Journal of
Marine Science and Engineering

MDPI

Review

Sustainable Maritime Transport: A Review of Intelligent Shipping Technology and Green Port Construction Applications

Guangnian Xiao [1], Yiqun Wang [1], Ruijing Wu [2,*], Jinpei Li [3] and Zhaoyun Cai [4]

[1] School of Economics and Management, Shanghai Maritime University, Shanghai 201306, China; gnxiao@shmtu.edu.cn (G.X.); 202330710078@stu.shmtu.edu.cn (Y.W.)
[2] School of International Business Administration, Shanghai International Studies University, Shanghai 200083, China
[3] School of Economics and Management, Beijing University of Chemical Technology, Beijing 100029, China; jinpeili@mail.buct.edu.cn
[4] Department of Industrial and Manufacturing Systems Engineering, The University of Hong Kong, Hong Kong SAR, China; zhyuncai@connect.hku.hk
* Correspondence: 2020010@shisu.edu.cn

Abstract: With the global economy's relentless growth and heightened environmental consciousness, sustainable maritime transport emerges as a pivotal development trajectory for the shipping sector. This study systematically analyzes 478 publications searched in the Web of Science Core Collection, from 2000 to 2023, utilizing bibliometric methods to investigate the application areas in sustainable development within the shipping industry. This study begins with an analysis of annual publication trends, which reveals a substantial expansion in research endeavors within this discipline over recent years. Subsequently, a comprehensive statistical evaluation of scholarly journals and a collaborative network assessment are conducted to pinpoint the foremost productive journals, nations, organizations, and individual researchers. Furthermore, a keyword co-occurrence methodology is applied to delineate the core research themes and emerging focal points within this domain, thereby outlining potential research directions for future research. In addition, drawing on the keyword co-occurrence analysis, the advancements in intelligent shipping technologies and green port construction applications within sustainable maritime transport are discussed. Finally, the review discusses the existing challenges and opportunities of sustainable maritime transport from a theoretical and practical perspective. The research shows that, in terms of intelligent shipping technology, data security and multi-source data are the focus that people need to pay attention to in the future; a trajectory prediction for different climates and different ship types is also an area for future research. In terms of green ports, Cold Ironing (CI) is one of the key points of the green port strategy, and how to drive stakeholders to build sustainable green ports efficiently and economically is the future developmental direction. This review serves to enhance researchers' comprehension of the current landscape and progression trajectory of intelligent shipping technologies, thereby fostering the continued advancement and exploration in this vital domain.

Keywords: bibliometric analysis; sustainability; maritime transport; trajectory prediction; green port

check for updates

Citation: Xiao, G.; Wang, Y.; Wu, R.; Li, J.; Cai, Z. Sustainable Maritime Transport: A Review of Intelligent Shipping Technology and Green Port Construction Applications. *J. Mar. Sci. Eng.* **2024**, *12*, 1728. https://doi.org/10.3390/jmse12101728

Academic Editor: Mihalis Golias

Received: 22 July 2024
Revised: 21 September 2024
Accepted: 23 September 2024
Published: 1 October 2024

1. Introduction

Shipping, the lifeblood of the global economy, carrying nearly 90% of the world's trade in goods, is the most cost-effective and energy efficient mode of transport, and a key pillar of sustainable economic development worldwide [1]. Its main business is to undertake the transport of the subject goods on the basis of trade demand, and transport the subject matter from the port of departure to the port of arrival [2]. With the continuous growth of global trade and the vigorous development of the marine economy, the importance of maritime transport as an important link to connect the world is self-evident. However, while bringing economic benefits, traditional maritime transport is also accompanied by environmental pollution, high energy consumption, and low operational efficiency, which brings challenges to the marine ecological environment and global sustainable development. Therefore, the sustainable development of maritime transport has become an urgent problem to be solved.

In the literature search sources of this review, the literature reviews on sustainable maritime transport are increasing year by year; the number of reviews in 2023 was nine. It can be found that the research field mainly focuses on maritime traffic safety issues and maritime transport emission reduction technologies. Shi et al. (2017) conducted a comprehensive review of papers published in 19 transport journals between 2000 and 2014, and listed the research topics, research methods, and data analysis techniques of maritime transport respectively [3]. Tian et al. (2017) reviewed the application research of the Internet of Vehicles (IoV) in the field of shipping, discussed how IoV technology can improve the level of ship intelligence, operational efficiency and navigation safety, and pointed out the technical obstacles to the application of ad hoc network technology in the ocean environment and the shortcomings of the existing research in solving long-distance communication problems [4]. Parhamfar et al. (2023) mainly explored the economic advantages of offshore wind in green ports compared to other renewable energy technologies, and outlined a variety of renewable energy technologies that are compatible with ports [5]. Huang et al. (2023) comprehensively reviewed various decarbonization technologies, and by comparing the emission reduction potential and the economic feasibility of various technologies, they showed that alternative fuels and hybrid power systems have great potential in reducing carbon emissions and improving sustainability, and the emission reduction potential can be further improved by combining alternative fuels with hybrid power systems with high control flexibility [6]. Employing 491 articles on marine accidents, Cao et al. (2023) demonstrated that human factor analyses of remote control ships and accident prevention in Arctic waters have become research hotspots, while innovative methodologies like machine learning and big data mining have also shown substantial insights in elucidating marine accident causation [7]. Xu et al. (2023) directed their attention towards the domain of maritime transport safety management and crisis response, discovering that technologies driven by data or intelligence, including scenario modeling, digital replicas, and data-based simulations, held the potential to bolster the development of resilient maritime transport systems [8].

In this context, with the increasing importance of globalization and environmental sustainability, the sustainable development of maritime transport as a major mode of international trade is particularly important [9]. At the same time, the two directions of intelligent shipping technology and green port construction have also become the key driving forces to promote the sustainable development of maritime transport. This study aims to review the application status, technical characteristics and future developmental trend of intelligent shipping technology and green port construction in sustainable maritime transport. By systematically combing and analyzing academic literature in related fields, we can better understand the important role of intelligent shipping technology and green port construction in maritime transport; we can also provide valuable references for relevant policy formulation, technology research and development, and industrial development.

The rest of this study is organized as follows: Section 2 provides an overview of data collection and research methods. Section 3 introduces the bibliometric analysis and research results. Based on the analysis results of bibliometric methods, Section 4 summarizes and analyzes the hot research areas of intelligent shipping technology and green port construction. Section 5 presents the challenges and opportunities for the future of sustainable maritime transport, taking into account current technological trends and market demands. Section 6 provides conclusions.

2. Research Methods and Data Collection

2.1. Bibliometric Method

The bibliometrics method, originally conceptualized by Pritchard in 1969, serves as a literature evaluation method utilizing statistical means to undertake a thorough quantitative assessment of the research articles published within a particular discipline [10]. By visualizing massive data sets and enabling the visualization of broad data collections, this review makes it easier to map the present state, subjects, and boundaries for the area of study, and helps academics understand the discipline's dynamic attributes and structural framework [11]. In comparison to alternative literature review methodologies, the advantage of bibliometrics lies in its capacity to yield more impartial and trustworthy outcomes, thereby furnishing researchers with a comprehensive understanding of the advancements within a specific domain [12]. As shipping has grown more slowly than other transport systems like airplanes, railroads, and cars, application research for marine intelligent transport systems in shipping likewise began later than other transport systems. Bibliometrics can be used to gain a more comprehensive understanding of the research status and the impending developmental trajectory within this field. This review constructs a comprehensive analytical framework to analyze and visualize sustainable maritime transport research published from 2000 to 2023, as shown in Figure 1. In this review, bibliometric analysis will include the following aspects: (1) annual publication trends; (2) source journals analysis; (3) collaboration network analysis; (4) keyword co-occurrence analysis.

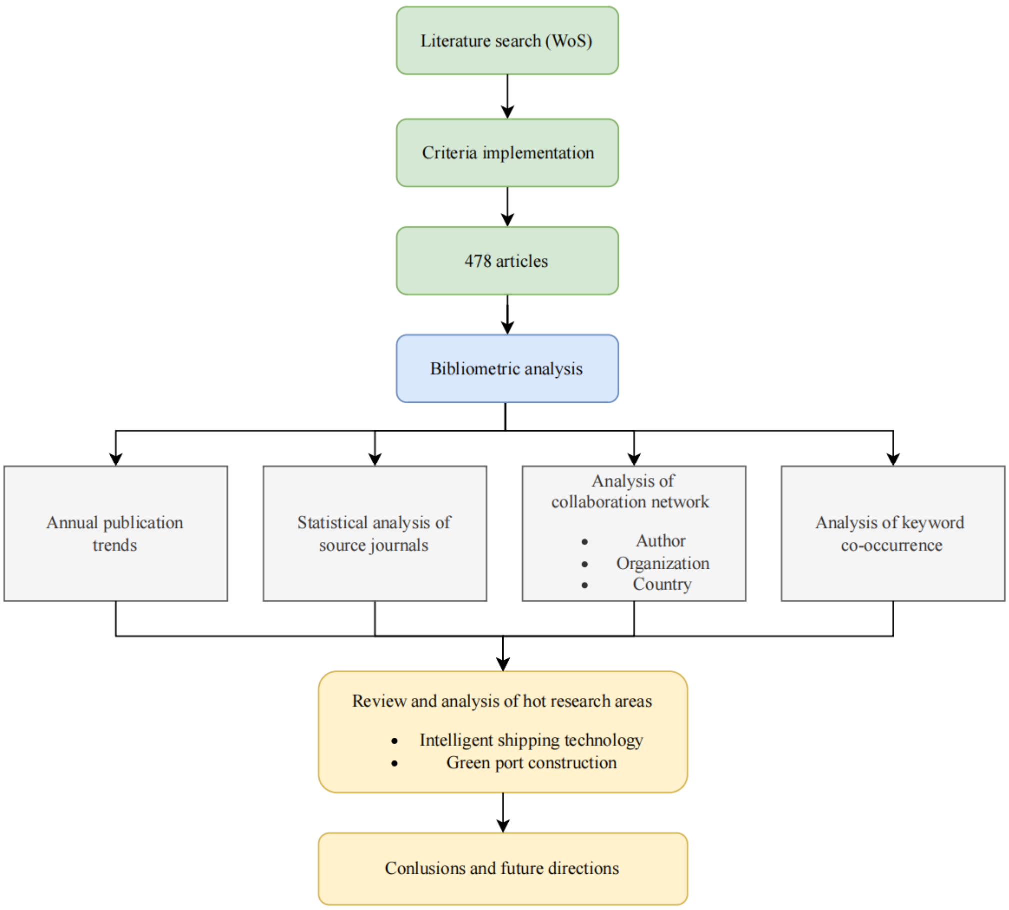

Figure 1. The integrated analysis framework.

2.2. Data Collection

Web of Science (WoS), a cutting-edge information service platform managed by Clarivate, includes the world's most important and groundbreaking research projects, and has become a widely recognized leading search tool for scientific metrics and evaluation [13]. We used SSCI and SCI-Expanded data from the WoS core collection as our data sources for this review.

2.3. Information Retrieval

The review endeavor centers around the application of intelligent shipping technology and green port construction within the context of sustainable maritime transport. Consequently, the delimitation of inquiry topics is imperative, encompassing the key domains of “maritime transport”, “shipping technology”, and “green port.” Regarding the subject search term “maritime transport”, it does not necessarily encompass the entire spectrum of pivotal technologies, as evidenced by the research findings presented by Ahmed et al. [14], so that this review selects some keywords closely related to maritime transport (such as intelligent, big data, artificial intelligence, automatic, efficiency, sustainability, emissions, ports, clean energy, etc.) to improve the breadth of the retrieved data.

To ensure the transparency and comprehensiveness of this research, a detailed explanation of the selection of this series of keyword searches is given below.

(1) Core basic keywords: “maritime” and “shipping” directly point to the field of maritime transportation, covering all activities of maritime transportation, and can ensure the direct relevance of the search scope, excluding other unrelated topics.
(2) Topic keywords: “maritime transport” is directly related to the core research field and serves as the basic background of the review. In addition, “shipping transportation” or “maritime transportation” as a synonym for “maritime transport”, further expands the search to include a wider range of shipping-related literature.
(3) Keywords related to intelligent shipping technology: The terms “intelligent” and “automatic” accurately encapsulate the fundamentals of intelligent shipping technology and will concurrently serve as benchmarks for the future development of sustainable maritime transport. Furthermore, “big data” and “artificial intelligence” pinpoint the pivotal technologies enabling intelligent shipping, ensuring that the latest research and application cases of artificial intelligence-related intelligent ship technology, such as automated ship operation and ship trajectory prediction, can be searched during the retrieval process.
(4) Keywords related to green port construction: The terms “sustainability” and “efficiency” emphasize the research focus on sustainable shipping, environmental friendliness, and resource efficiency, which is in line with the prevailing trends in the shipping industry. In addition, “ports”, “emissions”, and “clean energy” directly address the second large part of the paper, green port construction, by emphasizing environmental goals of reducing greenhouse gas emissions and encouraging the use of clean energy sources, such as solar and wind, thereby broadening the literature search related to the green port Initiative.

The specified literature types encompass “articles” and “review”, with a preference for those published in the English language, and spanning the years 2000 through 2023. This selection was deliberate, as articles undergo rigorous peer review, ensuring their academic rigor and quality, while reviews offer valuable insights into the contemporary landscape and evolving trends within the research domain [15]. English serves as the primary medium for international scholarly discourse, enhancing the quality and credibility of literature, thereby fostering global research collaboration and exchange. On the one hand, the time frame of “2000–2023” facilitates a focus on recent research advancements, offering contemporary insights, and ensuring the timeliness and scientific rigor of literature reviews. Conversely, given the publication lag in journals, publications in 2024 might not yet be available, thus excluding them from the search criteria [16]. Ultimately, a total of 478 publications were identified, comprising 438 articles and 40 reviews. The definitive search parameters are outlined in Table 1.

Table 1. Search parameters.

Parameter	Content
Database	SCI-Expanded and SSCI
Time range	2000–2023
Document type	Article or Review
Language	English
Search formula	TS = ((“maritime”) AND (“shipping”) AND (“maritime transportation” OR “maritime transport” OR “shipping transportation”) AND (“intelligent” OR “automatic” OR “big data” OR “artificial intelligence” OR “sustainability” OR “efficiency” OR “ports” OR “clean energy” OR “emissions”))

3. Results and Literature Analysis

This segment may be organized under various subheadings and aimed at providing visual analysis results, and a concise and accurate description of the experimental conclusion.

3.1. Annual Publication Trends

This study reviews the literatures published from 2000 to 2023 on the application of intelligent shipping technology and green port construction in sustainable maritime transport, analyzing the annual publication trends to provide insights into the evolution of research and potential future developmental trends within this domain [17,18]. Figure 2 shows a statistical graph of published research works since 2010. At the dawn of the 21st century, due to the sluggish progression of artificial intelligence technology, there were few research studies on intelligent shipping technology and green port construction in sustainable maritime transport. As can be seen from Figure 2, the number of published papers was relatively flat from 2010 to 2016. Despite the modest annual number of publications within this domain, there has been a consistent yearly escalation in the number of publications, surpassing the preceding year’s count. Since 2016, the applied research has been in a rapid growth stage, and the number of relevant publications has increased year by year, reaching the peak in 2023. Notably, publications from the past three years comprise an impressive 55% of the total publications reviewed herein, suggesting a heightened interest among scholars in recent years towards the research pertaining to sustainable maritime transport.

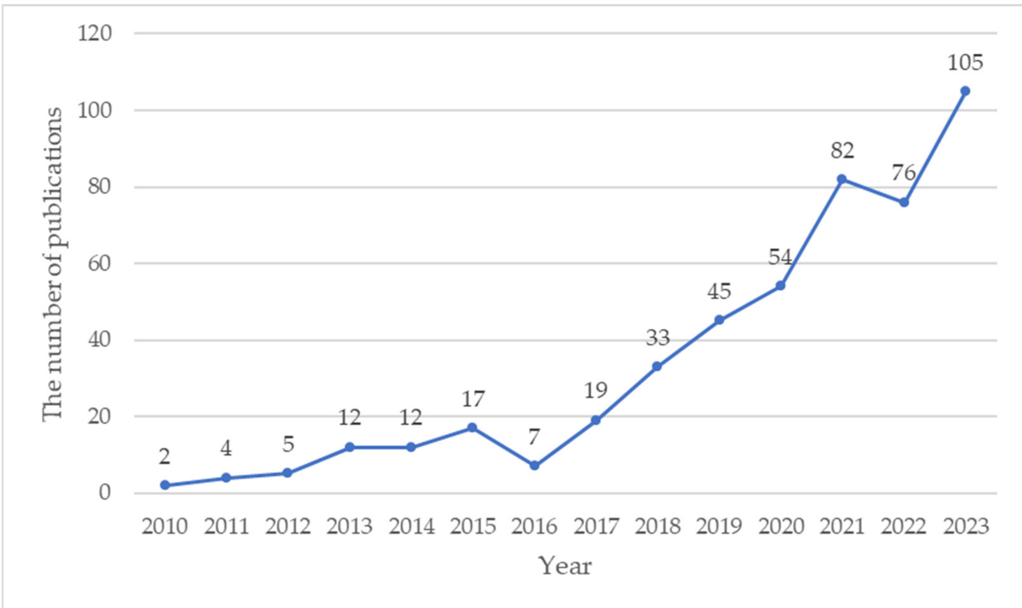

Figure 2. Annual publication statistics trends from 2010 to 2023.

This growth trend primarily stems from the international demand for sustainable development and the rapid evolution and integrated application of advanced technologies.

Firstly, with the increasing global emphasis on environmental protection and sustainable development, the maritime transport sector, as a crucial pillar of international trade, has seen its green transformation and intelligent development become an international consensus. Governments, international organizations, and research institutions worldwide have intensified their investments in this domain, fostering the development and application of relevant technologies, thereby promoting the prosperity of related academic research. Secondly, the rapid advancements in technologies, such as artificial intelligence, big data, and the Internet of Things, have provided robust technical support for intelligent shipping and green port construction. The continuous breakthroughs and integrated applications of these advanced technologies have not only enhanced the efficiency and safety of maritime transport, but propelled the deep-seated implementation of green and low-carbon concepts within the shipping industry.

3.2. Statistical Analysis of Source Journals

This comprehensive review encompassed 478 publications dispersed across 149 distinct journals. For clarity and emphasis, Table 2 presented a list of the 15 most prolific journals, collectively contributing 49% of the total articles under examination in this review. Among them, Sustainability has the highest production, with 37 publications. It was followed by Transportation Research Part D: Transport and Environment (27 publications) and Maritime Policy & Management (25 publications). Publications in these three respected journals account for approximately 18.6% of the publications searched in this review, indicating their critical influence in the field of sustainable maritime transport, providing valuable benchmarks and important references for academic work in the field.

Table 2. Most productive journals.

Journal Name	Publications	Percentage (%)	H-Index
Sustainability	37	7.74	12
Transportation Research Part D: Transport and Environment	27	5.65	19
Maritime Policy & Management	25	5.23	14
Journal of Marine Science and Engineering	24	5.02	7
Transportation Research Part E: Logistics and Transportation Review	20	4.18	15
Maritime Economics & Logistics	16	3.35	9
Ocean Engineering	16	3.35	10
Marine Policy	12	2.51	7
Transport Policy	11	2.30	8
Journal of Cleaner Production	10	2.09	9
Ocean & Coastal Management	10	2.09	8
Applied Sciences-Basel	8	1.67	5
International Journal of Shipping and Transport Logistics	7	1.46	5
Energies	6	1.26	3
Transportation Research Part B: Methodological	6	1.26	6

From the H-index of journal influence in Table 2, the Transportation Research journals series (Parts B, D, E) feature prominently in the list, showing that these journals have attracted many high-quality publications, and have a high academic influence and research quality in the field of intelligent shipping technology and green port construction, which has promoted the rapid development of the field. Among them, Transportation Research Part D: Transport and Environment and Transportation Research Part E: Logistics and Transportation Review ranked the top with an H-index of 19 and 15, respectively. As technology continues to advance, sustainable maritime transport will continue to evolve in a more efficient, intelligent, and environmentally friendly direction. Future research will pay more attention to technological innovation and integration, promote interdisciplinary cooperation, and improve the overall research level.

Many journals related to environmental protection such as Sustainability, the Journal of Cleaner Production, Applied Sciences-Basel, and Energies are also listed in Table 2, indicating that sustainable development and environmental protection are current research hotspots and future research trends. These journals not only focus on technological innovation, but emphasize the environmental benefits and social responsibility of technological applications. Finally, it can be found that the number of Maritime Policy & Management publications ranks third in the statistics, while Marine Policy and Transport Policy rank eighth and ninth, respectively. It shows that the formulation and introduction of a series of maritime and transport policies have gradually played an important role in shipping. The effective implementation and steady promotion of policies also provide strong support for the rapid development of technology, which can more efficiently promote the transformation and application of research results.

3.3. Analysis of Collaboration Network

3.3.1. Author Collaboration Analysis

Scrutinizing the authorship of the paper can help researchers gain insights into the utilization of intelligent shipping advancements and environmentally friendly port development within the realm of sustainable maritime transport [19]. Table 3 presents the most influential authors in this application area. The top 15 authors all published more than four papers, of which Shuaian Wang owned the most publications, with 20, H-index 13. According to the results of the analysis, 5 of the top 15 authors in the field of sustainable maritime transport are from China. This reason is inseparable from China's specific policy drivers in the field of shipping. Over the past decade, the Chinese government has recognized the importance of sustainable maritime transport strategies and implemented policies such as financial incentives and research project grants to support research in this area, which has facilitated the output of academic works by Chinese researchers. At the same time, China's academic culture, which emphasizes collective achievement and competition between research teams, also drives researchers to strive to contribute to the country's efforts in advancing maritime transport technology.

Table 3. Most productive authors.

Author	Publications	Percentage (%)	H-Index
Shuaian Wang	20	4.18	13
Elizabeth Lindstad	14	2.93	12
Zaili Yang	12	2.51	8
Kjetil Fagerholt	10	2.09	7
Harilaos Psaraftis	9	1.88	9
Kum Fai Yuen	8	1.67	7
Cesar Ducruet	8	1.67	8
Xueqin Wang	6	1.26	6
Qiang Meng	6	1.26	6
Jukka-Pekka Jalkanen	6	1.26	4
Kevin Li	6	1.26	6
Thalis Zis	6	1.26	6
Yiik Diew Wong	5	1.05	5
Lu Zhen	5	1.05	3
Jasmine Siu Lee Lam	4	0.84	4

To examine the collaborative efforts among authors in the realm of intelligent shipping technology and green port construction applications within maritime transportation, we built an author collaboration network using VOSviewer software version 1.6.20 [20]. The detailed steps of the algorithm are shown in Table 4. Figure 2 shows the collaborative network among authors, with at least 22 documents containing 67 projects, 72 links, and 27 clusters. Each author is associated with an article, with the size depicting the total count of publications. The links between projects signify the collaboration among authors, where the line thickness reflects the intensity of their collaboration. The coloration of the items represents the outcome of the clustering analysis, indicating that items sharing the same hue (i.e., authors) are affiliated with the same research group. As depicted in Figure 3, because of the academic collaboration between the authors, multiple research teams were established around the application of smart shipping technology and green port construction in sustainable maritime transport. Furthermore, the clustering pattern exhibited in Figure 3 underscores the prevalence of intra-cluster connections over inter-cluster ones.

Table 4. Search request based on the collaboration network of authors.

Step	Search Request
1	Choose type of data as 'Create a map based on bibliographic data'.
2	Choose data source as 'Read data from bibliographic database files'.
3	Select the file set as 'Web of Science'.
4	Set the type of analysis as 'Co-authorship', the unit of analysis as 'Authors' and counting method as 'Full counting'.
5	The minimum number of documents of an author is set to three; The minimum number of citations of an author is set to zero.
6	Select all connected items.

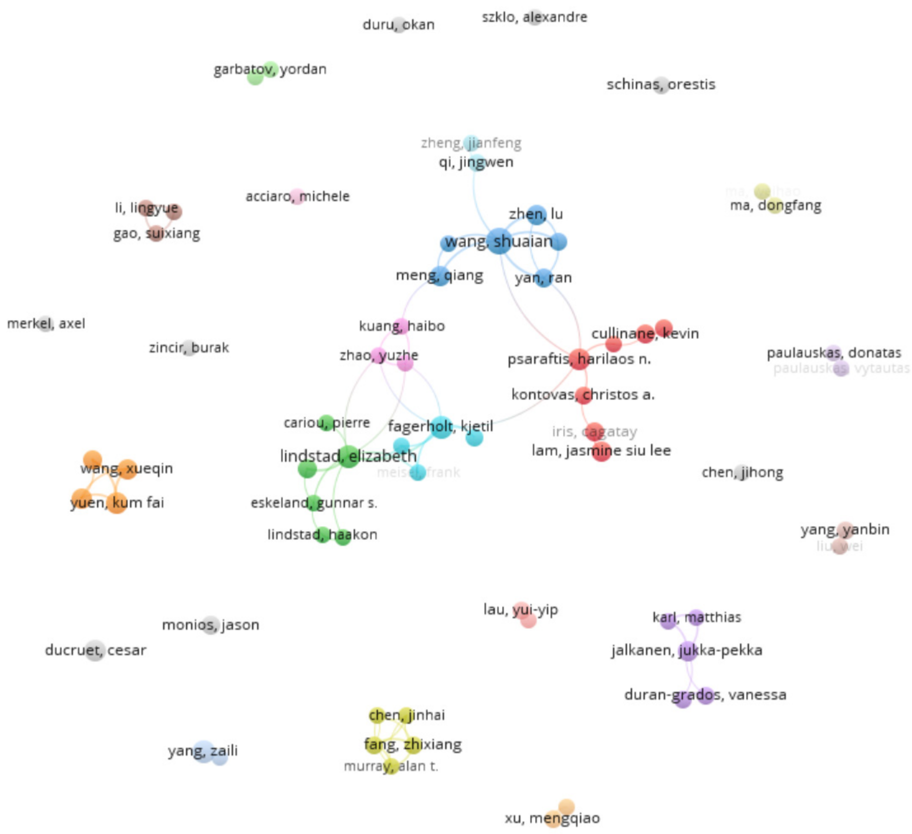

Figure 3. Collaboration network of authors.

These include key authors Harilaos Psaraftis and Lu Zhen working with industry leaders such as Shuaian Wang and Yan Ran on the challenges of maritime transportation, optimization of shipping emissions, and carbon emissions [21–23]. Elizabeth Lindstad and Kjetil Fagerholt from the Norwegian University of Science and Technology, who have worked together six times, on ship lifetime fuel and power system selection in 2022 and 2023, respectively, in the journal Transportation Research Part D: Transport and Environment [24,25]. Moreover, Zaili Yang from the University of Liverpool, has conducted in-depth research on modeling and analysis of sustainable transport networks and ship trajectory prediction, and has also made great achievements in a series of new methods and technologies, such as Bayesian networks and deep learning methods [26–28]. Harilaos

Psaraftis has also worked with Christos Kontovas 11 times on green ship routes and balancing the economics and environment of maritime transportation [29–31]. As you can see in Figure 3, the orange cluster on the left is mainly the collaboration of Kum Fai Yuen, Yiik Diew Wong from Nanyang Technological University, and Xueqin Wang from the University of Science and Technology of China, who have collaborated 63 times on research areas such as maritime logistics and sustainable shipping; Kevin Li has also cooperated with Kum Fai Yuen 23 times [32–35]. Cesar Ducruet of the French National Centre for Scientific Research has done some work on the structure of space networks and port cities [36–38]. Qiang Meng is a professor in the Department of Civil and Environmental Engineering at the National University of Singapore, whose outstanding contributions to the maritime sector are mainly shipping and intermodal transport analysis, having worked with Shuaian Wang 48 times on container speed optimization and liner deployment as early as 2011 [39–41]. Jukka-Pekka Jalkanen is the lead developer of the Ship Traffic Emissions Assessment Model (STEAM) of the Finnish Meteorological Institute, where he conducts in-depth research on shipping emissions and air pollution, mainly in the Baltic Sea [42,43]. Thalis Zis, from Imperial College London, specializes in ways to decarbonize shipping and reduce emissions from port operations, and has worked with Harilaos Psaraftis 16 times on ports [44,45]. In addition, Lam Jasmine Siu Lee from the Technical University of Denmark has also made remarkable achievements in the shipping field, focusing on the green port economy, port vessel emissions, and other directions. She has published 16 articles in "Maritime Policy & Management", and 8 articles in "International Journal of Shipping and Transport Logistics" and "Transportation Research Part E: Logistics and Transportation Review", respectively. She has also worked with Cagatay Iris six times, and the two conducted review analysis and operations management studies on port energy issues in 2019 and 2021, respectively [46,47]. This observation may stem from the nascent stage of research in sustainable maritime transport, where collaborations are primarily confined to within individual research teams. Consequently, cooperation across teams remains an underdeveloped area requiring further exploration, resulting in limited inter-team collaboration [48].

3.3.2. Organization Collaboration Analysis

The 478 publications included in the review were published by 635 diverse organizations. Table 5 compiles the leading organizations that exhibit the most vigorous engagement in the realm of sustainable maritime transport research. The top 10 organizations contribute nearly 46% of academic publications, four of which are from China, two from Norway, and most of the rest are from universities in coastal cities. Among these organizations, the Hong Kong Polytechnic University and the Norwegian University of Science and Technology tied for the top spot with 24 publications, followed by Dalian Maritime University (23 publications), and Shanghai Maritime University (19 publications). This highlights China's key role in advancing sustainable maritime research and application. SINTEF is one of the largest independent research organizations in Europe, with multidisciplinary expertise in the fields of technology, natural sciences, and social sciences. Its aim is to contribute to the development of society by conducting research in the natural sciences, technology (including architecture and civil engineering), and health and social sciences in cooperation with the Norwegian University of Science and Technology.

To analyze the collaboration between organizations in the application field of intelligent shipping technology and green port construction, VOSviewer software version 1.6.20 is used to build an organization collaboration network. The specific search steps are shown in Table 6. Figure 3 illustrates a collaborative network among organizations, with a minimum document count of 5, consisting of 29 projects, 5 clusters, 72 links, and a total link strength of 111. As depicted in Figure 4, each project serves as a representation of an organization, with the proportional size of each symbol reflecting the quantity of published articles emanating from that particular entity. The connections between projects indicate collaboration between organizations, and the thickness of the links signifies the strength of the collaboration between organizations. In terms of project scale and the number of collaborations, the Hong Kong Polytechnic University plays a key role as a bridge in the collaborative network, with 10 universities working with it. As the challenges of sustainable maritime transport become more complex and interconnected, many universities are placing greater emphasis on research investment and talent attraction in maritime related research, and further collaboration between these top organizations is expected. This includes not only academic partnerships, but a close collaboration with industry, governments and non-governmental organizations, which can work to translate research findings into practical technologies in the future.

Table 5. Most productive organizations.

Organizations	Publications	Percentage (%)
Hong Kong Polytechnic University	24	5.02
Norwegian University of Science and Technology (NTNU)	24	5.02
Dalian Maritime University	23	4.81
Shanghai Maritime University	19	3.97
Nanyang Technological University	16	3.35
Technical University of Denmark	14	2.93
Wuhan University of Technology	14	2.93
Liverpool John Moores University	13	2.72
SINTEF	13	2.72
University of Lisbon	11	2.30

Table 6. Search request based on the collaboration network of organizations.

Step	Search Request
1	Choose type of data as 'Create a map based on bibliographic data'.
2	Choose data source as 'Read data from bibliographic database files'.
3	Select the file set as 'Web of Science'.
4	Set the type of analysis as 'Co-authorship', the unit of analysis as 'Organizations' and counting method as 'Full counting'.
5	The minimum number of documents of an organization is set to five; The minimum number of citations of an organization is set to zero.
6	Select the largest set of connected items instead of all items.

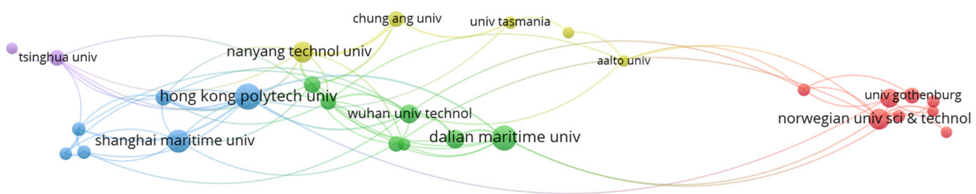

Figure 4. Collaboration network of organizations.

3.3.3. Country Collaboration Analysis

Analyzing the country information in this review can understand the research contributions of various countries in intelligent shipping technology and green port construction, as well as the exchanges and cooperation among them. Between 2000 and 2023, 65 countries have contributed to the study of the field of sustainable maritime transport through publications in SCI core databases. Table 7 shows the top 10 countries ranked by the number of publications. China contributes the most papers in this application field, with a total of 141 publications. Following closely behind are England (46 publications), the United States (42 publications), and Norway (39 publications). In addition, China accounts for nearly 30% of all publications in the field of sustainable shipping, far more than other countries, indicating that China provides a great impetus for the development of the field. The significant lead of China in terms of publication output can be primarily attributed to macro-level factors. Firstly, the Chinese government has placed great importance on the strategy of becoming a maritime power and sustainable development goals in recent years. Through a series of policy guidance and support, it has provided a strong impetus for the research and development of marine technology and environmental protection technologies. Driven by "the Belt and Road" Initiative, in particular, China has been committed to enhancing the intelligence and greenness of global port facilities, which has directly promoted academic research and practical applications in related fields. Secondly, as the world's second-largest economy, China boasts a vast market demand and industrial foundation. Both state-owned and private enterprises, in collaboration with major universities, have actively responded to national calls while pursuing economic benefits and scientific research needs. They have increased investment in scientific research, promoted technological innovation and experience-sharing, and made significant contributions to China's research in the field of sustainable maritime transport.

Table 7. Most productive countries.

Country	Publications	Percentage (%)
China	141	29.50
England	46	9.62
the United States	42	8.79
Norway	39	8.16
Spain	36	7.53
France	31	6.49
Sweden	29	6.07
Singapore	28	5.86
Germany	25	5.23
South Korea	25	5.23

To elucidate on country-to-country collaborations, we employ the VOSviewer software version 1.6.20 to construct a collaborative network map. The specific search steps are shown in Table 8. Figure 5 shows the collaborative network between countries with at least four papers, with 36 projects, 163 links, and a total link strength of 322. The size of the projects indicates that China is the leading country in terms of publications. Among them, China has collaborated with 23 countries, contributing to a total link strength of 91. Following China are England (21 collaborating countries, with a total link strength of 51) and Norway (19 collaborating countries, with a total link strength of 35). The thickness of the links shows that the cooperation between China and England is the closest, with a link strength of 16. This is followed by cooperation between China and Singapore (link strength 14) and the United States (link strength 10).

Table 8. Search request based on the collaboration network of countries.

Step	Search Request
1	Choose type of data as 'Create a map based on bibliographic data'.
2	Choose data source as 'Read data from bibliographic database files'.
3	Select the file set as 'Web of Science'.
4	Set the type of analysis as 'Co-authorship', the unit of analysis as 'Countries' and counting method as 'Full counting'.
5	The minimum number of documents of a country is set to four; The minimum number of citations of a country is set to zero.
6	Select all connected items.

However, we can also see from Figure 5 that some countries have fewer publications, less intensive cooperation with other countries, and numerous countries are absent from this collaborative network. On the one hand, this may be attributed to the fact that cooperation among countries in the field of sustainable maritime transport often involves the sharing of intellectual property rights and the distribution of benefits, and the inability to reach a consensus may hinder the development of such cooperation. On the other hand, disparate countries might hold diverse interpretations and necessitate varying standards and norms pertaining to sustainable maritime transport, thereby posing potential barriers to collaborative research endeavors across national borders. Significant differences in technical standards and norms among countries may lead to incompatibility, thereby increasing the difficulty of collaborative research among nations. Therefore, for the purpose of future research, further enhancement of international academic cooperation is imperative in the application of human intelligent shipping technology and green port construction in sustainable maritime transport.

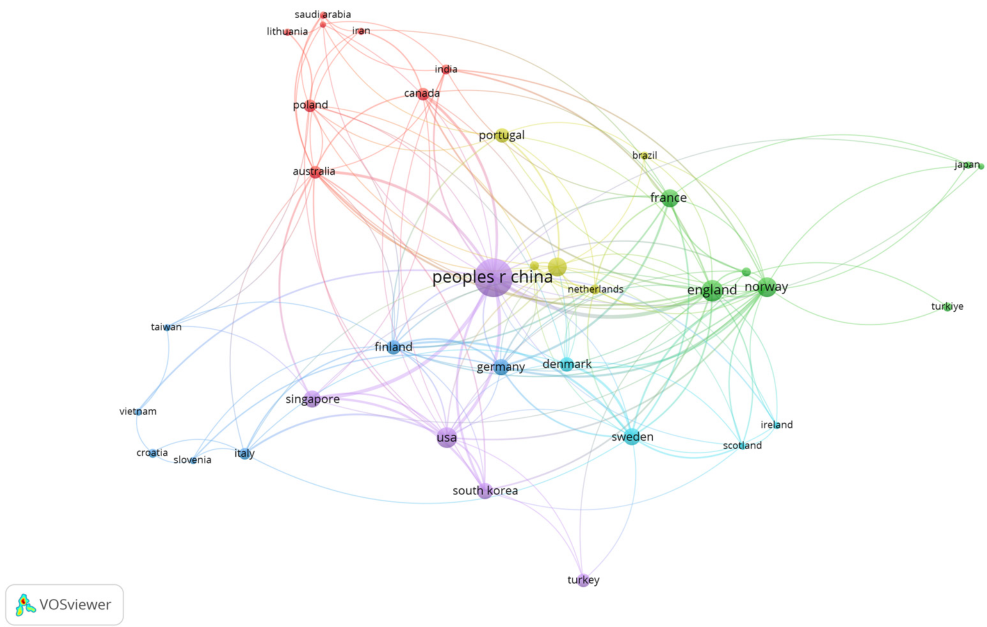

Figure 5. Collaboration network of countries.

3.4. *Analysis of Keyword Co-Occurrence*

Keywords, which are concise summaries of the core content of a paper, can be utilized by VOSviewer version 1.6.20 for bibliometric analysis to identify the major research clusters in the field of sustainable maritime transport [49]. Table 9 lists the top 10 keywords with the highest frequency, among which "maritime transport" is the most frequently mentioned keyword, appearing 136 times, followed by its close synonym "maritime transportation". It reflects that these keywords are the basic word of research in this field. This is followed by the high frequency of keywords such as "emissions" and "shipping emissions", with researchers increasingly focusing on environmental sustainability in the maritime sector in recent years. This trend is likely driven by the formal entry into force of international agreements such as the Paris Agreement in 2016, and the growing public awareness of the environmental impact of maritime transport [50,51]. The emergence of "model", "optimization" and "speed optimization" indicates that people are interested in using technological advances such as simulation and prediction to face challenges in various aspects of the maritime industry. With the rapid development of data accessibility and technology, future research will explore more sophisticated optimization algorithms, autonomous shipping technologies, and alternative fuels to further improve the sustainability of shipping. Finally, the keywords "port" and "management" also appear in Table 6, which shows that ports are the key nodes of the maritime transportation system, and relevant studies such as the construction and management of green ports will be crucial to the future maritime transportation field.

As depicted in Figure 6, an all-keyword co-occurrence network has been constructed. In this network, each item signifies a keyword whose size indicates the frequency of occurrence. The concurrent manifestation of two keywords is denoted as keyword co-occurrence, wherein the spatial proximity between these elements serves as an indicator of the intensity of their interconnection, with a diminished separation alluding to a more pronounced correlation. The color of the items represents the clustering results, with items of the same color indicating they belong to the same cluster, while those of different colors belong to distinct clusters. These connections signify the coexistence associations among keywords, while the density or thickness of these connections serves as a measure of the robustness of these relationships, thereby reflecting their inherent strength. Figure 6 displays the keyword co-occurrence network, with the minimum occurrence threshold set at six and the unit of analysis for all keywords. The resulting network diagram contains 136 items, six clusters, 2807 links, and a total link strength of 5061.

Table 9. High-frequency keywords.

Keyword	Occurrences	Links	Average Published Year
Maritime transport	136	131	2020
Maritime transportation	79	98	2019
Emissions	64	103	2021
Model	50	93	2020
Ships	46	97	2021
Shipping emissions	32	74	2021
Ports	31	76	2021
Optimization	31	72	2020
Management	28	76	2019
Speed optimization	28	64	2021

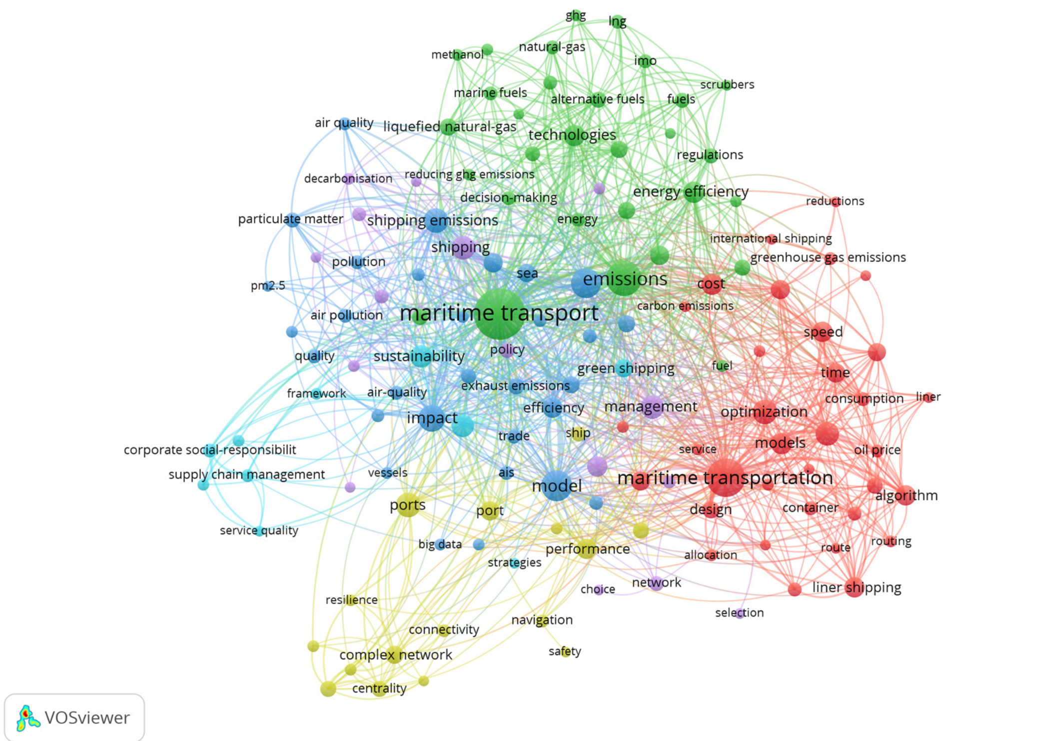

Figure 6. Keywords co-occurrence network.

Intelligent transportation originated from land transportation and was later referenced to water transportation, leading to the concept of "intelligent shipping". An intelligent waterway transportation system is an intelligent transportation system applied to the waterway environment [52]. The shipping system consists of three most basic elements: channels, ships, and ports, along with the various support and security systems [53]. As can be seen from Figure 6, the green cluster and red cluster focus on the application of intelligent shipping technology centered on "technology" and "algorithm". The blue and yellow clusters focus on port air pollution and greenhouse gas emissions from ships under the keyword "port" and "shipping emissions". These two clusters represent current research hotspots in sustainable maritime transport applications and provide directions for future research in this field. In addition, the light blue cluster shows the important support of the maritime supply chain for the management of shipping enterprises in recent years, which will be the emerging trend and digital technology of the future of maritime transport. Next, Section 4 will focus on the literature review of the two clusters of intelligent shipping technology and green port construction.

4. Review and Analysis of Hot Research Areas

4.1. Intelligent Shipping Technology

Intelligent shipping technology is the product of the deep integration of modern information technology and the shipping industry. The shipping industry has undergone an intelligent transformation across all aspects through the adoption of advanced technologies, such as artificial intelligence, big data, and the Internet of Things, thereby enhancing the efficiency, safety, and environmental sustainability of maritime operations. Ships are the main carriers of maritime transportation. As a major application of intelligent shipping technology, intelligent ships enhance navigation safety and operational efficiency through real-time monitoring, automated navigation, and intelligent collision avoidance. These functions are enabled by equipping vessels with sensors, radars, and communication devices [54].

To date, remarkable achievements have been made in autonomous navigation research and development projects globally. In February 2020, the Japan Shipbuilding Industry Association funded 3.4 billion yen for over 40 Japanese institutions to form five alliances, conducting six exploratory autonomous navigation experiments validating the feasibility of key technologies (e.g., autonomous berthing and unberthing, collision avoidance, target image processing) for long voyages [32]. This project represents the world's broadest autonomous navigation research and development across vessel types. In November 2021, the Netherlands Forum Smart Shipping (SMASH) released a smart shipping roadmap outlining a vision for the development of smart shipping in the Netherlands by 2030, marking the first systematic framework for smart shipping development in Europe [55]. In June 2022, the Korean Hyundai Heavy Industries Group and SK Corporation collaborated to complete a 33-day transoceanic autonomous navigation test of "Prism Courage" spanning 5500 nautical miles. The vessel autonomously routed, adjusted speeds, assessed environments, and executed 100 collision avoidance maneuvers. The test results indicated a 7% improvement in fuel efficiency and a 5% reduction in greenhouse gas emissions. This marks the sole reported transoceanic test for an 180,000-cubic-meter ultra-large LNG autonomous vessel [56]. In China, the concept of intelligent ship navigation was first introduced in the "Intelligent Ship Regulations" (2015) issued by the China Classification Society (CCS) in 2015. In December 2019, the "Jin Dou Yun" unmanned autonomous cargo ship, jointly developed by Zhuhai Yunhang Intelligent Technology Co., Ltd., in collaboration with universities and the government, successfully completed its maiden voyage carrying cargo autonomously [57].

To guide the standardized and safe development of autonomous marine navigation technology, a series of regulations have been successively promulgated. The IMO Maritime Safety Committee's 105th session endorsed the MASS Code roadmap as the paramount international rule for intelligent ship navigation, to commence voluntarily from 1 January 2025, and mandate on 1 January 2028, after accumulating implementation experience [58]. Since the establishment of the Smart Shipping Working Group (ISO/TC8/WG10) by the International Organization for Standardization's Committee on Ships and Marine Technology in 2016, it integrates and manages resources from ISO/TC 8 (including SC6 and SC11) in the area of smart shipping, which will actively promote and coordinate the widespread application of smart shipping technologies in the maritime industries of various countries on an international scale [59].

Nowadays, the industry and academia have placed an emphasis on intelligent maritime monitoring and ship behavior recognition, a commitment that supports efforts to enhance maritime safety and reduce accidents [60]. Among these focal points, the accurate prediction of ship trajectories is a critical challenge in intelligent maritime traffic systems, serving as a fundamental prerequisite for effective collision detection and risk assessment. The Automatic Identification System (AIS) provides an important opportunity for realizing intelligent ship identification and maritime traffic flow supervision, and has been widely adopted and applied by various countries [61,62]. There are a total of 17 articles on trajectory prediction in the literature sources of this review. Among them, Zhang et al. (2022) provide a comprehensive review of existing methods for ship trajectory prediction, with a focus on advanced deep learning techniques and the data sources used. This review article discusses auxiliary technologies, complexity analyses, benchmark comparisons, performance metrics, as well as methods for enhancing model performance. Finally, the article outlines the current challenges and future research directions in this field [63]. Table 10 summarizes and refines the trajectory prediction methods and specific applications used in the other 16 papers, providing the latest research direction for ship behavior recognition and marine traffic detection.

Table 10. Relevant methods and techniques of ship trajectory prediction.

Model/Method	Description	Applications in Shipping	Ref.
A framework of CCT discovery	Using a maritime dataset collected from the AIS system, the proposed framework automatically and unsupervisedly identifies clusters of conflict trajectories.	To identify conflicting trajectories based on the features of maritime conflict behavior among ships on the open sea	[64]
A CNN-SMMC architecture	Training a neural network on labeled AIS data to effectively accomplish the classification task.	To label a ship's movement into three types based on AIS data	[65]
An integrated approach of vessel trajectory and navigating state prediction	Combining machine learning, physical motion modeling, and particle filtering to produce reliable forecasting results.	To enhance situation awareness for maritime traffic safety management	[66]
A hybrid model (ARIMA-LSTM)	The ARIMA-LSTM model forecasts near-future ship trajectories using AIS data to aid in subsequent ship collision avoidance.	To maneuver a ship safely by considering the estimated risk of collision	[67]
A bidirectional data-driven trajectory prediction method	Integrating the output results of the Encoder-Decoder model, driven by both forward and backward data.	To improve the accuracy of ship trajectory prediction and reducing the risk of accidents	[68]
A multi-ship collision risk model	Integrating a GRU neural network with the UKF to estimate ship positions at various times and analyze the uncertainty of these positions over time.	To provide early warning of multi-ship collision risk	[69]
A deep bi-directional information-empowered (DBDIE) prediction mode	Integrates two bi-directional networks and optimizing the weights of model units using an attention mechanism.	To help manned ships achieve high-accuracy predictions and enable MASS to develop more reasonable operational strategies	[70]

Contemporary research results related to ship trajectory prediction are largely based on the utilization of AIS data. Currently, neural networks have garnered extensive application in forecasting the navigational path and operational status of ships, thereby enhancing predictive capabilities within the maritime domain. Various types of neural networks, including Artificial Neural Networks (ANN), neuroevolutionary ANN [71], Backpropagation (BP) networks [72], and Generalized Regression Neural Networks (GRNN) [73], have been utilized for predictive tasks. As a prevalent approach, the utilization of ANN technology excels in the thorough analysis and extraction of historical big data via meticulous model training. The BP neural network, an exemplar of the multi-layered feedforward network architecture, stands as a widely embraced ANN variety that undergoes refinement via the error backpropagation algorithm. Given appropriate network configuration and intensive training, this methodology attains remarkable predictive precision, and adeptly models intricate nonlinear relationships [74]. Chen et al. (2020) designed a Ship Motion Image Generation and Labeling (SMIGL) algorithm to convert a ship's AIS trajectory into different moving images, thereby fully leveraging the classification capabilities of CNNs. The findings indicate that the proposed CNN-SMMC exhibits good performance in classifying AIS data [65].

Additionally, one of the typical deep learning models, the recurrent neural network (RNN), is commonly used for trajectory prediction applications, including public transportation forecasting, location prediction problems, and destination prediction. A common issue with RNN is the diminishing or escalating gradient phenomenon across lengthy sequences, thereby compromising their capacity to grasp long-range dependencies efficiently. The standard RNN model includes Long Short-Term Memory (LSTM) and Gated Recursive Units (GRUs). The LSTM network, a specialized RNN model, was devised to mitigate the gradient vanishing issue inherent in traditional RNNs. By virtue of their ability to capture and sustain long-term dependencies, LSTM networks are well-suited for tackling long-sequence prediction tasks, particularly those involving intricate ship trajectories. Furthermore, LSTM networks demonstrate flexibility in processing sequences of varying lengths, accommodating ship trajectories of diverse durations. Another noteworthy RNN variant, GRU has emerged as a solution to the challenges posed by long-term memory retention and gradient vanishing during backpropagation. GRU offers advantages in terms of training simplicity and efficiency enhancement. It achieves this by integrating the forget and input gates into a unified update gate and merging the hidden layer with the memory cell into a reset gate. These structural refinements streamline the overall operation and elevate performance [74]. Unlike traditional LSTM, Bi-directional LSTM (Bi-LSTM) networks use forward and backward information for input sequences. Wu et al. conducted a trajectory prediction model that integrates Convolution LSTM (ConvLSTM) and sequence-based Seq2Seq models. Experimental findings reveal that this model surpasses two comparative benchmarks in predicting turn trajectories, and delivers enhanced accuracy for linear movements, significantly boosting overall prediction precision [75]. Li et al. (2024) introduced a novel predictive method named Deep Bidirectional Information Enabling (DBDIE), which enhances feature extraction by integrating Bi-LSTM and Bi-directional Gated Recurrent Unit (Bi-GRU) neural networks. According to experimental results, the new DBDIE model provides a novel strategy for improving the precision and efficacy of ship trajectory prediction, outperforming all classical methods in delivering the most desirable prediction outcomes [70]. Bi-LSTM, comprising two distinct LSTMs, possesses the capability to capture both past and future information. Research has demonstrated that, in the context of time series forecasting tasks, the Bi-LSTM model surpasses its unidirectional counterpart in terms of performance. Analogously, the Bi-GRU, as an advancement upon the GRU, harnesses both forward and backward temporal cues to bolster prediction accuracy.

However, raw AIS data can suffer from data errors, inconsistent data formats, high latency, coverage limitations, and other issues. These limitations can ultimately result in inaccurate prediction outcomes. Currently, AIS systems are divided into shore-based and space-based types. Shore-based AIS systems typically offer restricted, localized coverage, frequently confined to a radius of approximately 50 nautical miles, thereby limiting their scope to nearby areas. Correspondingly, space-based AIS networks are emerging to address these limitations by expanding coverage beyond these local boundaries. However, despite their broader reach, space-based AIS networks may experience delays of several hours, indicating that these systems are not without their own challenges [76,77]. Furthermore, AIS data are prone to several potential error sources. For instance, inaccuracies in satellite navigation systems can result in erroneous location information. Additionally, AIS shipboard transponders may be switched on or off, or malfunction during a voyage, introducing further discrepancies in the data. Moreover, static AIS data elements like Maritime Mobile

Service Identity (MMSI), ship type, and the captain are predominantly input manually, which can lead to ambiguities or inaccuracies in the information provided.

4.2. Green Port Construction

A port is an important transportation hub connecting water and land transportation, plays a key role in international trade and, as a key node of international logistics and the supply chain, it is also an important position of information construction. As the need for energy conservation and emission reduction grows, green ports are becoming increasingly important to maintain the growth of maritime transportation. Initiatives such as the "Clean Air Action Plan" implemented by the Port of Long Beach and the Port of Los Angeles (Jelenić, 2016), the "Clean Air Action Program" developed by the Port of Rotterdam (Mshe, 2012), and the "Clean Air Strategy" for the Port of New York and New Jersey (Port of NY & NJ, 2009) underscore a global shift towards sustainable practices. Building on this momentum, China's recent "Fourteenth Five-Year Plan for Water Transport Development" (2020–2025) further exemplifies this global commitment. The plan prioritizes the development of green and low-carbon water transport, integrates advanced environmental protection technologies, and emphasizes the use of clean energy within port operations, positioning China at the forefront of sustainable maritime logistics [78].

Governmental concern for port-related environmental pollution has intensified over time, reflecting a broader understanding of the issues highlighted by numerous studies, including those by Corbett et al. (2009), which identify stationary vessels and port cargo handling facilities as primary sources of carbon emissions, contributing to 74% of the emissions within these zones [79]. This concern has catalyzed the academic and industrial sectors to explore innovative strategies for managing port emissions effectively. Recent advancements have introduced comprehensive methodologies that align with operational efficiency and environmental sustainability to enhance the assessment of carbon emissions within port operations. Dong et al. proposed a port-centric method for evaluating the performance of the coal transport chain (PCTC), considering both foreland and hinterland elements. This approach utilizes real data from China's coal North–South transportation corridor to provide decision-making support for shippers and port owners [80]. Following this, a study on Chinese ports provided a scenario-based forecasting model that analyzes carbon emissions trends and peak situations under different future scenarios, allowing ports to plan and adjust strategies accordingly [81]. Additionally, research focused on the Guangzhou Port examined how government subsidy policies influence carbon emissions within the port's collection and distribution network, offering insight into policy impacts on port emissions [82]. Another tiered approach involved creating detailed emissions inventories for port vessels by considering various operational modes, which enhances the granularity and accuracy of emission assessments [83].

Amidst these evolving strategies to tackle port emissions, various innovative models and technologies have been proposed to enhance the efficiency and sustainability of port operations. Jiang et al. constructed a mathematical model, which described the complex issues of ship scheduling and berth allocation in restricted channels, and proposed an adaptive, two-population, multi-objective genetic algorithm NSGA-II-DP to solve the problem. When it comes to port scheduling, the model algorithm outperformed the traditional queuing model, better meeting the goals of efficiency and cost-saving for port management [84]. Further illustrating the application of smart technologies in port operations, Liu et al. (2024) conducted a study of Tianjin port, highlighting how smart port infrastructures, such as IoT and AI, can enhance the sustainability and efficiency of port operations through improved logistics and operational practices [85]. Moreover, the application of Renewable Energy Technologies (RET) in ports is being increasingly recognized for its potential to mitigate environmental impacts. Parhamfar et al. (2023) summarized the potential, challenges and economic aspects of applying RETs in green ports. They discussed how fuel cells might be used as a backup or primary power source to provide ports with electricity. The results showed that RETs can play a significant role in helping the marine sector achieve its sustainable development objectives and pave the way for the construction of eco-friendly and more productive ports [5].

Addressing the regulatory landscape, the International Maritime Organization's (IMO) Marine Environment Protection Committee (MEPC) has proposed a long-term carbon tax on ports (IMO, 2005) [86]. To reduce carbon emissions in port areas, operators primarily focus on optimizing ship berth allocation, improving the loading efficiency of wharf cranes and utilizing low-sulfur diesel fuel. To address the gap in joint berth and shore crane allocation under carbon emission tax policies, Wang et al. proposed models for the two tax policies, respectively, focusing on carbon emission of Quality Control (QC), and developed a series of equivalent or loose models [87]. In order to reduce berth emissions from ships calling at ports, Wu et al. investigated the Shore Power Deployment Problem (SPDP) in container shipping networks, established a framework to capture the complex relationship between governments, ports and ships, and utilized the proposed labeling algorithm to bring huge environmental and health benefits to the implementation of subsidy programs [88]. Wang et al. also explored the integrated issue of berth allocation and QC allocation under carbon emission tax considerations. They developed a dual-objective integer programming model aimed at minimizing both the total completion delay of all tasks and the total operating cost of all quality control [89].

The shipping industry's move towards shore power represents a cutting-edge approach to reducing greenhouse gas emissions. In May 2019, the IMO adopted resolution MEPC.323 (74), entitled "Invitation to Member States to encourage voluntary cooperation between the port and the shipping sectors to contribute to reducing GHG from ships". The resolution advocates for regulatory, technical, operational, and economic actions within the port sector. Shore power, sometimes referred to as Cold Ironing (CI), Alternative Marine Power (AMP), or Onshore Power Supply (OPS), is one of the main resolutions supported by the IMO to reduce greenhouse gas (GHG) emissions. In fact, studies have shown that CI is effective in reducing shipping emissions both at sea and in ports [90,91]. Daniel et al. (2024) analyzed the influence of CI on international environmental regulations and incentives using a bulk carrier case study. Their findings showed that CI can increase the Carbon Intensity Indicator (CII) by 7.8%, and they proposed policy changes to incorporate CI into Energy Efficiency Design Index (EEDI) and Energy Efficiency Existing Ship Index (EEXI) calculations. Currently, CI has the potential to eliminate 100% of emissions from ships at berth [92].

5. Existing Challenges and Future Opportunities for Sustainable Maritime Transport

The maritime transport industry is at a critical juncture, with the increasing demands for sustainability and technological innovation driving significant changes. While intelligent shipping technologies and green port construction present new opportunities for reducing environmental impacts and improving efficiency, numerous challenges, such as data inaccuracies, network security, equipment failure, regulatory hurdles, high costs, and international coordination persist. This section explores both the obstacles and opportunities that lie ahead for achieving sustainable maritime transport, focusing on the integration of advanced technologies and the development of eco-friendly port construction.

5.1. Intelligent Shipping Technology

With the rapid development of computer technology, artificial intelligence technology and other scientific and technological fields, significant progress has been made in the development of intelligent ship technology, but there are still some problems to be solved in the future. Firstly, the limitation of AIS data will lead to the inaccurate prediction of ship trajectory. In terms of intelligent shipping technology, many scholars rely on visualization, simulation, data mining, machine learning, neural network, and other technologies to study ship historical trajectory based on AIS data. However, the original AIS data may confront challenges pertaining to restricted coverage area, elevated latency periods, inaccuracies in data, along with disparities in data formatting, which may hinder its efficacy [63]. In addition, there is limited research on the trajectory data under special climatic conditions and different vessel backgrounds. Taking the tropical cyclone Veronica that occurred in the northwest waters of Australia in 2019 as an example, a Bayesian network framework was constructed based on AIS data to study the actual behavior trajectory and delay characteristics of ships during tropical cyclones [93]. This is one of the future research directions, such as extreme climate, common accidents at sea, ship type, ship size, deck crew, sailing status and so on [94,95].

In addition to using only track-related data, various maritime data sources are also thoroughly explored to help predict ship tracks, including onboard sensor data, meteorological data and port operations data. Before making decisions in complex navigation scenarios where collision avoidance is required, individual sensors may encounter redundancy, conflicts, and deficiencies in target identification. Additionally, sensors can be impacted by uncontrollable factors such as severe weather. It is imperative to consider the uncertainty of data sources and the inconsistency of multi-sensor data to enhance data reliability. Therefore, another prevailing challenge lies in identifying and integrating multi-source heterogeneous maritime data to support ship motion pattern recognition. In the context of future autonomous navigation, the integration of AIS, radar, and GPS data will be essential for more autonomous and accurate perception of the surrounding navigation environment. Moreover, the fusion of multi-source shipboard data with intelligent route planning will be a key area for future research [96].

In addition, the new development model of Shipping 4.0 proposed at the First World Maritime Science and Technology Conference signifies that people are generating massive amounts of data at different levels, and utilizing data mining and database programs to extract information from these data [97]. Among them, data security and privacy protection will also become important issues of concern. Ensuring that ship data is not accessed and tampered with unauthorizedly, while protecting the personal privacy of crew members are crucial issues that need to be addressed in technological development. Furthermore, equipment failure remains a significant unsolved issue in the maritime transportation sector. Currently, failure mode and effects analysis (FMEA) is regarded as a reliable technique for mitigating risks and enhancing shipping safety. Integrating it with Bayesian networks, generative adversarial networks (GANs), and other methods represents a promising direction for future research [98,99].

With the in-depth application of machine learning and deep learning algorithms in the shipping industry, the autonomy of intelligent ships will be significantly enhanced in the future, thereby reducing operational costs, and improving efficiency and safety. However, it is noteworthy that in the current research, there exists inconsistency between uncontrollable navigation environments, dynamic traffic flows, and simulation-based methods. It must be acknowledged that models, algorithms, and practical operations still cannot achieve a high degree of accuracy and seamless integration [96]. The primary reason lies in the fact that the real navigation environment is complex, dynamic, and nonlinear, and conducting actual tests on ships can be costly. Therefore, the generalization and operability of methods and models need to be comprehensively evaluated and considered in future research.

In terms of maritime transportation, the potential benefits of blockchain technology for shipping enterprises are becoming increasingly apparent [100]. In recent years, blockchain technology has been identified as a potential solution for achieving maritime supply chain integration and enhancing the efficiency of maritime logistics [101]. A significant research focus in the future could be on integrating blockchain technology and digital technologies into shipping supply chains. This integration would involve conducting extensive research investigations and multiple case studies to test and validate the proposed framework. The aim is to provide ship management with enhanced decision support, ultimately serving as a reference for strategic decision-making within enterprises [102].

5.2. Green Port Construction

While green port construction plays a crucial role in advancing maritime sustainability, it continues to face some limitations. Major challenges include the high cost of infrastructure upgrades and the adoption of new technologies. For instance, implementing renewable energy sources like solar or wind, modifying equipment to lower emissions, and introducing smart logistics systems are all expensive initiatives that can strain port budgets, especially for smaller or developing ports [103]. Furthermore, these upgrades often require long-term investments that might not yield immediate economic benefits, making it harder to evaluate them financially [104]. Additionally, building green ports requires advanced technologies and highly skilled labor, both of which are often in short supply. The integration of smart systems, such as IoT and AI, to optimize operations and reduce environmental impacts necessitates extensive technical expertise and training, which may be lacking in many port regions [105]. This skill gap presents a barrier to achieving the full potential of green port initiatives.

The lack of standardized regulations across different regions and countries has posed barriers to implementing green port initiatives as well [106]. Ports operating under different legal frameworks face difficulties in aligning their green initiatives with international standards, which creates discrepancies in environmental performance. This inconsistency often leads to inefficiencies, as ports in countries with stricter regulations may be at a competitive disadvantage compared to those with more lenient policies [107].

Moreover, operational challenges due to the conflict of goals between efficiency and emission reduction also pose significant difficulties. Ports must find ways to reduce emissions without compromising efficiency, which can be a complex and resource-intensive task [108]. Take the Shanghai port case study as an example. As the port has implemented greener technologies, it has had to contend with adjusting operational schedules and energy sources, which initially created inefficiencies [109]. Achieving carbon emission reduction targets often involves implementing advanced optimization models, but these systems may not always align with the fast-paced, high-efficiency requirements of busy ports. The conflict is particularly evident in ports striving to remain competitive while simultaneously adhering to stringent environmental policies [110].

In terms of future opportunities for green port development, CI stands out as a key innovation in the electrification of the maritime industry. CI technology, which involves switching from diesel engines to shore-based electrical power while ships are docked, offers significant potential for reducing emissions and integrating alternative energy sources into port operations. Looking forward, CI could be utilized as part of a broader green port strategy, serving both electric ships and conventional vessels retrofitted to use onshore power. This technology not only lowers greenhouse gas emissions, but contributes to energy efficiency and improved air quality in port regions.

Moreover, the integration of CI with RETs presents a promising area for future research and development. By combining RETs such as solar, wind, or hydrogen with smart port technologies—such as Artificial Intelligence (AI), Internet of Things (IoT), and blockchain—ports can optimize energy consumption and reduce operational costs. These digital solutions will enable real-time monitoring and management of energy flows, further enhancing the environmental performance of green ports. For instance, AI and IoT could analyze energy usage patterns to improve efficiency, while blockchain could facilitate transparent carbon accounting and collaboration across the supply chain [111].

In addition to technological advancements, future opportunities lie in the collaboration among stakeholders, including shipowners, port operators, and policymakers [112]. Joint efforts in developing standardized regulations and incentivizing sustainable practices will help accelerate the adoption of CI and other green technologies. As regulatory frameworks evolve to enforce stricter emission standards, ports will need to invest in cleaner infrastructure, and the cost of retrofitting ships for CI will become more economically viable through subsidies or carbon credits [113].

6. Conclusions

This review summarizes the relevant publications on the application of intelligent shipping technology and green port construction in the field of sustainable maritime transport and adopts bibliometric methods to collect 462 publications between 2000 and 2023, based on SCI Expanded, SSCI, and ESCI databases. The research reveals that over the past 13 years, the literature in the field of sustainable maritime transport applications has become increasingly extensive, with a rapid growth in the number of publications, particularly since 2018. Furthermore, the study underscores the preeminent position of the Journal of Marine Science and Engineering, Ocean Engineering, and IEEE Transactions on Intelligent Transportation Systems, as evidenced by their substantially higher publication output in this area compared to other journals. This shows their status as leading publications within the field, providing researchers with invaluable resources and guidance for their endeavors.

An analysis of the author collaboration network reveals that, despite certain individuals contributing a higher volume of publications, academic cooperation within the field remains predominantly confined to individual research teams, with limited instances of cross-team collaboration. For upcoming research endeavors, reinforcing inter-team collaboration holds paramount importance. This collaboration has the potential to expand research vistas, integrate multifaceted approaches and viewpoints, transcend the limitations posed by narrow perspectives, and ultimately fortify the trustworthiness of research findings.

According to the analysis of the organizational collaboration network, Wuhan University of Technology, Dalian Maritime University, Hong Kong Polytechnic University, and Shanghai Maritime University have produced numerous publications in sustainable maritime transport, significantly contributing to the field's advancement. However, an analysis of the organizational collaboration network diagram indicates a lack of intimate collaboration among these organizations. To propel the field's growth further, organizations must enhance their partnerships, foster knowledge and research experience sharing, and collaboratively facilitate the dissemination and utilization of research outcomes.

According to the country collaboration analysis, China stands as a foremost contributor within the scholarly corpus of sustainable maritime transport, boasting the largest volume of publications (190), trailed closely by the United States and England. The VOSviewer-constructed country collaboration network analysis highlights China's dominance not only in publication volume but in the extent and intimacy of international collaborations, underpinned by the Chinese government's steadfast commitment to fostering sustainable maritime transport development. Nevertheless, given shipping's inherently global nature, confronting challenges necessitates concerted efforts across nations. Each country harbors distinct strengths and expertise in shipping, emphasizing the urgency to deepen international cooperation and harness complementary knowledge bases to propel the holistic progress of sustainable maritime transport research.

The analysis of keyword co-occurrence unveils the pivotal research clusters within the realm of sustainable maritime transport applications. Among the various keywords identified, AIS data stands out as the most prevalent, constituting a pivotal research hotspot within this domain. Furthermore, the findings underscore AI technology, trajectory forecasting, eco-friendly ports, and additional clusters as contemporary focal points of research within this field. Based on the analysis, it is found that there are two hot areas in the direction of sustainable maritime transport, namely intelligent shipping technology and green port construction. Therefore, the research status of these two applications is described, providing references for researchers in any future exploration in this field. Finally, the development of intelligent shipping technology and green port construction in sustainable maritime transport is discussed from two aspects of existing challenges and future opportunities. As far as intelligent shipping technology is concerned, with the rapid development of big data and intelligence, data security and data source integration will become the focus of urgent attention in the future. In ship trajectory prediction, research on different climates and different ship types will also become the direction for future research.

In terms of green port construction, in recent years, more scholars have paid attention to the application of CI in ports, and some studies have also shown that CI has become one of the indispensable energy sources in the future and is a major focus for future research.

During the inaugural address of the second United Nations Global Sustainable Transport Conference, Xu Lirong, the Chairman and Party Secretary of COSCO Shipping Group, eloquently remarked: "Maritime transport is a key force to promote the development of global sustainable transport. We will actively fulfill our social responsibilities, vigorously promote technological innovation in the industry, actively support and drive the industry to move towards a green and sustainable direction, and contribute China's shipping strength to the sustainable development of global transportation [1]". The results of this review can assist scholars in understanding the development trend in the field of sustainable maritime transport, gaining a better comprehension of the current status in this field and identifying potential research opportunities.

Furthermore, it must be acknowledged that this review has limitations, and further in-depth investigation is needed. Firstly, despite conducting a systematic literature review process, the reliance on a specific database (WoS) for article selection inevitably led to the potential omission of some significant articles. Furthermore, the selection of search keywords was limited to the themes of the selected papers and the two focal areas, namely intelligent shipping technology and green port construction, which constitutes another limitation of this review. This approach may have overlooked other challenges faced by the shipping industry in its current state and practice, such as those related to maritime logistics and transportation accident risks. Therefore, future research should aim to minimize bias by utilizing a wider range of databases to select relevant papers. Additionally, this review primarily focused on the analysis of scientific papers, neglecting the inclusion of mandatory regulations, patents, and industry documents, which represents a possible limitation. To expand the scope and depth of this research, future endeavors should delve deeper into these aspects. Lastly, this review solely employs bibliometric methods for its comprehensive analysis. While these methods primarily focus on providing abundant data support and quantitative analysis, enabling researchers to grasp research trends in the maritime transportation field from a macro perspective, they inherently fall short in deeply elucidating the causal relationships between different technologies and strategies, or evaluating their actual effectiveness. To overcome this limitation, future research could consider integrating multiple research methodologies, such as case studies and experimental validations. By comprehensively analyzing data and information from diverse sources, we can offer more scientific and rational suggestions and guidance for the sustainable development of the shipping industry.

Author Contributions: Conceptualization, G.X. and Y.W.; methodology, G.X., Y.W., R.W. and Z.C.; writing—original draft preparation, G.X. and Y.W.; writing—review and editing, G.X., R.W., J.L. and Z.C.; funding acquisition, G.X. and J.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by National Natural Science Foundation of China, grant number 52472323, Beijing Natural Science Foundation, grant number 9244032, The Ministry of Education of Humanities and Social Science project, grant 23YJC630190 and Shanghai Sailing Program, grant 21YF1445800.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Readers can access our data by sending an email to the corresponding author Guangnian Xiao.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Ma, S.R. Addressing the climate challenge: Transforming and innovating together the second UN global sustainable transport conference focuses on the future of the maritime industry. *Marit. China* **2021**, *11*, 24–25.
2. Wang, J.Y. Analysing the impact of the worldwide outbreak of new crown on the shipping industry. *Pearl River Water Transp.* **2020**, 82–83. [CrossRef]
3. Shi, W.M.; Li, K.X. Themes and tools of maritime transport research during 2000–2014. *Marit. Policy Manag.* **2017**, *44*, 151–169. [CrossRef]
4. Tian, Z.; Liu, F.; Li, Z.; Malekian, R.; Xie, Y. The development of key technologies in applications of vessels connected to the Internet. *Symmetry* **2017**, *9*, 211. [CrossRef]
5. Parhamfar, M.; Sadeghkhani, I.; Adeli, A.M. Towards the application of renewable energy technologies in green ports: Technical and economic perspectives. *IET Renew. Power Gener.* **2023**, *17*, 3120–3132. [CrossRef]
6. Huang, J.X.; Duan, X.L. A comprehensive review of emission reduction technologies for marine transportation. *J. Renew. Sustain. Energy* **2023**, *15*, 032702. [CrossRef]
7. Cao, Y.; Wang, X.; Yang, Z.; Wang, J.; Wang, H.; Liu, Z. Research in marine accidents: A bibliometric analysis, systematic review and future directions. *Ocean. Eng.* **2023**, *284*, 115048. [CrossRef]
8. Xu, M.; Ma, X.; Zhao, Y.; Qiao, W. A systematic literature review of maritime transportation safety management. *J. Mar. Sci. Eng.* **2023**, *11*, 2311. [CrossRef]
9. Wu, X.; Wu, J.; Xu, L. Advanced research on the sustainable maritime transportation. *J. Mar. Sci. Eng.* **2024**, *12*, 1104. [CrossRef]
10. 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]
11. Ellegaard, O.; Wallin, J.A. The bibliometric analysis of scholarly production: How great is the impact? *Scientometrics* **2015**, *105*, 1809–1831. [CrossRef] [PubMed]
12. Wallin, J.A. Bibliometric methods: Pitfalls and possibilities. *Basic Clin. Pharmacol. Toxicol.* **2005**, *97*, 261–275. [CrossRef] [PubMed]
13. Zhu, J.; Liu, W. A tale of two databases: The use of Web of Science and Scopus in academic papers. *Scientometrics* **2020**, *123*, 321–335. [CrossRef]
14. Ahmed, S.; Alshater, M.M.; Ammari, A.E.; Hammami, H. Artificial intelligence and machine learning in finance: A bibliometric review. *Res. Int. Bus. Financ.* **2022**, *61*, 101646. [CrossRef]
15. Xiao, G.; Yang, D.; Xu, L.; Li, J.; Jiang, Z. The application of artificial intelligence technology in shipping: A bibliometric review. *J. Mar. Sci. Eng.* **2024**, *12*, 624. [CrossRef]
16. Xiao, G.; Chen, L.; Chen, X.; Jiang, C.; Ni, A.; Zhang, C.; Zong, F. A hybrid visualization model for knowledge mapping: Scientometrics, SAOM, and SAO. *IEEE Trans. Intell. Transp. Syst.* **2024**, *25*, 2208–2221. [CrossRef]
17. Adnan, A.R.; Widowati, R.; Nuryakin. Evolution and trends in Indonesian green marketing research: A systematic review (2018-2023). *J. Green Econ. Low-Carbon Dev.* **2023**, *2*, 162–174. [CrossRef]
18. Torku, A.; Chan, A.P.C.; Yung, E.H.K. Age-friendly cities and communities: A review and future directions. *Ageing Soc.* **2021**, *41*, 2242–2279. [CrossRef]
19. Xu, C.; Yu, D.; Yang, H.; Yu, S. 20 years of economic corridors development: A bibliometric analysis. *J. Appl. Econ.* **2021**, *24*, 173–192. [CrossRef]
20. Waltman, L.; van Eck, N.J.; Noyons, E.C.M. A unified approach to mapping and clustering of bibliometric networks. *J. Informetr.* **2010**, *4*, 629–635. [CrossRef]
21. Wang, S.; Zhen, L.; Psaraftis, H.N.; Yan, R. Implications of the EU's inclusion of maritime transport in the emissions trading system for shipping companies comment. *Engineering* **2021**, *7*, 554–557. [CrossRef]
22. Zhen, L.; Yuan, Y.; Zhuge, D.; Psaraftis, H.N.; Wang, S. Subsidy strategy design for shore power utilization and promotion. *Marit. Policy Manag.* **2023**, 1–33. [CrossRef]
23. Zhuge, D.; Wang, S.; Zhen, L.; Psaraftis, H.N. Data-Driven modeling of maritime transportation: Key issues, challenges, and solutions. *Engineering* **2023**, *31*, 25–26. [CrossRef]
24. Lagemann, B.; Lagouvardou, S.; Lindstad, E.; Fagerholt, K.; Psaraftis, H.N.; Erikstad, S.O. Optimal ship lifetime fuel and power system selection under uncertainty. *Transp. Res. Part D Transp. Environ.* **2023**, *119*, 103748. [CrossRef]
25. Lagemann, B.; Lindstad, E.; Fagerholt, K.; Rialland, A.; Erikstad, S.O. Optimal ship lifetime fuel and power system selection. *Transp. Res. Part D Transp. Environ.* **2022**, *102*, 103145. [CrossRef]
26. Jiang, M.Z.; Lu, J.; Qu, Z.H.; Yang, Z.L. Port vulnerability assessment from a supply Chain perspective. *Ocean. Coast. Manag.* **2021**, *213*, 105851. [CrossRef]
27. Li, H.H.; Jiao, H.; Yang, Z.L. AIS data-driven ship trajectory prediction modelling and analysis based on machine learning and deep learning methods. *Transp. Res. Part E Logist. Transp. Rev.* **2023**, *175*, 103152. [CrossRef]
28. Wang, J.G.; Li, H.H.; Yang, Z.L.; Ge, Y.E. Shore power for reduction of shipping emission in port: A bibliometric analysis. *Transp. Res. Part E Logist. Transp. Rev.* **2024**, *188*, 103639. [CrossRef]
29. Psaraftis, H.N.; Kontovas, C.A. Balancing the economic and environmental performance of maritime transportation. *Transp. Res. Part D Transp. Environ.* **2010**, *15*, 458–462. [CrossRef]

30. Psaraftis, H.N.; Kontovas, C.A. Speed models for energy-efficient maritime transportation: A taxonomy and survey. *Transp. Res. Part C Emerg. Technol.* **2013**, *26*, 331–351. [CrossRef]
31. Psaraftis, H.N.; Kontovas, C.A. Decarbonization of maritime transport: Is there light at the end of the tunnel? *Sustainability* **2021**, *13*, 237. [CrossRef]
32. Chua, J.Y.; Wang, X.Q.; Yuen, K.F. Sustainable shipping management: Definitions, critical success factors, drivers and performance. *Transp. Policy* **2023**, *141*, 72–82. [CrossRef]
33. Wang, X.Q.; Yuen, K.F.; Wong, Y.D.; Li, K.X. How can the maritime industry meet Sustainable Development Goals? An analysis of sustainability reports from the social entrepreneurship perspective. *Transp. Res. Part D Transp. Environ.* **2020**, *78*, 102173. [CrossRef]
34. Yuen, K.F.; Li, K.X.; Xu, G.Y.; Wang, X.Q.; Wong, Y.D. A taxonomy of resources for sustainable shipping management: Their interrelationships and effects on business performance. *Transp. Res. Part E Logist. Transp. Rev.* **2019**, *128*, 316–332. [CrossRef]
35. Yuen, K.F.; Wang, X.Q.; Wong, Y.D.; Li, K.X. The role of stakeholder participation and sustainability integration in maritime transport: A structure-conduct-performance analysis. *Transp. Policy* **2020**, *99*, 44–53. [CrossRef]
36. Ducruet, C. Port specialization and connectivity in the global maritime network. *Marit. Policy Manag.* **2022**, *49*, 1–17. [CrossRef]
37. Mou, N.X.; Xu, H.Q.; Liu, Y.; Li, G.Q.; Zhang, L.X.; Ducruet, C.; Zhang, X.H.; Wang, Y.C.; Yang, T.F. Does the Chinese coastal ports disruption affect the reliability of the maritime network? Evidence from port importance and typhoon risk. *Int. J. Appl. Earth Obs. Geoinf.* **2024**, *129*, 103846. [CrossRef]
38. Rousset, L.; Ducruet, C. Disruptions in Spatial Networks: A Comparative Study of Major Shocks Affecting Ports and Shipping Patterns. *Netw. Spat. Econ.* **2020**, *20*, 423–447. [CrossRef]
39. Du, Y.Q.; Meng, Q.; Wang, S.A.; Kuang, H.B. Two-phase optimal solutions for ship speed and trim optimization over a voyage using voyage report data. *Transp. Res. Part B Methodol.* **2019**, *122*, 88–114. [CrossRef]
40. Wang, S.A.; Meng, Q. Sailing speed optimization for container ships in a liner shipping network. *Transp. Res. Part E Logist. Transp. Rev.* **2012**, *48*, 701–714. [CrossRef]
41. Wang, S.A.; Meng, Q. Container liner fleet deployment: A systematic overview. *Transp. Res. Part C Emerg. Technol.* **2017**, *77*, 389–404. [CrossRef]
42. Aakko-Saksa, P.T.; Lehtoranta, K.; Kuittinen, N.; Järvinen, A.; Jalkanen, J.P.; Johnson, K.; Jung, H.; Ntziachristos, L.; Gagné, S.; Takahashi, C.; et al. Reduction in greenhouse gas and other emissions from ship engines: Current trends and future options. *Prog. Energy Combust. Sci.* **2023**, *94*, 101055. [CrossRef]
43. Kangasniemi, O.; Simonen, P.; Moldanová, J.; Timonen, H.; Barreira, L.M.F.; Hellén, H.; Jalkanen, J.P.; Majamäki, E.; D'Anna, B.; Lanzafame, G.; et al. Volatility of a ship's emissions in the Baltic Sea using modelling and measurements in real-world conditions. *Atmosphere* **2023**, *14*, 1175. [CrossRef]
44. Lagouvardou, S.; Psaraftis, H.N.; Zis, T. Impacts of a bunker levy on decarbonizing shipping: A tanker case study. *Transp. Res. Part D Transp. Environ.* **2022**, *106*, 103257. [CrossRef]
45. Lagouvardou, S.; Psaraftis, H.N.; Zis, T. A literature survey on market-based measures for the decarbonization of shipping. *Sustainability* **2020**, *12*, 3953. [CrossRef]
46. Iris, Ç.; Lam, J.S.L. A review of energy efficiency in ports: Operational strategies, technologies and energy management systems. *Renew. Sustain. Energy Rev.* **2019**, *112*, 170–182. [CrossRef]
47. Iris, Ç.; Lam, J.S.L. Optimal energy management and operations planning in seaports with smart grid while harnessing renewable energy under uncertainty. *Omega* **2021**, *103*, 102445. [CrossRef]
48. Chen, Y.; Wang, W.; Chen, X.M. Bibliometric methods in traffic flow prediction based on artificial intelligence. *Expert Syst. Appl.* **2023**, *228*, 120421. [CrossRef]
49. Yu, D.; Xu, Z.; Fujita, H. Bibliometric analysis on the evolution of applied intelligence. *Appl. Intell.* **2019**, *49*, 449–462. [CrossRef]
50. Halim, R.A.; Kirstein, L.; Merk, O.; Martinez, L.M. Decarbonization pathways for international maritime transport: A model-based policy impact assessment. *Sustainability* **2018**, *10*, 2243. [CrossRef]
51. Traut, M.; Larkin, A.; Anderson, K.; McGlade, C.; Sharmina, M.; Smith, T. CO_2 abatement goals for international shipping. *Clim. Policy* **2018**, *18*, 1066–1075. [CrossRef]
52. Yan, X.P.; Liu, C.G. Review and prospect for intelligent waterway transportation system. *CAAI Trans. Intell. Syst.* **2016**, *11*, 807–817. [CrossRef]
53. He, X.H. Research of Structure Frame Designing of Shipping Intelligent Transportation System. Ph.D. Thesis, Tongji University, Shanghai, China, 2007.
54. Chen, X.; Wu, H.; Han, B.; Liu, W.; Montewka, J.; Liu, R.W. Orientation-aware ship detection via a rotation feature decoupling supported deep learning approach. *Eng. Appl. Artif. Intell.* **2023**, *125*, 106686. [CrossRef]
55. SMASH! SMASH! Launches Roadmap Smart Shipping during Europort. Available online: https://smashnederland.nl/en/news/smash-launches-roadmap-smart-shipping-during-europort/ (accessed on 3 November 2021).
56. A world first! Very Large LNG Ship Across the Ocean: Half Autonomous, Half Crew Operated! Captain: "Greatly Improve the Crew's Working Comfort!". Available online: https://www.cnss.com.cn/html/sdbd/20220606/346369.html (accessed on 6 June 2022).

57. China's First Self-Developed Unmanned Cargo Ship Has Completed Its Maiden Voyage. Available online: https://www.eworldship.com/html/2019/NewShipUnderConstrunction_1215/155317.html (accessed on 15 December 2019).
58. ISOTC8/WG10. International Organization for Standardization Ship and Marine Technology Committee Intelligent Shipping Working Group (ISOTC8/WG10) 8th Meeting. Available online: http://www.cansi.org.cn/cms/document/17656.html (accessed on 17 May 2022).
59. Maritime Safety Committee. Maritime Safety Committee (MSC 105), 20–29 April 2022. Available online: https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/MSC-105th-session.aspx (accessed on 29 April 2022).
60. Wang, W.; Yang, Y.; Yang, X.; Gayah, V.V.; Wang, Y.; Tang, J.; Yuan, Z. A negative binomial Lindley approach considering spatiotemporal effects for modeling traffic crash frequency with excess zeros. *Accid. Anal. Prev.* **2024**, *207*, 107741. [CrossRef]
61. Enguehard, R.A.; Devillers, R.; Hoeber, O. Comparing interactive and automated mapping systems for supporting fisheries enforcement activities—A case study on vessel monitoring systems (VMS). *J. Coast. Conserv.* **2013**, *17*, 105–119. [CrossRef]
62. Enguehard, R.A.; Hoeber, O.; Devillers, R. Interactive exploration of movement data: A case study of geovisual analytics for fishing vessel analysis. *Inf. Vis.* **2013**, *12*, 65–84. [CrossRef]
63. Zhang, X.; Fu, X.; Xiao, Z.; Xu, H.; Qin, Z. Vessel trajectory prediction in maritime transportation: Current approaches and beyond. *IEEE Trans. Intell. Transp. Syst.* **2022**, *23*, 19980–19998. [CrossRef]
64. Lei, P.-R. Mining maritime traffic conflict trajectories from a massive AIS data. *Knowl. Inf. Syst.* **2020**, *62*, 259–285. [CrossRef]
65. Chen, X.; Liu, Y.; Achuthan, K.; Zhang, X. A ship movement classification based on Automatic Identification System (AIS) data using Convolutional Neural Network. *Ocean. Eng.* **2020**, *218*, 108182. [CrossRef]
66. Xiao, Z.; Fu, X.; Zhang, L.; Zhang, W.; Liu, R.W.; Liu, Z.; Goh, R.S.M. Big data driven vessel trajectory and navigating state prediction with adaptive learning, motion modeling and particle filtering techniques. *IEEE Trans. Intell. Transp. Syst.* **2022**, *23*, 3696–3709. [CrossRef]
67. Abebe, M.; Noh, Y.; Kang, Y.-J.; Seo, C.; Kim, D.; Seo, J. Ship trajectory planning for collision avoidance using hybrid ARIMA-LSTM models. *Ocean. Eng.* **2022**, *256*, 111527. [CrossRef]
68. Xiao, Y.; Li, X.; Yao, W.; Chen, J.; Hu, Y. Bidirectional data-driven trajectory prediction for intelligent maritime traffic. *IEEE Trans. Intell. Transp. Syst.* **2023**, *24*, 1773–1785. [CrossRef]
69. Wang, M.; Wang, Y.; Cui, E.; Fu, X. A novel multi-ship collision probability estimation method considering data-driven quantification of trajectory uncertainty. *Ocean. Eng.* **2023**, *272*, 113825. [CrossRef]
70. Li, H.; Xing, W.; Jiao, H.; Yang, Z.; Li, Y. Deep bi-directional information-empowered ship trajectory prediction for maritime autonomous surface ships. *Transp. Res. Part E Logist. Transp. Rev.* **2024**, *181*, 103367. [CrossRef]
71. Liu, R.W.; Liang, M.; Nie, J.; Yuan, Y.; Xiong, Z.; Yu, H.; Guizani, N. STMGCN: Mobile edge computing-empowered vessel trajectory prediction using spatio-temporal multigraph convolutional network. *IEEE Trans. Ind. Inform.* **2022**, *18*, 7977–7987. [CrossRef]
72. Tu, E.; Zhang, G.; Rachmawati, L.; Rajabally, E.; Huang, G.B. Exploiting AIS data for intelligent maritime navigation: A comprehensive survey from data to methodology. *IEEE Trans. Intell. Transp. Syst.* **2018**, *19*, 1559–1582. [CrossRef]
73. Xu, Y.; Yao, W.; Zheng, X.; Chen, X. An iterative information integration method for multi-level system reliability analysis based on Bayesian Melding Method. *Reliab. Eng. Syst. Saf.* **2020**, *204*, 107201. [CrossRef]
74. Li, H.; Jiao, H.; Yang, Z. Ship trajectory prediction based on machine learning and deep learning: A systematic review and methods analysis. *Eng. Appl. Artif. Intell.* **2023**, *126*, 107062. [CrossRef]
75. Wu, W.; Chen, P.; Chen, L.; Mou, J. Ship trajectory prediction: An integrated approach using ConvLSTM-Based Sequence-to-Sequence Model. *J. Mar. Sci. Eng.* **2023**, *11*, 1484. [CrossRef]
76. Scorzolini, A.; Perini, V.D.; Razzano, E.; Colavolpe, G.; Mendes, S.; Fiori, P.; Sorbo, A. European enhanced space-based AIS system study. In Proceedings of the 2010 5th Advanced Satellite Multimedia Systems Conference and the 11th Signal Processing for Space Communications Workshop, Cagliari, Italy, 13–15 September 2010; pp. 9–16.
77. Mazzarella, F.; Arguedas, V.F.; Vespe, M. Knowledge-based vessel position prediction using historical AIS data. In Proceedings of the 2015 Sensor Data Fusion: Trends, Solutions, Applications (SDF), Bonn, Germany, 6–8 October 2015; pp. 1–6.
78. Ministry of Transport of the People's Republic of China. Water Transport "14th Five-Year" Development Plan. Available online: https://xxgk.mot.gov.cn/2020/jigou/zhghs/202204/t20220407_3649837.html (accessed on 29 January 2022).
79. Corbett, J.J.; Wang, H.; Winebrake, J.J. The effectiveness and costs of speed reductions on emissions from international shipping. *Transp. Res. Part D Transp. Environ.* **2009**, *14*, 593–598. [CrossRef]
80. Dong, M.; Li, Y.; Xu, X.; Zha, Y. A practical accessibility evaluation method for port-centric coal transportation chains: Considering the environment and operational adaptability. *Sustainablility* **2022**, *14*, 11619. [CrossRef]
81. Fan, S.; Lu, Z. Research on the peak carbon dioxide emission strategy of Chinese port based on carbonemission estimation. *Front. Environ. Sci.* **2022**, *9*, 789970. [CrossRef]
82. Jiang, L.; Tang, S.; Wang, G.; Yu, T.; Yuan, J. The evaluation of government subsidy policies on carbon emissions in the port collection and distribution network: A case study of Guangzhou Port. *Front. Mar. Sci.* **2023**, *10*, 3389. [CrossRef]
83. Cammin, P.; Yu, J.; Voß, S. Tiered prediction models for port vessel emissions inventories. *Flex. Serv. Manuf. J.* **2023**, *35*, 142–169. [CrossRef]

84. Jiang, X.; Zhong, M.; Shi, J.; Li, W.; Sui, Y.; Dou, Y. Overall scheduling model for vessels scheduling and berth allocation for ports with restricted channels that considers carbon emissions. *J. Mar. Sci. Eng.* **2022**, *10*, 1757. [CrossRef]
85. Liu, M.; Lai, K.-h.; Wong, C.; Xin, X.; Lun, Y.H. Smart ports for sustainable shipping: Concept and practices revisited through the case study of China's Tianjin port. *Marit. Econ. Logist.* **2024**, 1–46. [CrossRef]
86. Zhang, C.; Xiao, G.; Xu, L. Manufacturers' emission-reduction investments in competing supply chains with Prisoner's Dilemma: The economic and environmental impacts of Retailer(s) capital Constraint(s). *Transp. Res. Part E Logist. Transp. Rev.* **2024**, *187*, 103602. [CrossRef]
87. Wang, T.; Wang, X.; Meng, Q. Joint berth allocation and quay crane assignment under different carbon taxation policies. *Transp. Res. Part B Methodol.* **2018**, *117*, 18–36. [CrossRef]
88. Wu, L.; Wang, S. The shore power deployment problem for maritime transportation. *Transp. Res. Part E Logist. Transp. Rev.* **2020**, *135*, 101883. [CrossRef]
89. Wang, T.; Du, Y.; Fang, D.; Li, Z.-C. Berth allocation and quay crane assignment for the trade-off between service efficiency and operating cost considering carbon emission taxation. *Transp. Sci.* **2020**, *54*, 1307–1331. [CrossRef]
90. Sciberras, E.A.; Zahawi, B.; Atkinson, D.J. Reducing shipboard emissions—Assessment of the role of electrical technologies. *Transp. Res. Part D Transp. Environ.* **2017**, *51*, 227–239. [CrossRef]
91. Yu, J.; Voß, S.; Tang, G. Strategy development for retrofitting ships for implementing shore side electricity. *Transp. Res. Part D Transp. Environ.* **2019**, *74*, 201–213. [CrossRef]
92. Daniel, H.; Trovao, J.P.F.; Williams, D. Shore power as a first step toward shipping decarbonization and related policy impact on a dry bulk cargo carrier. *eTransportation* **2022**, *11*, 100150. [CrossRef]
93. Zhang, C.; Zhao, P.; Huang, Z.; He, Z.; Niu, Y.; Huang, G.; Chen, Y. Assessing vessel transportation delays affected by tropical cyclones using AIS data and a bayesian network: A case study of veronica in northwestern Australia. *Ocean. Eng.* **2024**, *308*, 118385. [CrossRef]
94. Chen, X.; Wei, C.; Xin, Z.; Zhao, J.; Xian, J. Ship detection under low-visibility weather interference via an ensemble generative adversarial network. *J. Mar. Sci. Eng.* **2023**, *11*, 2065. [CrossRef]
95. Chen, X.; Zheng, J.; Li, C.; Wu, B.; Wu, H.; Montewka, J. Maritime traffic situation awareness analysis via high-fidelity ship imaging trajectory. *Multimed. Tools Appl.* **2024**, *83*, 48907–48923. [CrossRef]
96. Zhang, D.; Chu, X.; Liu, C.; He, Z.; Zhang, P.; Wu, W. A review on motion prediction for intelligent ship navigation. *J. Mar. Sci. Eng.* **2024**, *12*, 107. [CrossRef]
97. Soares, C.G. Intelligent shipping technology and development trend. In Proceedings of the first World Conference on Navigation Science and Technology, Qingdao, China, 17–19 October 2023.
98. Tuncel, A.L.; Sezer, S.I.; Elidolu, G.; Uflaz, E.; Akyuz, E.; Arslan, O. A rule-based Bayesian network modelling under evidential reasoning theory for risk analysis of anchoring operation in maritime transportation. *Ocean. Eng.* **2024**, *292*, 116521. [CrossRef]
99. Yigin, B.; Celik, M. A prescriptive model for failure analysis in ship machinery monitoring using Generative Adversarial Networks. *J. Mar. Sci. Eng.* **2024**, *12*, 493. [CrossRef]
100. Singh, S.; Chakraborty, K.; Pratap, S.; Singh, M.; Zhou, F. Analysing factors influencing the adoption of blockchain technology in maritime freight enterprises. *Enterp. Inf. Syst.* **2024**, *18*, 2326676. [CrossRef]
101. Queiroz, M.M.; Telles, R.; Bonilla, S.H. Blockchain and supply chain management integration: A systematic review of the literature. *Supply Chain. Manag. Int. J.* **2020**, *25*, 241–254. [CrossRef]
102. Shin, S.; Wang, Y.; Pettit, S.; Abouarghoub, W. Blockchain application in maritime supply chain: A systematic literature review and conceptual framework. *Marit. Policy Manag.* **2024**, *51*, 1062–1095. [CrossRef]
103. Puig, M.; Wooldridge, C.; Darbra, R.M. Identification and selection of environmental performance indicators for sustainable port development. *Mar. Pollut. Bull.* **2014**, *81*, 124–130. [CrossRef]
104. Dinwoodie, J.; Tuck, S.; Knowles, H.; Benhin, J.; Sansom, M. Sustainable development of maritime operations in ports. *Bus. Strategy Environ.* **2012**, *21*, 111–126. [CrossRef]
105. Özispa, N.; Arabelen, G. Sustainability issues in ports: Content analysis and review of the literature (1987–2017). *SHS Web Conf.* **2018**, *58*, 01022. [CrossRef]
106. Chen, X.; Dou, S.; Song, T.; Wu, H.; Sun, Y.; Xian, J. Spatial-temporal ship pollution distribution exploitation and harbor environmental impact analysis via large-scale AIS data. *J. Mar. Sci. Eng.* **2024**, *12*, 960. [CrossRef]
107. Acciaro, M.; Ghiara, H.; Cusano, M.I. Energy management in seaports: A new role for port authorities. *Energy Policy* **2014**, *71*, 4–12. [CrossRef]
108. Lirn, T.-C.; Wu, Y.; Chen, Y. Green performance criteria for sustainable ports in Asia. *Int. J. Phys. Distrib. Logist. Manag.* **2013**, *43*, 427–451. [CrossRef]
109. Zeng, Y.; Yuan, X.; Hou, B. Analysis of carbon emission reduction at the port of integrated logistics: The port of Shanghai case study. *Sustainability* **2023**, *15*, 10914. [CrossRef]
110. Peng, Y.; Li, X.; Wang, W.; Li, R. Review on energy saving and emission reduction strategies of green container ports. *J. Traffic Transp. Eng.* **2022**, *22*, 28–46. [CrossRef]
111. Mansoursamaei, M.; Moradi, M.; González-Ramírez, R.G.; Lalla-Ruiz, E. Machine learning for promoting environmental sustainability in ports. *J. Adv. Transp.* **2023**, *2023*, 2144733. [CrossRef]

112. Xiao, G.; Cui, W. Evolutionary game between government and shipping enterprises based on shipping cycle and carbon quota. *Front. Mar. Sci.* **2023**, *10*, 1132174. [CrossRef]
113. Bakar, N.N.A.; 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]