The Evolution of Green Port Research: A Knowledge Mapping Analysis

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Abstract: Green port research integrates numerous theoretical and empirical studies of topics of important concern over the years, involving comprehensive scientific analyses. Learning about the global evolution of research on green ports can improve the understanding and evaluation of green ports by scholars and practitioners. In this paper, a total of 1051 papers from the Web of Science core collection for the period during 1992–2021 are collected as sample data. Based on the database, an analysis is conducted with CiteSpace software to map the knowledge regarding the field of green ports and explore the current research trends; the cooperation networks among countries (regions), institutions, and authors; and the evolution and mutation of keywords. The results indicate that the overall number of green port papers has increased over time. The countries with the highest numbers of papers published and the greatest influence are China and the United States, respectively. Additionally, the cooperative networks among authors, institutions, and countries are not mature enough and need to be strengthened further. Existing studies focus on the environmental impacts, evaluation, and construction of green ports. Recent trends indicate that researchers have become increasingly focused on reducing emissions, optimizing operations, evaluating policies, and identifying post-pandemic health issues associated with green ports. This study contributes to knowledge by assessing the state of the most significant studies published in the field of green port research, and the results contribute to a better understanding of green port research, which can further provide directions for the sustainable development of green ports.

Keywords: green port; CiteSpace; visual analysis; knowledge mapping; bibliometric

1. Introduction

Ports are important gateways for international trade, involving value-added services, such as loading and unloading cargo. Ports also provide warehousing and packaging functions and are hubs for the arrangement of inland transportation [1–3]; thus, ports are considered to play the greatest role in “green logistics” [4]. Approximately 80% of the global trade volume and more than 70% of value passed through maritime transport and global ports in 2018 [5,6]. However, the negative impact of ports on the environment is significant, and various ecological challenges exist [7], such as those associated with greenhouse gas emissions [8], water pollution [9], waste disposal, land use, and energy consumption [5]. With the increased environmental awareness of the public, the concept of green ports has emerged [10]. As early as January 2005, the Port of Long Beach adopted the Green Port Policy, establishing the basic framework for environmentally friendly port operations [11]. The concept of green ports was formally proposed at the United Nations Climate Change Conference in 2009 [12]. Green ports refer to ports with a healthy ecological environment, reasonable utilization of resources, low energy consumption, and minimized pollution on the basis of an organic combination of port development, efficient resource use, and environmental protection [12]. In July 2021, the International Maritime Organization announced the “World Maritime Theme 2022: New Technologies for Green Shipping” [13]. To cope with the increasingly serious environmental and energy consumption problems,
the adoption of new technologies and operation management plans to build green ports (GLCPs) has become essential for future development [14]. In recent years, green ports have attracted increasing attention from industry and academia [15,16].

Scholars have performed numerous studies of the drivers, innovations, and challenges of green ports, laying a solid foundation for green port practices. In terms of drivers, economic and technological measures can enhance the competitiveness of green ports; such measures involve the designing of concession agreements, changing business models [17], and improving green technologies [18]. Environmental and policy factors can create external pressures on green ports; for example, water pollution [9], noise pollution [19], and emissions may require regulatory requirements [20]. Technological innovation in green ports involves several areas, such as basic, operational, and energy measures. In terms of basic measures, the environment should be considered in planning policies and infrastructure, emission inventories should be established to monitor port activities, and environmental improvements and efficiency gains should be achieved through sustainable construction methods [21]. In terms of operational measures, reducing the ship turnaround time (TAT) [22], developing virtual arrival (VA) systems [23], establishing automated operating systems for container terminals [24], and reducing truck emissions [25] are important tasks. In terms of energy measures, alternative energy measures, such as the use of liquefied natural gas [26], clean fuels [27], alternative energy systems with electrification [28], hybrid and renewable energy [29] measures, and smart measures with technologies, such as edge computing [30], artificial intelligence, blockchain [31], and drones [32], should be employed. Environmental issues will continue to present challenges in the future related to the sufficiency of technological changes in ports to offset the increasing ecological pressure of maritime traffic [33], the use of integrated energy systems [34], and the balance between ecological and economic benefits [32]. Previous studies have extensively investigated different areas, groups, and solutions associated with green ports, and the research results have provided theoretical and technical support for green port development.

However, due to the breadth of topics related to green ports and immense difficulty of comprehensively understanding green port-related topics, it is important to assess the literature from a holistic perspective. Additional analyses of the literature using rigorous bibliometric tools can provide new insights not previously captured. Bibliometrics is an interdisciplinary science in which mathematical and statistical methods are used for the quantitative analysis of knowledge vectors [35,36]. This approach is based on computational techniques and social statistics, which are applied to quantitatively analyze a process; additionally, the inputs and outputs of scientific and technological activities are used to develop knowledge maps of the scientific, technological domain, and other related domains [37]. Scientific knowledge mapping illustrates features in the knowledge domain as objects in an image to show the process of scientific knowledge development and the corresponding structural relationships [38], thus providing new knowledge while portraying the known knowledge relationships. With the digitization of scientific and technical literature and the development of data analysis techniques, it is now possible to explore research hotspots and the impacts of evolutionary processes through analyses at different scales [39]. This method has been applied by many scholars in different fields, such as port logistics [39], seafarer health [40], dry port design [41], and green shipping [42]. Therefore, in this study, the current status and development trends of green ports are explored from a bibliometric perspective to identify the focus and priority areas of green port research, assess the development of different aspects of green ports, and help provide a comprehensive and broad reference regarding the practical implications of green port development for various stakeholders.

The objectives of this study are to explore bibliometric-based green port research and to track the evolution of research topics over time in terms of green port technology and management trends. The research process was guided by the following research questions:

RQ (1) What are the publication trends of green port research?
RQ (2) Who are the main authors, institutions, and countries contributing to green port research?

RQ (3) Which papers and authors have had the greatest impact on the field of green ports, and what are the links between these papers and authors?

RQ (4) What are the research keywords and important areas in green port research? What are the trajectories of knowledge evolution and future research trends?

To answer the above questions and provide a comprehensive review of green port research, objective research themes related to green ports are identified, the evolution of the knowledge of green ports is assessed, and the results are combined with those of a traditional literature review based on the Web of Science Core Collection database and the results of scientometric analysis and knowledge mapping [43]. The added value of this study is that it provides an in-depth bibliometric analysis of the evolution of green port topics in the literature, and a map of green port knowledge structures is developed. This bibliometric and visual assessment of green port research can help new researchers identify the most relevant topics, countries, institutions, journals, authors, and articles in the green port field. This research contributes to green port policy decision making and the development of potential initiatives by identifying areas of interest and future directions for green port research.

The structure of this article is as follows. First, the background of the research related to green ports is introduced. In the second section, the research methods and literature search strategies are introduced. The knowledge graph and results of analyses of publications, countries/regions, authors, co-authors, and various studies are presented, and keyword clustering is performed. Additionally, future research hotspots are proposed. Section IV presents the conclusions.

2. Materials and Methods

In this study, bibliometric analysis was used to explore green ports based on an analysis of the literature and scientific mapping [44]. The literature analysis involves examining the contributions of publications, authors, countries, and affiliations involved, and is used to highlight the consideration of various features in different fields [45]. Scientific mapping can be used to map the evolution and structure of a research field and visualize the relationships between thematic networks and subfields, focusing on the intellectual interactions and structural links among research components (e.g., authors, institutions, countries, and journals) [45]. Three types of cocitation analysis were performed in this study. First, a cocitation analysis of cited references was conducted to understand the structure of cited references in the focal domain. Second, a cocitation analysis of cited authors was performed to identify influential authors by estimating citation records. Finally, co-occurrence analysis was performed to analyze frequent words appearing in publications and understand the thematic relationships [46,47]. This technique can be used to complement cocitation analysis and predict future research topics in the field [45].

In bibliometric analysis, knowledge turning points are crucial. Therefore, CiteSpace software was used for the systematic bibliometric review focusing on key data, and the structure and evolution of knowledge of a topic were characterized [48]. CiteSpace is based on a macroscopic research perspective and has the following beneficial traits: (a) it can efficiently handle citation data obtained from popular academic databases and open-access sources; (b) it allows users to perform various bibliometric analyses and visualize the results; (c) as Java-based software, it is actively maintained and updated with new visual analysis features and theoretical developments; and (d) it can support progressive network analysis based on time-slicing strategies and interactivity schemes [49].

There are different types of databases available online, including Google Scholar, ProQuest, Science Direct, the Web of Science (WoS), and Scopus [50]. In the current paper, WoS was used as the data source. There were two reasons for using WoS. First, WoS is considered to provide comprehensive information from the leading journals and influential publications worldwide, with visualizations and statistics for analyzing data regarding
various research topics, authors, document types, time frames, countries, universities, and institutions [51]. Second, the publications downloaded from this database are in a format that can be directly read by the software tools described above, and the analysis tool used in this study, CiteSpace, was originally developed based solely on the WoS database [52]; therefore, the results generated using WoS will be more reliable and accurate than those from other databases. WoS is one of the most widely used databases, and it allows entire batches of articles to be downloaded in a variety of formats that are commonly used by mapping and data analysis applications. In addition, to minimize the potential loss of information by eliminating duplicate publications from various sources, no other databases were included in this study.

The scientometric method was used to establish a scientific knowledge graph of the green port literature, and CiteSpace software was applied to select specific information, such as authors, institutions, keywords or cocitations, to obtain a visual map that is then used to determine the current research status, research hotspots, and frontier directions in related subject areas. A three-stage approach [41] was used in the search strategy to identify and evaluate studies of the topic of green ports published in peer-reviewed journals.

In the first phase, WoS was used as the main search engine for articles. The WoS Science Network is considered the most authoritative journal database in the world and has been widely used in bibliometric analysis, with more consistent and standardized results retrieved from WoS than from other databases, such as Scopus [53]. The WoS Core Collection (WoSCC) database contains papers from leading global journals that require rigorous peer reviews [54]. For this reason, previous scholarly studies have mainly adopted the ‘article’ document type in the WoS database during data collection. We also followed this approach [54].

First, data obtained from the database of the Ocean University of China Library were added to the scientific database, and through a WoS search, the data used were retrieved on 18 February 2022, based on the following search strategy:

(a) Topic = ‘port’ and ‘pollution’; ‘port’ and ‘natural ecosystem’; ‘port’ and ‘shore power’; ‘port’ and ‘green energy’; ‘port’ and ‘automated container terminal’; ‘green port’ and ‘operation’; ‘green port’ and ‘management’;
(b) Database = ‘SCI-EXPANDED’ or ‘SSCI’ or ‘A&HCI’ or ‘CPCI-S’ or ‘CICI-SSH’ or ‘ESCI’;
(c) Time span = ‘1991–2021’;
(d) Document type = ‘article’ or ‘conference papers’ or ‘review paper’;
(e) Language = “English”.

Through this strategy, a total of 3813 records were retrieved.

The unrelated subject areas that were excluded in the second phase were those that did not fall within the scope of logistics and maritime transport, and the search results included papers that were not related to green ports [53]; hence, unrelated subject areas were identified through consensus among researchers, and at least two members of the senior research team agreed on the results. Subject areas, such as Earth and Planetary Sciences, Pharmaceuticals, Biochemistry, Genetics and Molecular Biology, Physics, and Astronomy, were found to be irrelevant to the scope of our review. Furthermore, a manual review was conducted by two senior researchers, ultimately retaining 1544 papers related to the research topic.

In the final phase, duplicate and invalid studies were removed through CiteSpace software, resulting in a total of 1051 papers related to the research topic. Nonetheless, we identified high-quality papers through the above search process, and this number was deemed sufficient for assessing the current research situation and trends in green port research.

3. Results and Discussion

3.1. Annual Publication Output

The number of published documents reflects progress in developing a field of research from a given perspective. Following the data collection and identification, a total of
1051 papers were obtained; their chronological distribution and corresponding cumulative results were used to establish a statistical chart of the number of papers related to green ports (Figure 1).

![Figure 1. Distribution of green port publications from 1992 to 2021.](image)

1. 1992–2000: The number of papers published each year was mainly in the single digits, reaching six in 2000, indicating that the international research on green ports was still in the initial stage of development during this period. The relevant concepts and theories were not mature. Some scholars in this phase became concerned with anthropogenic pollution in port areas [55], recognized that ballast water and sediments in ports could be a pathway for the invasion of harmful species [56], conducted studies on the environmental impact of port activities [57], and analyzed the energy and environmental benefits of natural gas as a clean fuel [58].

2. 2001–2010: The average number of annual papers published during this period increased to a certain extent; the number of papers published in 2010 reached 30, and the total number in the period reached 129. The research related to green ports gradually received increased attention, and the related research was enriched. The academic community in this period focused on automation technologies to enhance the efficiency of port operations [59,60], the optimization of port-related algorithms [61], the scheduling of automated guided vehicles [62], and other research topics.

3. 2011–2021: The number of papers published annually was generally higher than double digits, displaying a rapid growth trend; notably, the annual number of articles published after 2018 reached more than 100, and in 2021, it reached 205. The research related to green ports was continuously enriched, showing great research potential. Studies in this phase focused on multi-objective planning analysis to achieve economic and environmental benefits for ports [63,64], reducing the consumption of energy through model algorithm optimization [65], reducing the environmental impacts of green ports, and enhancing the green management of ports [66].

Based on the results for the three time periods, the scientific research on green ports shows a rapid growth trend, and the main reason for this change is that the related global environmental problems have become increasingly serious. Notably, the construction of green ports needs to be improved to combat climate change, and the technical and management measures applied for green ports must be enhanced. Moreover, resources and energy must be conserved, and the marine environment and ecology must be protected. A total of 1051 major journals included in the WoSCC were used for publication between 1992 and 2021 (see Table 1). Table 1 lists (1) the top-10 categories based on the total number of published papers in the WoS, (2) the top-10 publishers of relevant papers, and (3) the top-10 journals in terms of publication volume.
Table 1. Top-10 WoS categories, publishers, and publication titles from 1992 to 2021.

| WoS Category                  | Record Count | Publisher   | Record Count | Publication Title                  | Record Count |
|-------------------------------|--------------|-------------|--------------|-------------------------------------|--------------|
| Environmental Sciences        | 411          | Elsevier    | 407          | Sustainability                      | 54           |
| Transportation                | 180          | IEEE        | 131          | Transportation Research Part D: Transport and Environment | 52           |
| Transportation Science        | 153          | MDPI        | 115          | Marine Pollution Bulletin           | 39           |
| Technology                    |              |             |              |                                     |              |
| Environmental Studies         | 149          | Springer Nature | 98          | Science of The Total Environment    | 36           |
| Green Sustainable Science     | 124          | Taylor & Francis | 76          | Journal of Cleaner Production       | 26           |
| Technology                    |              |             |              |                                     |              |
| Engineering Electrical        | 119          | Wiley       | 19           | Maritime Policy & Management        | 25           |
| Electronic                   |              |             |              |                                     |              |
| Oceanography                  | 81           | Copernicus Gesellschaft MBH | 18          | Ocean & Coastal Management          | 23           |
| Energy Fuels                  | 80           | IOP Publishing, Ltd. | 18          | Atmospheric Environment             | 18           |
| Engineering Environmental     | 76           | Sage        | 16           | Energies                            | 16           |
| Engineering Civil             | 75           | Coastal Education & Research Foundation | 14          | Journal of Marine Science and Engineering | 16           |

3.2. Country/Region/Institution Cooperation Analysis

The difference in the number of publications among countries (regions) reflects, to some extent, the different levels of interest in green port research. By analyzing the collaborative networks among countries/regions, it was possible to identify priority countries/regions that generate high numbers of publications and have a significant impact on the research field; additionally, the collaborative relationships among these entities can be identified. In CiteSpace, the time period was set to 1992–2021 with an interval of 1 year, the node type was country or region, and the labeling parameter was G-Index = 25. Calculations were performed with the results to obtain a country/region cooperation map (Figure 2) and visualize the collaborations among institutions (Figure 3).

We observed a total of 81 countries and regions that conducted green port research from 1992 to 2022, with an intertwined network of partners. Figure 2 presents a map of the collaborative network of countries/regions created using CiteSpace software. A data analysis yielded the following information: the total number of network nodes was 81 (N = 81), the nodes were connected by 232 links (E = 232), and the density of the research network was 0.0716 (density = 0.0716). The circles in the figure represent frequencies, and the size of the circles is proportional to the frequency counts. Lines connecting different nodes indicate the simultaneous presence of multiple nodes in the same study. Centrality indicates the importance of a particular node in the network [54]. Therefore, the greater the centrality, the greater the influence of the associated country/region. Figure 2 and Table 2 present that the country/region with the most published papers is China (Counts = 225), followed by the USA (counts = 94), Italy (counts = 65), Spain (counts = 59), the United Kingdom (counts = 41), Australia (counts = 38), and Germany (counts = 31). China leads in the number of studies, with a larger red area around each node, indicating that most of the studies were published in recent years. Compared to that in developed countries, the research conducted on green ports in China started late [12], but exploded as Chinese ports entered the ranks of the world’s major ports [67]. However, the impact of these
studies is relatively low (centrality = 0.09). The number of studies in the United States ranks second, and the USA nodes are more uniform over time, indicating that the relevant research papers were published more consistently in the United States. Additionally, the USA studies rank first in terms of impact (centrality = 0.24). For example, a review of green ports and maritime logistics conducted by Hoda et al. (2016) has been widely cited [68], and an overview of transport operations and material handling equipment presented by Carlo et al. (2014) has had a considerable impact on the field [69]. Italy displays the third-highest number of studies and the second-highest impact (centrality = 0.23), with notable studies on energy-management strategies [70] and effective measures for the development of green ports [71]. From the perspective of network structure, the periphery of some nodes, such as those for Australia, South Korea, and the United Kingdom, is red, and the color of the connections with other countries is vivid, indicating the strong intermediary role of these countries and regions as bridges in the network structure.

Figure 2. A map of countries and regions with corresponding green port logistics-related publications.

Table 2. The top-10 countries/regions in frequency and centrality between 1992 and 2022.

| Rank | Country    | Count | Centrality |
|------|------------|-------|------------|
| 1    | China      | 225   | 0.09       |
| 2    | USA        | 94    | 0.24       |
| 3    | Italy      | 65    | 0.23       |
| 4    | Spain      | 59    | 0.05       |
| 5    | England    | 41    | 0.15       |
| 6    | Australia  | 38    | 0.09       |
| 7    | South Korea| 32    | 0.01       |
| 8    | Germany    | 31    | 0.05       |
| 9    | Taiwan     | 26    | 0.03       |
| 10   | Croatia    | 25    | 0.00       |
Figure 3 presents the collaborative network graph for publishing institutions; this figure was obtained with CiteSpace software. The following information can be derived from the data: the total number of network nodes was 316 (N = 316), the nodes were connected by 331 links (E = 331), and the density of the research network was 0.0067. It can be concluded that the research network map related to green ports has a low density, which means that the research institutions are relatively widely distributed, and there is a need to further strengthen the cooperation among institutions. The institution that published the most papers was Shanghai Maritime University (records = 61), followed by Hong Kong Polytech University (records = 18) and Dalian University (records = 15), as presented in Table 3. Shanghai Ocean University, Hong Kong Polytech University, and Dalian Ocean University are intermediaries with relatively high connectivity capabilities, thus constituting important network nodes in the knowledge map of green port-related research institutions. Specifically, these institutions display certain cooperative relations with other institutions. There are many isolated points in the figure, indicating that some institutions do not cooperate with any other institutions.

Table 3. Statistical table of papers published by research institutions.

| No. | Institution                         | Records | No. | Institution                         | Records |
|-----|------------------------------------|---------|-----|------------------------------------|---------|
| 1   | Shanghai Maritime University       | 61      | 7   | University of Rijeka               | 13      |
| 2   | Hong Kong Polytechnic University  | 18      | 8   | Nanyang Technological University   | 11      |
| 3   | Dalian University of Technology   | 15      | 10  | University of Ljubljana            | 10      |
| 4   | Dalian Maritime University        | 15      | 11  | National University of Singapore   | 10      |
| 5   | Wuhan University of Technology    | 15      | 12  | Fudan University                   | 10      |
| 6   | Shanghai Jiao Tong University    | 13      | 13  | Shanghai University                | 10      |

3.3. Author Distribution and Cluster Analysis

High-yield authors are important in academic research innovation, and they have played an important role in enriching the research related to green ports. Table 4 presents the high-yield authors of green port-related studies.
As presented in Table 4, the authors with the highest number of research outputs are Jihong Chen (15), followed by Wenyuan Wang (12), Yan Zhang (12), Yun Peng (9), Zheng Wan (8), Tony R Walker (7), Beatriz Tovar (7), and Jasmine Siu Lee Lam (7). As a social network, the author writing network is important for processes, such as creating and sharing knowledge. The cooperative network generated by CiteSpace is presented in Figure 4. Each author is a network node, and the cooperation among authors is denoted by connections. The larger a node in the map, the more frequently the corresponding author published papers, and the greater the number of connections they have, the higher their frequency of collaborating with other authors. The degree of clustering in the author collaboration networks is typically used to obtain the density of the resulting visual network, i.e., the ratio of the actual number of connections in the network to the number of theoretical connections in the ideal state of the same network:

\[ D = \frac{E}{C_V} = \frac{2E}{V(V-1)} \]  

(1)

where \( E \) is an actual connection and \( V \) is the number of nodes in the network. When \( D \) is 1, the network is fully connected; when \( 0 < D < 1 \), the network is not fully connected, and the greater the value of \( D \), the greater the degree of network convergence and the closer the scope of cooperation between the authors. In Figure 4, \( V \) is 2440 and \( E \) is 6144. The density of the author cooperation network for green port-related studies is 0.0021, and the network aggregation density is low.

As presented in Figure 4, Yan Zhang, Jihong Chen, and Wenyuan Wang are the most prominent nodes. There are three important collaborating groups in the center of the network, and some authors, such as Fan Zhang, Huang Liu, and Liu Xiaotong Wang, act as ‘bridges’ to connect different collaborating groups. Overall, cooperation within the Yan Zhang group is common, and there is less cooperation within the Jihong Chen group. From a temporal perspective, the three groups of authors are connected by bright links, suggesting that these group researchers mainly published works recently. Specifically, the collaborative cluster with Jihong Chen as the core focused on the research areas, such as marine alternative energy (AMP) technology [72] (Chen J, 2019), carbon-dioxide-emission assessment [73], green port evaluation [74], and impact factor analysis [75]. The collaborative cluster with Wenyuan Wang and Yun Peng as the core focused on operation model optimization [76], energy consumption prediction [77], and shore-power-allocation strategies [78]. The collaborative cluster centered on Yan Zhang focused on air pollution from ships to ports [79] and developing specific impact analyses for geographical areas, such as Shanghai [80] and the Yangtze River Delta [81] in China. There were other smaller collaborative clusters, such as those around B. Tovar and M. Tichavska focused on port emission regulations [82,83], emission cost estimations [84], and high citation rates. There were also clusters around the Walker and Acciaro nodes, with a focus on the green marine certification of maritime companies [85] and green sustainability impact factors for port companies [86].

### Table 4. High-output authors in green port research.

| No. | Author              | Record Count | No. | Author                       | Record Count |
|-----|---------------------|--------------|-----|------------------------------|--------------|
| 1   | Jihong Chen         | 15           | 8   | Xianda Li                    | 6            |
| 2   | Wenyuan Wang        | 12           | 9   | Jasmine Siu Lee Lam          | 6            |
| 3   | Yan Zhang           | 12           | 10  | Chunlien Su                  | 6            |
| 4   | Yun Peng            | 9            | 11  | Weichun Ma                   | 6            |
| 5   | Zheng Wan           | 8            | 12  | Kevin Cullinane              | 6            |
| 6   | Tony R Walker       | 7            | 13  | Lang Xu                      | 6            |
| 7   | Beatriz Tovar       | 7            | 14  | Hyangsook Lee                | 5            |
also clusters around the Walker and Acciaro nodes, with a focus on the green marine certification of maritime companies [85] and green sustainability impact factors for port companies [86].

Figure 4. Visual spectrum of the author cooperation network.

3.4. Coauthor Distribution and Reference Cocitation Analysis

We extracted references of cocited literature (Figure 5) from the research data, obtained the lead authors from the cocitation analysis, and plotted a common network map of the authors (Figure 6).

Figure 5. Cocitation network for green port logistics-related research [87–94].
Green ports are described using high common citation groups, and the frequency of common citations of references is presented in Figure 5. An important reference is Liu H (2016) (frequency = 37) [87], who used advanced methods based on detailed dynamic ship activity data and observed that shipping emissions in East Asia accounted for 16% of the global shipping CO\textsubscript{2} emissions in 2013. During 2002–2005, this total was only 4–7%. Styhre L (2017) (frequency = 37) [88] published “Greenhouse Gas Emissions from Ships in Ports—A Case Study of Four Continents”, which explored greenhouse gas emissions from the transport sector, noting that reducing these emissions is a major challenge for policy makers. Winkel R. (2016) (frequency = 37) [89] published “The coastal power of Europe: potential and environmental benefits”, based on detailed estimates of ship emissions and associated energy needs in ports; the study provided an insight into the expected obstacles to implementing and developing recommended policy actions that could accelerate the green transformation of European ports. Davarzani H (2016) (frequency = 36) [68] explored the past and present research on green ports and maritime logistics to identify the established research topics and areas with future research potential. Fan QZ (2016) (frequency = 35) [90] established a model based on an automatic identification system, which was used to estimate ship exhaust emissions within 400 km of the Yangtze River Delta and East China Sea coastlines; the study showed that ship emissions have an important impact on the entire Yangtze River Delta region and East China. Innes A (2018) (frequency = 31) [91] explored the feasibility of installing cold ironing structures in medium-sized ports with several small berths, such as those in Hong Kong Port. Sofiev M (2018) (frequency = 31) [92] developed high-resolution emission inventories, and integrated atmospheric models and health risk functions to assess the impacts of PM 2.5 pollution associated with ships with and without low-sulfur fuels in 2020; notably, cleaner marine fuels were projected to reduce ship-related premature mortality and morbidity by 34% and 54%, respectively. Globally, approximately 2.6% of cardiovascular- and lung cancer-related deaths and approximately 3.6% of childhood asthma cases are due to PM 2.5 pollution. Viana M (2014) (frequency = 29) [93] reviewed the main chemical tracers emitted by shipping, the particle size distribution of shipborne particles, and the corresponding contributions to population exposure and atmospheric sedimentation, with a focus on particulate matter and gaseous pollutants,
and mitigation strategies were discussed. Song S (2014) (frequency = 27) [94] introduced a sophisticated activity-based approach developed based on a modern automatic identification system (AIS) with ship-by-vessel and real-time data support to estimate the social costs associated with emissions from ships in port areas and the emissions from the port of Shangyang Hill.

The most common citation among authors was Corbett JJ (frequency = 148). For example, in “The effectiveness and costs of speed reductions on emissions from international shipping”, the policy implications of fuel taxes and deceleration directives in the context of CO₂ emissions were explored [95]. A second common reference among authors was Eyring V (frequency = 85) [96], who established ship emissions algorithms for 2006 and two future scenarios involving fuel consumption in 2050 and emissions and the ship traffic density in 2010. Moreover, Corbett JJ collaborated with Eyring V to publish “Transport impacts on atmosphere and climate shipping,” The contributions of gas and particulate matter emissions from ocean transport to anthropogenic emissions and air quality were assessed, as were the deterioration of human health and climate changes caused by these emissions. Lam J. S. L. (frequency = 84) [97] was the third most commonly cited author and co-published “The Greening of Ports A Comparison of Port Management Tools Used by Leading Ports in Asia and Europe”, which involved port management tools owned by ports/public authorities. The extent to which these tools were implemented or encouraged during port operation and development was then analyzed.

3.5. Keyword Distribution and Cluster Analysis

The research hotspots usually refer to topics discussed in groups of papers with similar research content within a certain period of time. Keywords are an important part of a research paper and they transmit important information about the paper. Therefore, high-frequency keywords can be used to track research hotspots.

We applied data after format conversion and set the time interval to one year, the node type to “Keyword”, and the “Selection Criteria” to top 50; additionally, we merged some similar keywords for co-occurrence mapping, as shown in Figure 7.

Figure 7. Keyword co-occurrence network for green port logistics-related research.
In the map, N = 736 (number of nodes), E = 2698 (number of edges), and Density = 0.01 (network density). The frequency of keyword appearance is represented by the size and the color of the circle, and the lines represent the time of publication. The stronger the connection between two nodes, the more time the corresponding keywords take to co-occure. The following results can be derived from the map: (1) the ‘impact’ node displays the maximum size and frequency (119) from the perspective of the study, which means that the literature focuses on the relationships between the endogenous and exogenous influences of green ports. The nodes with many links are ship emissions, pollution, air quality, gas logistics, environmental management, and diversity. (2) The ‘port’ node is the second-largest node and has the second-highest frequency (99). With the continuous development of port theory and practice, the number of specific issues associated with green ports has increased. The nodes closely related to the port node are relatively large nodes, such as climate change, inventory, management, model, strategy, simulation, and allocation. (3) The ‘management’, ‘pollution’, and ‘emission’ nodes display the third-, fourth-, and fifth-largest sizes and frequencies (84, 81, 80), respectively. From the research content, the term ‘green port’ is associated with studies that focus on various initiatives to improve the management efficiency and reduce pollution and emissions. Nodes that are closely related to this node are optimization, sustainable port, policy, ballast water, source apportionment, algorithm, and environmental performance. (4) The ‘model’ node is the sixth-largest node and has the sixth-highest frequency (75). From the perspective of research methods, considering the complexity and uncertainty of green port research problems, the use of various quantitative models to analyze specific problems is the main paradigm of the current research. Nodes that are closely related to the model node are green port, exhaust emission, algorithm, and optimization.

From the perspective of centrality, the centrality of the keyword ‘algorithm’ (0.13) is the highest, followed by the values for design (0.12) and management (0.1). This result is related to the construction of green ports. The core process is operations management, and port operations research is often used in various modeling methods, such as mixed-integer programming (MIP), mixed-integer nonlinear programming (MINLP), and mixed-integer second-order cone programming (MISOCP). The above research methods need to be solved by using algorithms, and the most common algorithms are local branching (LB), particle swarm optimization (PSO), genetic algorithms (GAs), and some precision solution algorithms [11].

CiteSpace provides three algorithms for computing cluster labels: LSI, LLR, and MI. Studies have shown that the cluster recognition of the LLR algorithm is relatively representative and comprehensive, and the keyword clustering function is ideal [39]. Therefore, this algorithm was the focus of the cluster mapping of the keywords of green port studies (Figure 8), where Q = 0.6333 (greater than 0.3) indicated that the cluster column was reliable and the profile value S = 0.7956 (greater than 0.5) indicated that the structure was reasonable. Invalid clusters (e.g., hazardous cargo vessels), ten in total, were removed. The contour values of the keyword clusters ranged from 0.715 for cluster #4 to 0.973 for cluster #10. The size of the largest cluster (#0) was 126 papers and the size of the smallest cluster (#10) was 17 papers. Figure 9 shows a timeline of keyword co-occurrence networks related to green port research. Table 5 shows clusters of keywords in green port research. The 10 clusters were divided into three categories to assess the research on green ports and best understand the results of the cluster analysis.
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The 10 clusters were divided into three categories to assess the research on green ports
and best understand the results of the cluster analysis.

Figure 8. Keyword clustering diagram for green port logistics-related research.

Figure 9. A timeline of keyword co-occurrence networks related to green port research.

The first category mainly involved the analyses of the environmental impact of ports,
emphasizing the importance of green ports from different perspectives; this category
encompassed clusters #0, #5, and #6. (1) Cluster #0 (air quality) involved ship emissions
and human health. Container ships operating or berthing in ports can cause severe air
pollution in port cities [98], and high levels of air pollution may occur in port areas [99,100].
At present, the common solution is to dynamically allocate berths through shore power
applications and optimize berth operations considering fuel consumption and ship exhaust
emissions [101,102]; this approach can reduce exhaust emissions by optimizing the speed
of ship navigation [103]. (2) Cluster #5 (ballast water) involved planktonic bacteria, local
sea water, and the biological community structure. Ballast water is an important local

| Cluster ID | Size  | Silhouette | Mean (Year) | Label (LLR) |
|------------|-------|------------|-------------|-------------|
| 0          | 126   | 0.794      | 2018        | Air quality; container terminal; ship emission; human health; Gothenburg area |
| 1          | 116   | 0.739      | 2012        | Container terminal; automated container terminal; stor-
|            |       |            |             | age allocation; considering energy consumption; inte-
|            |       |            |             | grated internal truck yard crane |
| 2          | 71    | 0.824      | 2013        | Port operation; container terminal; supply network; mul-
|            |       |            |             | timethodological approach; integrating sustainability performance measurement |
| 4          | 60    | 0.715      | 2017        | Greening port; energy port concept planning zero-emis-
|            |       |            |             | sions port; installing cold ironing |
| 5          | 57    | 0.830      | 2015        | Ballast water; Xiamen port; planktonic bacteria; local sea water; community structure |
| 6          | 40    | 0.939      | 2014        | Environmental perturbation; coastal pollution monitor-
|            |       |            |             | ing; marine infrastructure; ecological enhancement; wave-energy conversion |
| 7          | 39    | 0.782      | 2017        | Green performance criteria; port development; natural environment; port sustainable development; green hand-
|            |       |            |             | brake |
| 8          | 36    | 0.876      | 2014        | Port earthing system; mutual influence; high-voltage shore-connected ship; to-ground fault; medium-voltage shoreside |
| 9          | 34    | 0.859      | 2014        | Port hinterland; literature review; research agenda; green concern; pearl river delta region |
| 10         | 17    | 0.973      | 2012        | Regional logistics system; port hinterland container dis-
|            |       |            |             | tribution; social cost efficiency; discrete choice analysis investigation; environmental parameter |

Table 5. Clusters of keywords in green port research.
source of marine pollution and has been found to introduce species worldwide [104]; specifically, it may cause heavy metal pollution [105]. The most effective technologies involve the replacement of ballast water at sea [106], innovative methods that provide seawater in a nondestructive manner at port facilities [107] and the selection of appropriate ship ballast water management strategies and treatment technologies [108]. (3) Cluster #6 (environmental perturbation) involved coastal pollution monitoring, marine infrastructure development, ecological enhancement, and wave-energy conversion. Port construction and operations inevitably create environmental disturbances; hence, there is a need to strengthen the control of emissions from port cargo handling activities [109]. Additionally, there is a need to strengthen monitoring to mitigate negative changes in water quality in ports [9] and heavy metal pollution; these tasks would require the timely measurement of environmental variables in port areas [110] and the systematic management of activities that generate environmental disturbances.

Table 5. Clusters of keywords in green port research.

| Cluster ID | Size  | Silhouette | Mean (Year) | Label (LLR)                                                                 |
|------------|-------|------------|-------------|-----------------------------------------------------------------------------|
| 0          | 126   | 0.794      | 2018        | Air quality; container terminal; ship emission; human health; Gothenburg area |
| 1          | 116   | 0.739      | 2012        | Container terminal; automated container terminal; storage allocation; considering energy consumption; integrated internal truck yard crane |
| 2          | 71    | 0.824      | 2013        | Port operation; container terminal; supply network; multimethodological approach; integrating sustainability performance measurement |
| 4          | 60    | 0.715      | 2017        | Greening port; energy port concept planning zero-emissions port; installing cold ironing |
| 5          | 57    | 0.83       | 2015        | ballast water; Xiamen port; planktonic bacteria; local sea water; community structure |
| 6          | 40    | 0.939      | 2014        | Environmental perturbation; coastal pollution monitoring; marine infrastructure; ecological enhancement; wave-energy conversion |
| 7          | 39    | 0.782      | 2017        | Green performance criteria; port development; natural environment; port sustainable development; green handbrake |
| 8          | 36    | 0.876      | 2014        | Port earthing system; mutual influence; high-voltage shore-connected ship; to-ground fault; medium-voltage shoreside |
| 9          | 34    | 0.859      | 2014        | Port hinterland; literature review; research agenda; green concern; pearl river delta region |
| 10         | 17    | 0.973      | 2012        | Regional logistics system; port hinterland container distribution; social cost efficiency; discrete choice analysis investigation; environmental parameter |

The second category included evaluation studies of green ports seeking to develop models for the construction of green ports, and this category encompassed clusters #7 and #9. (1) Cluster #7 (green performance criteria) involved port development, the natural environment, sustainable port development, and green constraints. The green port-performance evaluation involves environmental, economic, and other factors. When the relevant environmental and port performance goals are combined, the greenness of port performance can be optimized [11]. To date, there are several evaluation mechanisms for green ports, such as the APEC Port Services Network (APSN)-based Asia-Pacific Green Port Incentive Scheme (The Green Port Award System, GPAS), the Green Marine (GM) approach created by the North American Green Shipping Program (Green Marine Environmental Program), the European Sea Ports Organization (ESPO)-derived Eco-Ports environmental management standard, and the China Green Port Evaluation Standards. (2) Cluster #9 (port
hinterland) involved a literature review, research agenda, green concern, and the Pearl River Delta region. An increasing number of studies have focused on the environmental impacts of ports in hinterland areas and in the cities where ports are located; moreover, the corresponding green and sustainable development models have been explored. A port has both positive and negative effects on the city in which it is located [111], and port-site selection should consider not only the minimization of the transportation distance and transportation costs, but also the conditions of the environment [19], the degree of congestion, and the level of exhaust emissions [112]. In both the port and hinterland areas, the transport distance and cargo type should be comprehensively considered [113], and the organization and management of multimodal transport should be strengthened [114].

The third category involved building green ports from different dimensions, such as energy and infrastructure; this category encompassed clusters #1, #2, #4, #8, and #10. (1) Cluster #1 (container terminal) involved automated container terminals, storage allocation, energy consumption, and integrated internal truck yard cranes. Containers are handled, shipped, and stored via processes involving ports, and automated container terminal management is a major innovation in the field of intelligent port management [11]. Scholars have studied various algorithms for automated container terminal systems, such as the network simplex algorithm [115]. The improved GA-based algorithm [116] and the PSO algorithm based on a greedy search mechanism [117] have enhanced the efficiency of container handling [118] and promoted the development of green ports. (2) Cluster #2 (port operation) involved supply networks, combined methodologies, and the integration of sustainability performance measurements. Port operations need to comprehensively consider factors beyond the supply network, and a variety of methods must be used to achieve sustainable port development. Some scholars have focused on a sustainable perspective in the analysis of port operations [119], and various improvements have been proposed, such as the use of port management tools [97], management accounting tools [71], and five-dimensional models of port operations [120], to accelerate the process of port sustainability. (3) Cluster #4 (greening port) involved energy consumption at ports, the development of zero-emissions ports, and installing cold ironing systems at ports. Green ports need to optimize their energy management systems [97] and consider the fuel consumption and emission reduction performances of different energy systems [121]. Moreover, hybrid port energy storage systems [122] and renewable energy storage systems [123] should be used to improve energy efficiency. (4) Cluster #8 (port earthing system) involved mutual influence, high-voltage shore-connected ships, to-ground faults, and medium-voltage shore-side systems. The port city environment should be improved to reduce pollutant emissions from ships at berth [124]. Ports should consider the feasibility of equipping ships with shore power [89] based on assessments of changes in emissions and costs arising from the adoption of shore power technologies [125]. Additionally, shore power equipment could be used in certain ports, especially small- and medium-sized ports [91], to reduce emissions [126]. (5) Cluster #10 (regional logistics system) involved the port hinterland container distribution, social cost efficiency, discrete choice analysis investigation, and environmental parameters. Improving the efficiency of regional logistics systems is inseparable from the optimization of port shore-bridge and field-bridge scheduling. Considering the joint scheduling problem in regional logistics systems, it is necessary to design scheduling algorithms in combination with multiple real objectives at the regional scale, such as reducing carbon emissions by combining mathematical and simulation models with general regional models [127]. The goal of this approach is to avoid vessel delays and minimize energy consumption during operations based on a GA–PSO hybrid optimization algorithm [128]. Additionally, energy and time savings can be prioritized with cultural gene algorithms [129], and greedy random adaptive search algorithms can be applied for multi-objective optimization [130].
3.6. Trend

CiteSpace provides a burst detection function to detect keywords, and a sudden detection of keywords usually indicates that a research field has changed, reflecting the research frontier in the field [39]. A time-line visualization of keywords can be used to clearly and intuitively visualize the evolution and development of keyword clusters and word sets in different time periods, identify research trends, and clearly assess the evolution and mutation of words. Figure 10 shows a timeline diagram of green port research, with time as the horizontal coordinate, presenting the evolution of keywords in the temporal dimension and illustrating the characteristics of the research field in each phase from 2002 to 2021. To analyze the current research trends, we selected the relevant studies from the past 10 years, set the time interval to one year, and applied the burst detection function in CiteSpace [20]. The node type was “Keyword”, the selection criterion was “in the top 25”, and a mutation analysis of keywords was performed. The first 10 variants of the intensity of the change were obtained (Figure 11). The start and end times of mutations in the graph represent mutation cycles (represented by red lines). Keyword burst analysis is a useful tool for identifying the research directions that have received substantial attention over time [131]. In this case, the keywords “automated guided vehicle” displayed the greatest mutation intensity (value 6.08), followed by “green logistics.” The longest mutation time was 11 years, and the keywords for the most recent mutations were “reduction”, “source apportionment”, and “region”. 

Figure 10. Keyword time-zone map for green port research.
Combined with a second analysis of the literature, the frontiers of the research on green ports were as follows:

1) Green port emission reduction: In the context of reducing carbon emissions and other types of pollutants around the world, green ports play an important role in green supply chain management and still have considerable potential for future change [132]. On the one hand, green materials are involved in the process of green port construction, and the updating and renovation of port hardware and equipment can not only aid in achieving emission reduction goals, but also promote pollution prevention, such as by limiting heavy metal and garbage pollution [133]. On the other hand, through the deep integration of a new generation of information technology and green ports [134], highly intelligent ports will gradually be established, and various unmanned automated operation links will not only improve the efficiency of resource utilization, but also provide self-upgrading abilities.

2) Source apportionment: Green port construction is a long-term process that requires comprehensive management according to port resource endowments. In contrast to the general economic benefit maximization or cost minimization goals of ports, green port goals should consider environmental factors and involve multi-objective decisions [135]. In addition, resources, such as berths, shore bridges, and field bridges in a port, need to be planned in conjunction with the current conditions of the hinterland [111], not only to maximize the utilization of resources in the region but also to maximize the overall goals of the port. In addition, the optimization of green port resource management must be based on effective algorithms, and nonlinear solutions in multi-objective and large-scale situations are difficult to obtain, thus providing the research opportunities for scholars in this field [11].

3) Green port policy and evaluation (region): Different regions and port evaluation systems are characterized by objective differences. Studies of specific regions and specific port evaluation systems should be performed, [68], and research on green port evaluation systems should be improved to facilitate the efficient use of the energy and environmental resources at ports. Systematic statistical methods have made evaluation results more adaptable and comparable. At the same time, it is necessary to strengthen the policy evaluations of green ports, and the most advanced methodological tools in fields, such as economics and management, can be used to jointly improve evaluation systems and form comprehensive and dynamic evaluation systems [11].
(4) Green port studies should focus on the health issues experienced at ports. COVID-19 has had a strong negative impact on maritime trade, and there has been an increase in the amount of epidemic-proof materials transported [136]. Many countries have tried to recover their economies, thus increasing the demand for international shipping, and many studies have focused on the COVID-19 pandemic and changes in pollutant emissions in the maritime market [137,138]. However, the lack of workers and hinterland transport equipment, such as trucks, barges, and containers, has led to increased pollutant emissions when ships berth and receive services in ports [139]. Moreover, the cost of energy is likely to continue to increase due to the risk of epidemic transmission and the high demand for low-cost, cleaner energy in ports [140].

4. Conclusions

In this study, 1051 papers on green ports were selected as samples from the WoS from 1992 to 2001. Based on the selected papers, we used CiteSpace to analyze the discipline co-occurrence, publication characteristics, partnership, keyword co-occurrence, cocitation, burst word, and research theme trends. In summary, the analysis enabled us to answer the highlighted research problems. The conclusions were as follows.

For the first research question, RQ (1), we assessed the expansion of the research output in the green port field based on the publication volume and distribution. The general trend over the study period (1992–2021) indicated an increase in the number of published papers, suggesting that green port research is rapidly developing and will continue to be a hot topic. Three phases of the development of this research field according to the quantitative characteristics of published papers could be distinguished: 1992–2000, 2001–2010, and 2011–2021. Studies of green ports were mainly within the fields of environmental sciences, transportation, and transportation science and technology. The top three publishers were Elsevier, IEEE, and MDPI. Concerning the source journals, the most prolific journals in the green port field were Sustainability, Transportation Research Part D: Transport and Environment, and the Marine Pollution Bulletin.

In response to the second research question, RQ (2), we focused on determining the collaborative patterns among countries and institutions contributing to the outputs of green port research. The results show that 81 countries/regions have conducted green port research, with China, the United States, and Italy being the three countries with the most published papers; additionally, the United States, Italy, and the United Kingdom were the three countries with the greatest influence on the research. Concerning the institutions, Shanghai Maritime University, Hong Kong Polytechnic University, and Dalian University of Technology were the three with the most published papers. Other productive institutions were the University of Rijeka in the Republic of Croatia, Nanyang Technological University in Singapore, and the University of Ljubljana in the Republic of Slovenia. Cooperation among countries is still in an early stage, and the collaborative network among research institutions is not well connected. Thus, researchers should promote the internationalization and expansion of the research in this field.

To address the third research question, RQ (3), we identified the most widely read authors and papers in the green port research field. Based on the cocitation analysis, the most significant papers in the green port field were those by Corbett JJ [95], Eyring V [96], and Lam JSL [97]. Among other influential authors, we identified Liu H, Styhre L, Winkel R, and Davarzani H. Three initial, large, collaborative clusters were found with Jihong Chen, Wenyuan Wang, and Yan Zhang at the center, and other smaller collaborative clusters were identified with Beatriz Tovar and Tony R Walker at the center. All these authors laid the foundation for the research on green ports through their work.

Based on the fourth research question, RQ (4), we identified the most interesting research topics related to green ports. Recent scientific investigations of green ports have focused on the following issues: “impact”, “management”, “pollution”, “emissions”, and “model”. The ten clusters were divided into three categories: green port environmental impacts, evaluation, and construction. In the last three years, the keyword bursts in green
port research were as follows: “source apportionment”, “reduction”, “cost”, “region”, and “healthy”. Additionally, emission reduction, operation optimization, policy evaluation, and postpandemic health issues related to green ports are trends for future research.

This work added value to port research in practice and theory by providing a complete mapping of the green port research field. More collaborations across disciplines are required to explore the research gaps in the existing literature on green ports. The results of our analysis provide guidance for scholars interested in green ports and who are looking for opportunities to collaborate, which could enhance the sustainable development of green ports and the sharing of knowledge.

Additionally, we made some suggestions for future research regarding the construction of green ports. It is imperative to proposed standard but differentiated responsibility requirements for green ports. Although international organizations have formulated relevant environmental regulation programs and emission reduction measures, different ports have different resource endowments and are in development stages, and they lack clear technical standards and systematic green technology guidelines. Therefore, it is recommended that port green technology guidelines suitable for different development stages and different scales be developed, and that many aspects of port green innovation be promoted.

This paper had some limitations. The network analysis based on the WoS database may not be fully representative of the overall trends, and synonyms of subject words may lead to some literature omissions. Additionally, the online publication of some papers may lead to inconsistencies between collection and publication dates. As a result, the standards we used will be continually improved in the future.

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