokatos, G. Regulatory framework analysis for the unmanned inland waterway vessel. *WMU J. Marit. Aff.* **2021**, *20*, 357–376. [CrossRef]
186. Hall, P.V.; O'Brien, T.; Woudsma, C. Environmental innovation and the role of stakeholder collaboration in West Coast port gateways. *Res. Transp. Econ.* **2013**, *42*, 87–96. [CrossRef]
187. Poulis, E.; Poulis, K.; Dooley, L. 'Information communication technology' innovation in a non-high technology sector: Achieving competitive advantage in the shipping industry. *Serv. Ind. J.* **2013**, *33*, 594–608. [CrossRef]
188. Alamoush, A.S.; Ölçer, A.I.; Ballini, F. Drivers, opportunities, and barriers, for adoption of Maritime Autonomous Surface Ships (MASS). *J. Int. Marit. Saf. Environ. Aff. Ship.* **2024**, *8*, 2411183. [CrossRef]
189. Plomaritou, E.; Jeropoulos, S. The digitalisation in chartering business: Special reference to the role of e-bill of lading in the bulk and liner markets. *J. Ship Trade* **2022**, *7*, 28. [CrossRef]
190. Mukherjee, D.; Lim, W.M.; Kumar, S.; Donthu, N. Guidelines for advancing theory and practice through bibliometric research. *J. Bus. Res.* **2022**, *148*, 101–115. [CrossRef]
191. Breslin, D.; Bailey, K. Expanding the conversation through 'Debate Essays' and 'Review Methodology'papers. *Int. J. Manag. Rev.* **2020**, *22*, 219–221. [CrossRef]
192. Post, C.; Sarala, R.; Gatrell, C.; Prescott, J.E. Advancing theory with review articles. *J. Manag. Stud.* **2020**, *57*, 351–376. [CrossRef]