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Review

Research Trends in Dry Port Sustainability: A Bibliometric Analysis

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Abstract: This study consolidates research on operational sustainability in dry ports. A total of 232 papers published in the last 23 years (2000–2023) are reviewed to assess the breadth of research perspectives in dry port sustainable operations. Additionally, the findings summarize current research trends, identify flaws in the body of knowledge, and suggest potential research areas. A bibliographic analysis approach is deployed to explore the existing body of knowledge, review the concepts in depth, and narrow the focus on potential research areas. Within this context, a content analysis technique has been utilized to explore and understand the conceptual underpinnings of specific themes, typically involving trending subjects like sustainability, dry ports, inland ports, economic sustainability, social sustainability, and environmental sustainability. Tools such as BibExcel and VOSviewer were utilized to assist in conducting the bibliometric analysis. The majority of dry port research has concentrated on the definition, functions, policy and governance, location analysis, ownership, and dry port-seaport interaction. Less attention is paid to dry port sustainability in line with the Sustainable Development Goals (SDGs), the interaction of internal and external collaboration with dry port sustainability, dry port social sustainability, dry port economic sustainability, dry port environment sustainability, and dry port service quality. Specifically, there has been limited research output on the sustainability of dry ports within the context of landlocked nations. This study will raise awareness of unexplored areas for further research by focusing on critical issues that are not generally covered by scholars in existing literature, such as dry port internal sustainability management and external collaboration.

Keywords: dry port; sustainability; landlocked countries; bibliometric analysis

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1. Introduction

Dry ports are the essential nodes that connect the production base with the seaport [1,2]. The surge in containerization has led to congestion at seaports, prompting the integration of dry ports as a strategic measure to relieve congestion at seaports [2,3]. The concept of a dry port is focused on shifting intermodal terminals away from the seaport into the hinterland to reduce traffic congestion and facilitate the construction of storage facilities [4,5]. Designing a dry port is a major challenge for governments and operators to create an effective trade supply chain sustainably [5,6]. Conservatively, establishing a dry port system contributes to the consolidation of container movements from and to seaports, integrating nearby road and rail transportation modes, and thereby improving the overall sustainability of the trade logistics system [7]. To overcome the global sustainability challenges of trade logistics, efficient intermodal transportation via dry ports is necessary [8].

Dry ports ensure higher levels of land connectivity, cut demurrage costs, and reduce congestion and delays in the trade supply chain network [9]. Within the broader network of trade logistics operations, dry ports facilitate better integration with the various actors in the supply chain [10]. The ports serve to facilitate customs clearance activities at distant

inland sites, especially for landlocked countries to handle seaport functions in their own territory [11]. Khaslavskaya and Roso [12] emphasize that dry ports enable the reduction of risks related to trade, customs, and roads. Jeevan et al. [13] argued that dry ports function as internal intermodal terminals, providing high-capacity transport services that directly connect to seaports, thereby ensuring a seamless cargo chain when operated sustainably.

While effective dry ports are critical for a country's growth, their operations must take into account the economic, social, and environmental aspects for long-term sustainability [14]. The implementation of dry ports, which serve as a bridge between the road and railroad networks, is a potential solution and would also present a chance to develop intermodal solutions as a component of an integrated and more sustainable trade supply chain [15]. A dry port, as a link in the chain, could assist in addressing the issue of lowering environmental consequences in the area and easing traffic congestion [16].

The majority of dry port studies primarily focus on the concept's definition and function [5]. A substantial amount of research published over the last two decades indicates that the trends of dry ports vary across diverse geographical and institutional contexts [17]. The concept of dry port is undeniably richer and more diverse than merely being a continuation of port logistics and sea ports. However, the concept of dry ports has proven to be particularly challenging, as most of the literature is heavily reliant on narratives and specific case studies [11,16,17]. In most studies, location analysis, characteristics, services, ownership, and maturity level are the primary research focuses [18]. Khaslavskaya and Roso [12] argue that even though the research subject is relatively new and scattered, studies on dry ports predominantly consist of optimization and qualitative case studies. The authors highlight that the primary points of debate revolve around the economic impact, environmental impact, and role of dry ports in developing a seamless supply chain network. Nevertheless, there are very few studies that focus on the role of dry ports in sustaining trade logistics, particularly in terms of reducing negative environmental impacts and increasing economic and social benefits [19–21]. Alamoush et al. [22] emphasize that sustainability research is fast evolving and is primarily concerned with environmental issues; however, the data is scattered, making it difficult to draw comprehensive conclusions. This study aims to provide a comprehensive overview of the concepts discussing sustainable dry port operations, identify the most prevalent sustainability research areas within dry port operations, and identify gaps in the existing literature to highlight future research directions and lay the groundwork for sustainable dry port improvements. To address this aim, the following research questions are defined:

1. How does the dispersion of studies across time, authors, geographies, and topic areas provide insights into the development of the body of knowledge on dry port sustainability operations?
2. What do the most-cited studies on sustainable dry port suggest about significant subjects, conceptual themes, and multidisciplinary collaboration?
3. What are the research gaps in the sustainable dry port studies?

This report is divided into five sections: Section 1 provides the background and scope of this research; Section 2 examines the dry port sustainability literature to highlight the need for additional research; Section 3 discusses the process of the bibilometric analysis; Section 4 presents the results and discussions; and finally, Section 5 provides conclusions, future research directions, and limitations of this research.

2. Literature Review

Dry port is an integral part of a large transportation network, involving numerous stakeholders with diverse interests and ambitions [23]. To meet the rising demand for trade logistics, greater operational flexibility in ports and terminals is required [24]. Wilmsmeier and Monios [11] highlight that dry ports play a pivotal role in influencing seaport usage and enhancing the accessibility of inland areas. They are established to support port development and improve the efficiency of the trade logistics sector.

Research on dry ports is still in its infancy; the majority of publications concentrate on the conceptualization and definition of the activities, which vary depending on the viewpoints of the authors and the applications in different nations [23]. Rodrigues et al. [25] highlight that the investigation of the dry port establishment outside of Asia and Europe is lacking. They also emphasized the significance of developing decision-making models that consider the perspectives of a wide range of trade logistics stakeholders rather than focusing mainly on dry port locational issues. Furthermore, Muravev et al. [26] asserted that theoretical and practical research on intermodal terminals had significantly influenced the growth of dry ports around the world. Researchers focused on numerous criteria, such as operational efficiencies, to address various challenges associated with the operations of dry ports. However, the majority of studies focused on the key dry port parameters lack adequate systematization. Most research either focuses on a particular parameter or looks into how factors interact to affect the performance of dry ports [27].

Muravev et al. [26] argued that one of the key factors affecting the operational effectiveness and sustainability of dry ports is the possibility that such an unsystematic approach may raise overall logistics costs. As a result, it is crucial to systematically and thoroughly research the interrelations of parameters to improve a dry port's operational efficiency and reduce overall expenses. At the same time, Khaslavskaya and Roso [12] emphasize that dry ports can provide significant advantages to inter-land transport operators by enhancing distribution systems, lowering logistics costs, encouraging regional development, and minimizing transportation emissions.

The concept of the dry port has gained significant attention from scholars worldwide, owing to its potential to improve hinterland multimodal transportation, generate economic and social advantages, reduce environmental impacts, and improve trade logistics performance. Various studies addressed the general concepts of dry port development and performance [21]. In terms of approaches to studies, quantitative modeling and qualitative case studies predominate the research [18], with a very few publications based on surveys of shippers, freight forwarders, transportation operators, customs and dry port operators, manufacturing enterprises, and other trade supply chain participants [18]. Khaslavskaya and Roso [28] advise that more research is needed in the areas of the dry port networks by including the perspectives of multiple actors. In line with this, sustainable dry port operations are becoming one of the most promising research subjects due to the need to address global concerns (economic, environmental, and social) as part of academics' contribution to establishing a sustainable future for all [29].

There is a scarcity of research on the impact of internal sustainability management issues, such as sustainability leadership, employee sustainability behavior, participation, sustainability policy, sustainability training, and sustainability practices in line with dry port sustainability [24,29–31]. Moreover, the implications of external sustainability collaboration issues, such as government support, logistics service provider collaboration, and supplier collaboration, on sustainability performance have not been studied and supported with empirical studies [23,30–32]. It is crucial to have a comprehensive perspective on sustainability that takes economic, environmental, and social issues into account [33]. Over time, companies have acquired increased knowledge about sustainability concepts in response to the growing relevance and significance of sustainable development. Many port sustainability principles are applied and developed within the context of the broader triple bottom line sustainability paradigm, which includes economic, social, and environmental considerations [34]. Table 1 outlines a list of major theoretical developments in sustainability.

Table 1. List of Major Theories in Sustainability.

No.	Theories	Key Issues	Developed by	References
1.	Social responsibilities of business people.	Educating business people about their social responsibilities	Howard Bowen in 1953	[35]
2.	A new rationale for corporate social policy.	Relating economic performance to social responsibility	Committee for economic development in 1970	[35]
3.	A three-dimensional conceptual model of corporate performance.	Theoretical models of corporate social responsibility	Archie Carroll in 1979	[36]
4.	Strategic management stakeholder approach.	Theoretical models of corporate social responsibility	Edward Freeman in 1984	[37]
5.	The Triple Bottom Line of 21st Century Business.	Triple bottom line (economic, social, and economic sustainability)	John Elkington, 1987	[38]
6.	The management of material, information, and capital flows as well as cooperation among companies along the supply chain while integrating goals from all three dimensions of sustainable development.	Sustainable supply chain management	Seuring and Müller, 2008	[39]
7.	Sustainable development (SD) has become a fundamental strategy to guide the world's social and economic transformation.	Sustainable development goal	United Nations Sustainable Development Summit, 2015	[40]

As described in Table 1, researchers' perspectives are expanding steadily. The emphasis on each aspect of sustainability is advanced and contextualized in order to use it in various sectors. Businesses cannot thrive without financial gains, and since the economic realm arises from society, it is directly linked to the social dimension. The social dimension is embedded within the environment since society would not exist without the natural world. Beside the aforesaid theoretical basis, Black et al. [41] explored the factors (see Table 2) that impact the operations of dry ports and, consequently, their success from a sustainability perspective:

Table 2. Factors Influencing Dry Ports Operations.

• Advanced information systems	Expanding or reinforcing hinterland
• Better usage of regional transport infrastructure	Government logistics policies and support
• Capacity problems in seaport reduced	Institutional and regulatory systems streaming
• Collaboration among transport system actors	Lower cost of living to attract distribution centers into area
• Container tracking	Lower land costs and taxes
• Coordination of government agencies	Market-driven development
• Development of supporting infrastructure	Marketing support by local economic agencies and state
• Development of value-added services	Public-private ownership or government
• Double-stack trains	Temporary warehousing facility
• Emission reductions	

Given the increasing awareness of public engagement, stakeholders' attitudes have become a fundamental concern in the development of a dry port. Therefore, all three categories of sustainability (economic, social, and environmental) must be assessed concurrently when analyzing the sustainability performance [42] of dry ports. Environmental factors include pollutants in the air, emissions of greenhouse gases, utilization of land and soil, debris, noise and light issues, and water and climate change, all of which must be considered [43]. Economic dimensions include benefits to port users, fair competition, employment, local area economic development, tourism, and port investment [44]. Social dimensions consist of population growth, port area availability, security and safety, and neighboring relationships [37]. Despite technological growth, new management strategies, and the adoption of IT systems, the congestion issue persists in many container terminals. The lack of a proper maneuvering area, space in the container stacking area, and the operational area often significantly reduce the terminal efficency/productivity (measured as the number of containers handled per working hour), resulting in the delay of trucks at gates. In such cases, the only solution is the increase of the seaport capacity by means of a physical expansion and/or a (re)building of logistic infrastructure. However, this requires considerable capital investments, planning, and efforts and is often not feasible due to the proximity of built-up areas [45].

Despite the fact that the field of study is still developing and fragmented, five key theme areas have been identified: concept development, environmental effects, economic effects, performance of dry ports, and network effects [12]. Jeevan et al. [46] indicated that the dry port research has focused on six thematic areas: port governance and policy, port management, performance and competition, planning and development, dry port operation, and spatial analysis. Therefore, acquiring a comprehensive understanding of the existing literature through bibliometric analysis is important to track research developments in dry port sustainability, identify research gaps to serve as a springboard for subsequent studies, and mitigate disparities in defining thematic areas of studies in dry port sustainability.

3. Research Methodology

The study utilizes a bibliometric analysis approach to analyze the literature and identify any theoretical gaps. Bibliometric analysis employs a quantitative method that utilizes bibliometric data [47]. Bibliometric analysis approaches can be categorized into performance analysis and science mapping. Performance analysis primarily considers the contributions of research constituents, whereas science mapping focuses on the links between research constituents [48]. In general, these methods enable us to locate, organize, and analyze key topics in certain study areas [49]. Sustainability and dry ports are currently important subjects in academic research. While these two concepts are complementary, their relationship has not been well defined in the scientific literature. This study looks at the literature on dry ports and sustainability in an effort to close this gap [49,50].

The study assists in identifying and reviewing the literature related to the establishment of sustainable dry port operations. Within this scope, a content analysis approach has been adopted to uncover the intellectual structures of particular themes, frequently-involved hot topics, and key terms that have drawn interest from both evolutionary theory and academic research [48]. The researchers conducted a comprehensive bibliometric analysis using the open-source software BibExcel 2016–02-20 and VOSviewer 1.6.18 [49,51]. VOSviewer is widely utilized, offering a robust user interface and geographical visual capabilities [51]. It helps to identify keywords and trending issues, thematic evolution, and research focus. Bibexcel was chosen because it facilitates the analysis of diverse data retrieved from various databases and seamlessly works with a variety of network analysis tools, including VOSviewer [52,53].

An online search was conducted using keywords: sustainability, dry port, inland port, terminals, economic sustainability, social sustainability, environmental sustainability, dry port sustainability, and port sustainability framework. Academic journal articles

were retrieved from electronic databases such as Emerald Insight, Science Direct, Taylor & Francis, Google Scholar, and from resources available at Kuehne Logistics University and Addis Ababa University libraries. The study utilized the Web of Science and Scopus databases, using the titles, abstracts, and keywords' search options to search and download the articles. These databases were selected as they provide the most comprehensive reference database of peer-reviewed articles, offering a vast collection of international research across a broad spectrum of academic disciplines [54–57].

Data mining was carried out between April 2022 and March 2023. The research articles containing "sustainability* dry port" in the title and abstract, with the earliest publication occurring in 2000 and the most current in 2023, were the primary subject of this study. Prior to the year 2000, the United Nations regarded the social, economic, and environmental components of sustainability separately; however, with the adoption of the 'Millennium Declaration' in 2000, things changed dramatically. The researchers noticed that since then, scholars have initiated integrated studies in the field of sustainability [58]. The search code was (TITLE-ABS KEY (("sustainability*dry port")) AND (("environmental sustainability * dry port) OR ("social sustainability * dry port) OR ("economic sustainability * dry port) OR ("Green * dry port")). The result of the search was 232 journal articles, which were then included for further analysis. Figure 1 below, adapted from [49], depicts the logical sequence followed to address the methodological approach.

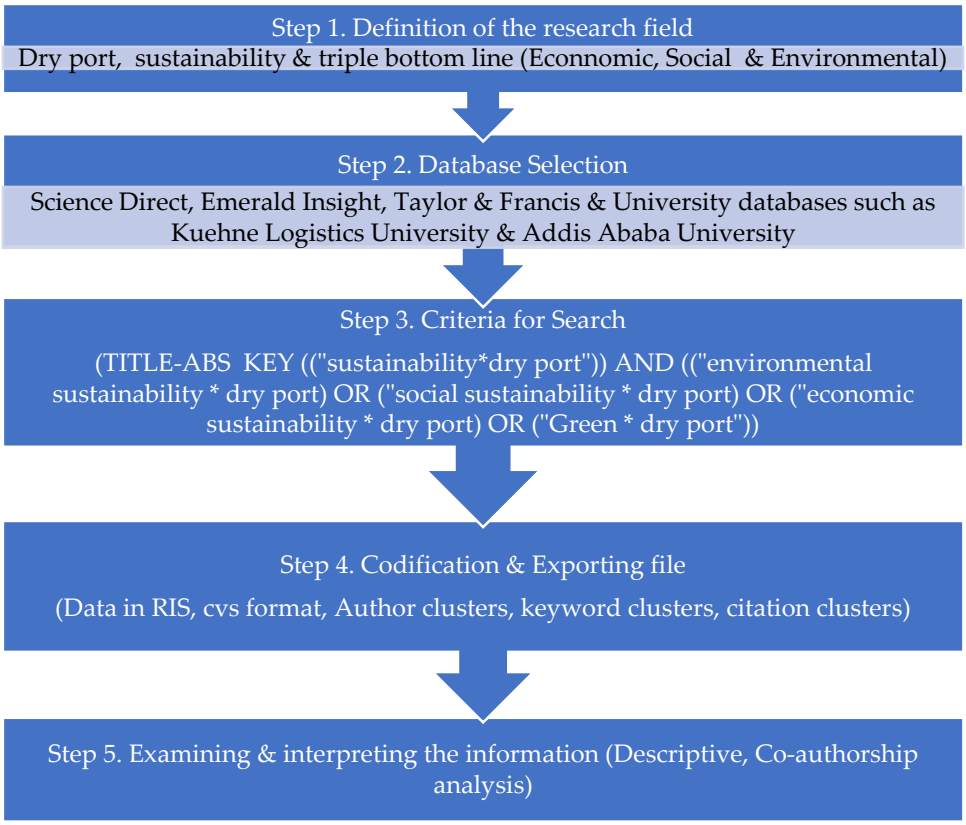

Figure 1. The Methodological Flow Chart for Bibliometric Analysis.(The asterisk is a common wildcard symbol that broadens a search by checking for words that begin with the same letters).

4. Results and Discussion

4.1. Dispersion of Studies across Time, Authors, Geographies, and Topic Areas

4.1.1. Mapping the Article Distribution

Using conjunction phrases to extend the search has helped to broaden the scope of mapping dry port research, despite the fact that there have been a limited number of articles published focusing solely on dry port sustainability. Figure 2 shows the number of articles

found utilizing the combination terms, as well as the year they were published. To understand the priority that the researchers placed on sustainable dry port operations, the distribution of studies throughout different time periods was examined. Studies on dry ports did not garner much attention before 2010. From 2010 to 2022, there was a considerable increase in publications focusing on sustainability and dry ports. Statistical analysis highlights that the notable increase in the number of articles published is between 2016 and 2020. Three factors are of significance in Figure 2: (1) Of the 64 sources indicated in Table 3, 25 provided more articles in 2016 than the previous year; (2) curiously, 64 outlets had many publications during that time; and (3) sustainability has gained importance since the introduction of the Sustainable Development Goals in 2015. It is anticipated that research and publications in the field of sustainable dry port operations will continue to increase to accelerate the adoption of the SDGs. For instance, as highlighted by Hwang and Kim [59] the need for green technology is essential to mitigate pollution and foster an environmentally friendly trade supply chain. Therefore, it is critical to develop emission control methods for dry ports and maintain a strategic agenda for future improvements and research. Furthermore, Awad-Núñez et al. [60] emphasized that the most essential variables for attaining sustainability in the dry port are those related to environmental protection. Therefore, the sustainability of the location demands a high respect for the natural environment. Researchers are expected to define parameters and tools that determine the most ideal locations for dry ports, recognizing it as a geographic and multidisciplinary problem with environmental, economic, and social ramifications that demands further research.

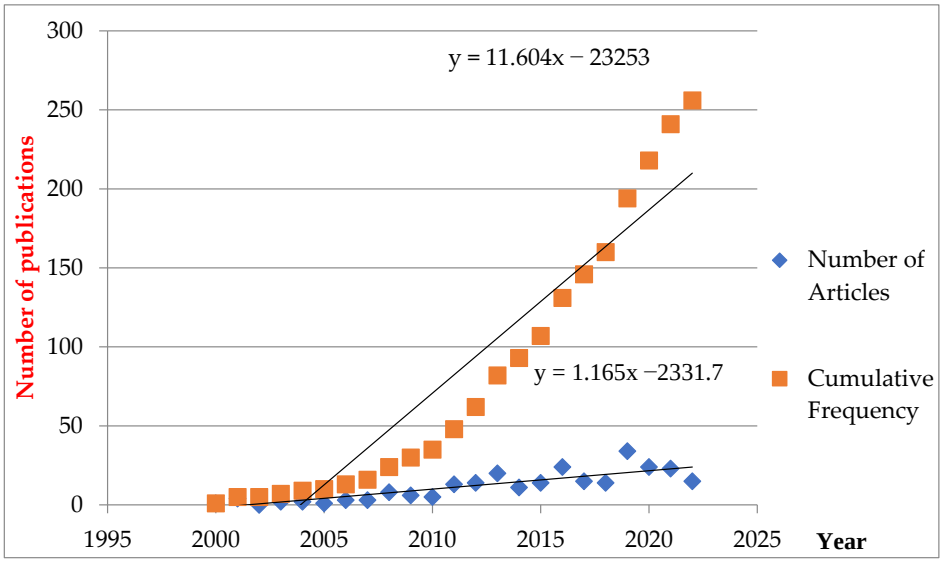

Figure 2. Publication patterns in relation to dry port sustainability from 2000 to March 2023.

Table 3. List of the top 25 publishing journals contributions to the areas of dry port sustainability.

Source	Number of Publications
Sustainability	31
Asian Journal of Shipping and Logistics	15
Maritime Policy and Management	14
Maritime Economics and Logistics	11
Journal of Transport Geography	8
Transactions on Maritime Science	8
Maritime Business Review	7
International Journal of Physical Distribution and Logistics Management	7

Table 3. *Cont.*

Source	Number of Publications
Research in Transportation Economics	6
Research in Transportation Business and Management	5
International Journal of Logistics Management	5
World Review of Intermodal Transportation Research	5
International Journal of Operations and Production Management	4
Transportation Research Part E: Logistics and Transportation Review	3
Transportation Research Part D: Transport and Environment	3
Transportation Research Procedia	3
Journal of Transportation Technologies	3
Journal of Cleaner Production	3
Journal of Shipping and Trade	3
Transportation Journal	3
European Business Review	3
Journal of Marine Science and Engineering	3
International Journal of Production Economics	3
Procedia-Social and Behavioral Sciences	3
Transportation Research Part C: Emerging Technologies	3

For future research on this issue, a fitting curve and a formula for trend changes in publications were developed, as shown in Figure 2:

$$y = 11.604x - 23253$$

where "y" denotes the total number of publications in each year and x denotes the year. The R-squared (R2) value was 0.8881, indicating that the model was an excellent fit; the input variables (years) explained 88% of the variation in the publications (y). This implies that the number of publications has increased over time, indicating that there are more areas that need to be investigated.

4.1.2. Most Productive Journals

Table 3 provides a list of the top 25 journals with the highest publication rates. According to the findings, researchers primarily published their research work in Sustainability, Maritime Economics and Logistics, Maritime Policy and Management, Research in Transportation Business and Management, Journal of Transport Geography, World Review of Intermodal Transportation Research, Transactions on Maritime Science, and the Asian Journal of Shipping and Logistics. The remaining papers were published in a variety of journals. The majority of research outputs being published in the Sustainability journal, as indicated by Table 3, may be attributed to the journal's emphasis on sustainability and its thematic approach. As the number of journals grows, researchers will have more opportunities to publish their findings in a variety of journals. Following that, the Scimago Journal Rank (SJR) and h-index are used to assess the quality of the journals. SJR is a size-independent indicator of journal evaluation in which citations from high-quality journals carry more weight than citations from low-quality journals, and h-index, which was originally developed as a measure of author impact, is used for journal evaluation in major citation databases such as Google Scholar, Scopus, and others [61]. In comparison to the number of publications, the h-index and SJR values of the Journal of Transport Geography and the International Journal of Physical Distribution and Logistics Management are both high, as indicated in Table 4.

Table 4. Ten publishing journals based on journal quality metrics.

No.	Journal Type	Impact Score	h-Index	Rank	SJR	Coverage History	Best Quartile
1	Sustainability—MDPI	4.39	136	7613	0.664	2009–2022	1
2	Asian Journal of Shipping and Logistics	3.63	31	7860	0.647	2009–2022	2
3	Maritime Policy and Management	3.83	67	5930	0.804	1976–2022	1
4	Journal of Transport Geography	6.6	132	1500	1.852	1993–2022	1
5	Maritime Economics and Logistics	4.88	59	4894	0.912	1999–2022	1
6	Transactions on Maritime Science	0.9	8	17,956	0.225	2017–2022	2
7	Maritime Business Review	2.55	14	10,019	0.518	2016–2022	2
8	International Journal of Physical Distribution and Logistics Management	7.09	128	1577	1.795	1990–2022	1
9	Research in Transportation Economics	4.25	58	4027	1.03	1994–2022	1
10	Research in Transportation Business and Management	5.05	45	4375	0.976	2011–2022	1

To gain a comprehensive understanding of the connections between authors and publications in dry port sustainable operations, we used the Hirsch index (h-index). Appendix A is a list of the twenty h-index intercept articles with at least 26 citations. This implies that the most frequently cited articles on dry port operations help to advance knowledge of sustainability (economic, social, and environmental).

4.1.3. Distribution of Articles by Country

The distribution of publications by country and institution (see Figures 3 and 4) was examined to detect academic interest in different countries. According to the findings, research in Asia, particularly in China, is more numerous, with a considerable number of publications in Europe (specifically Spain and Sweden) and insignificant numbers in Africa. More research is needed in developing countries in Africa to understand the context, challenges, and scientific solutions. Because landlocked developing nations rely on land transit routes across adjacent countries' territories to transport goods through their dry ports [58].

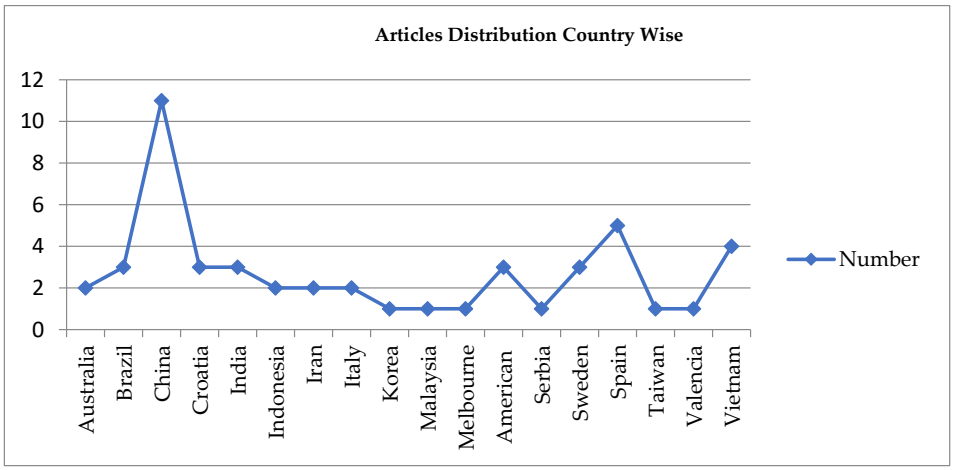

Figure 3. Distributions of articles by country.

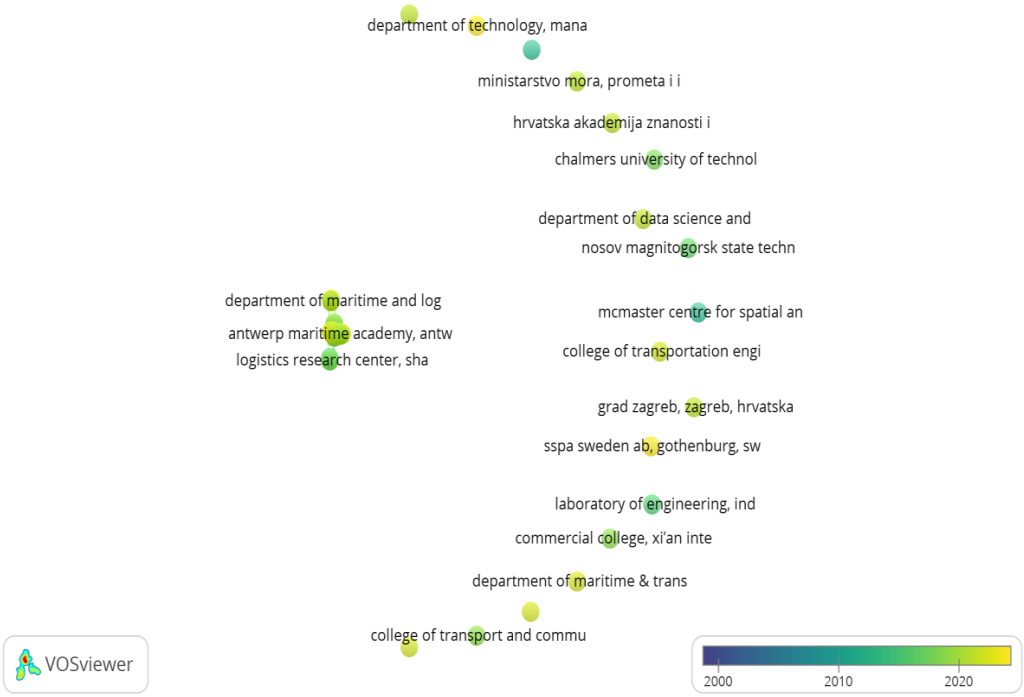

Figure 4. Distributions of articles by institutions.

4.2. Conceptual Themes and Multidisciplinary Collaboration in Dry Port Sustainability

4.2.1. Key Word Frequency Analysis

This section details a keyword frequency analysis performed using VOSviewer. The analysis explores the evolutionary trend of dry port research, identifies critical relationships, and highlights both current and emerging themes in this field. The VOSviewer program was utilized to generate bibliometric maps by importing 232 journal articles along with authors, keywords, and citations. A stronger link is indicated by a higher value, reflected as a positive numerical value when there is a link between these pairs of items. In VOSviewer, the minimum occurrences of a keyword were identified, and an overlay visualization approach was chosen to display the average publications per year, the link strength of keywords, and the number of occurrences. Figure 5 illustrates the most commonly used terms in dry port sustainability studies.

From the total of 232 articles analyzed on dry port sustainability in the period between 2000 and March 2023, a total of 500 keywords have been identified. The keywords are clustered into different thematic areas: dry port, inland port, sustainability, sustainable development, and intermodal transport. The researchers discovered that "dry port" and "intermodal" are highly emphasized concepts, as they appear in 118 research papers (31% of the total) and 54 (14%), respectively. In contrast, elements of the triple bottom line, such as social, environmental, and economic dimensions, did not appear frequently in the articles. Moreover, within the "intermodal" cluster, trends mainly focus on dry port location selection criteria, the analytical hierarchy process, Delphi, and simulation. Concerning "sustainability," the main research trends include corporate sustainability, decision-making, and logistics networks. On the other hand, in the dry port cluster, sea port competitiveness, dry port competitiveness, and port supply chain exhibit strong links. Finally, there are no study trends directly related to the "triple bottom-line," such as economic sustainability, social sustainability, and environmental sustainability.

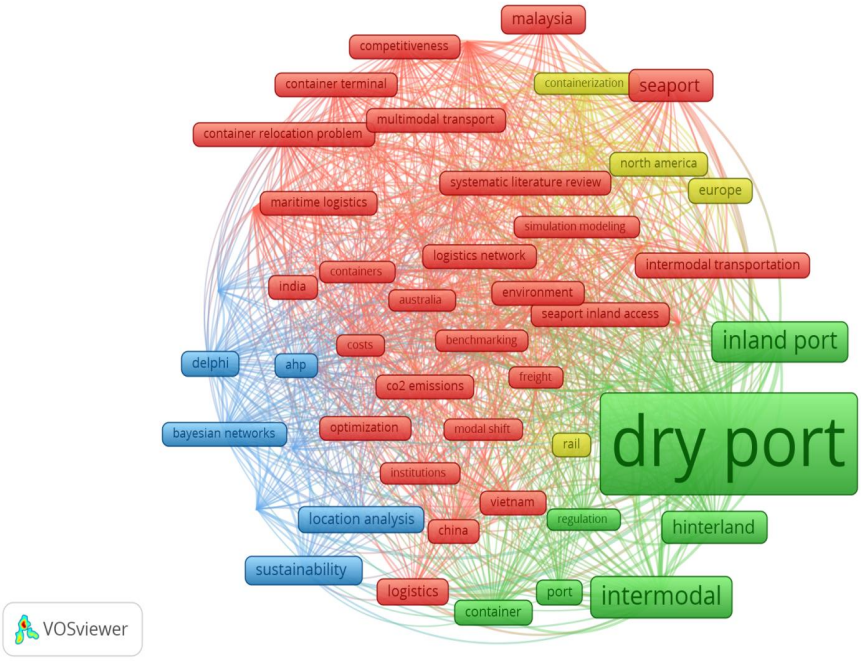

Figure 5. A network map highlighting the relationships between dry port sustainability and important topics between 2000 and March 2023.

4.2.2. Key Authors in Dry Port Sustainability Operation Research

This section aims to identify authors with higher productivity and illustrate their collaboration based on the co-authorship indicator. The most productive author is Roso, Violeta, who published 29 articles between 2000 and 2023, followed by Jeevan, Jagan, with a total of 17 research articles. Figure 6 shows the collaboration map among the main authors who have contributed publications on dry port and sustainability, as derived from the co-authorship analysis. The colors show the working groups, while the size of the circle varies according to the number of articles published by each author. The network shows a great dispersion, potentially favoring the rapid growth of the research area. Among the most productive authors, only Violeta Roso seems to have a stable international network of collaboration. As for the rest of the most productive authors, Jagan Javean, Gordon Wilmsmeier, Jason Monios, and Theo Notteboom also developed an international collaboration network on dry port and sustainability research (see Figure 6).

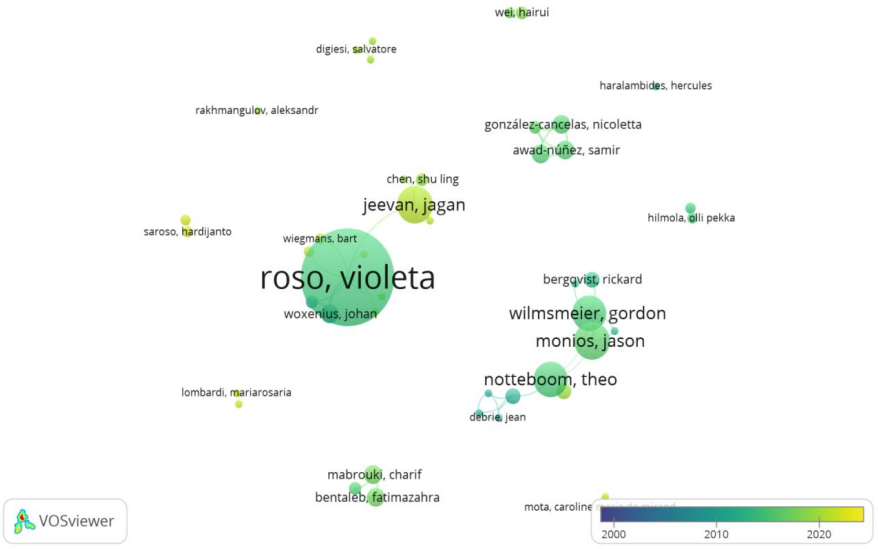

Figure 6. Key Authors in Dry Port Sustainability Operations Research.

4.2.3. Relevance Analysis

Noun phrases with high relevance (or noun phrases with a specific meaning), such as "visualization," "text mining," and "natural language processing," have a co-occurrence distribution that is highly biased towards certain other noun phrases. As a result, it is hypothesized that in a co-occurrence network, noun phrases with high significance are clustered together. Each cluster can be thought of as a topic [62]. or the analysis, the minimum number of occurrences of a term was set at 5 in the abstracts. A total of 39 of the 846 words reached the required level. A relevance score was assigned to each of the 39 terms, and the most pertinent terms were selected based on this score. The default selection comprised the top 60% of the most pertinent terms. The most pertinent terms were chosen, and these 39 terms were grouped into six major clusters, as shown in Figure 7. Each cluster in the visualization has a color that represents the density of terms at that position.

Figure 7. Relevance Analysis.

Research on sustainability has expanded in focus from individual companies to supply chains, where firms rely on the environmental and social performance of others, such as their suppliers. Environmental performance can involve resource use and waste minimization, and social performance can involve workers' health and safety in supply chains [63]. A relevance score is computed by VOSviewer. Terms that have a high relevance score typically correspond to certain themes that are addressed in the text data, whereas terms that have a low relevance score are typically more generic in nature and are not exhaustively addressed in the text. Regional development and sustainability have a minimum score of one out of the ten important scores in dry port research, as indicated in the figure below (Figure 8).

4.2.4. Methods of Data Analysis

Research on dry port sustainability is mostly qualitative case studies based on individual experiences and observations, as previously noted by researchers [17]. This section categorized the papers based on the type of methodology used, as depicted in Figure 9. A significant number of studies were analyzed by multi-actor multi-criteria, Delphi method and linear ranking, simulation, systematic literature review, AHP, analytical, and other techniques. The utilization of diverse analysis methodologies demonstrates the depth of

the analysis conducted on the subject under consideration. However, recent research on dry port sustainability tends to be more quantitative in nature. Numerous scholars have used multi-actor multi-criteria analysis as location analysis, is an increasingly important topic of research for dry port sustainability [64,65].

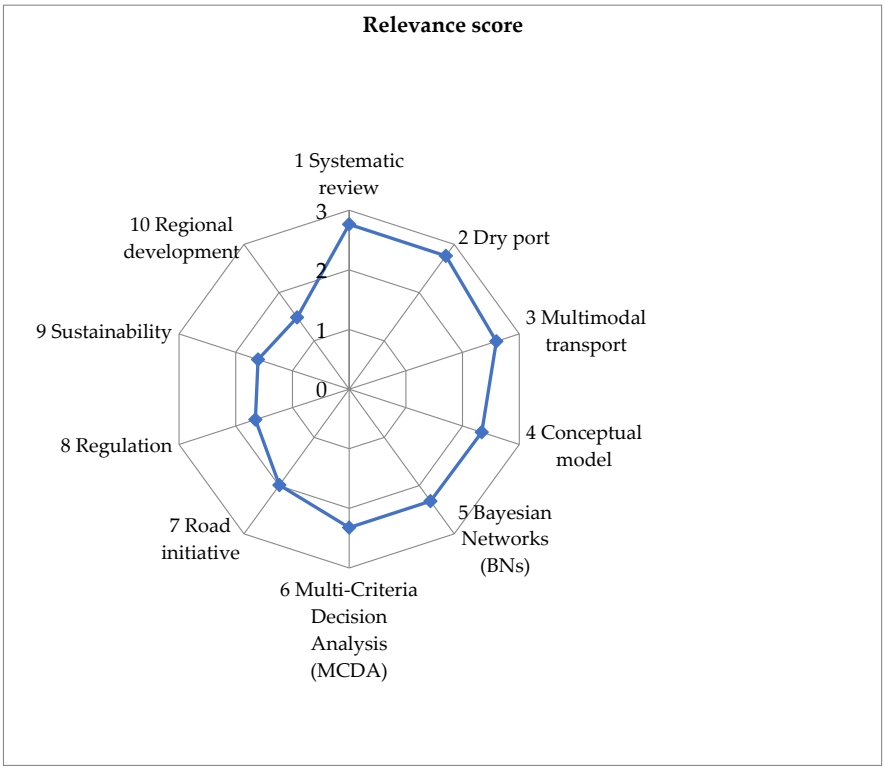

Figure 8. Relevance Score.

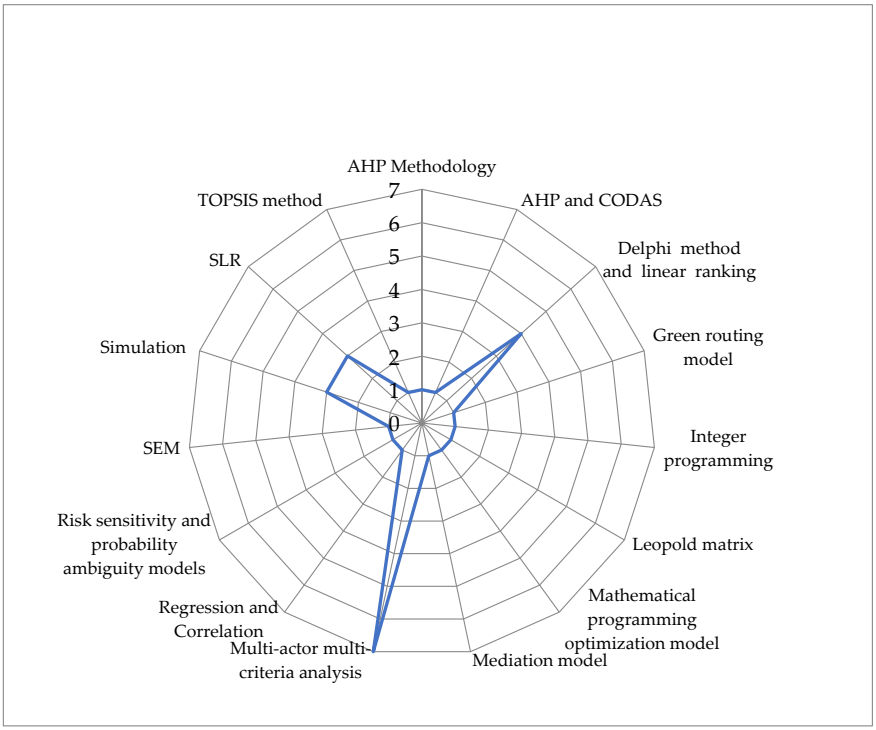

Figure 9. Methods of Data Analysis.

4.2.5. Factors Influencing Sustainable Performance

Hui et al. [66] argued that selecting a dry port poses a geographical multi-disciplinary dilemma with substantial economic, social, and environmental ramifications. Several factors influencing dry port sustainability are presented in Table 5.

Table 5. Factors Influencing Sustainable Performance.

No.	Factors	References
1.	Economic	
	Economic development	[67]
	Land price	[68]
	Regional development	[12]
	Transport emission costs	[66]
	Investments	[12]
	Accident cost	[66]
	Feasibility of implementation	[12]
	Profitability	[12]
2.	Social	
	Number of accidents	[15]
	Fatalities and injuries of traffic accidents per capita	[66]
	Accessibility to facilities and public transport	[66]
	Satisfaction of citizens and variety and quality of transport options	[66]
	Fatality and injuries resulted from air pollution	[66]
3.	Environment	
	CO_2 emissions and atmospheric pollutants	[15]
	Distance to natural spaces	[12]
	Less traffic congestion	[12]
	Energy use Population	[66]
	Population exposed to noise	[66]
	Land consumption for transport	[66]

4.2.6. Empirical Perspectives

Dry ports encounter implementation and development issues. These are influenced by the existing political, social, environmental, and financial regulations, as well as technical and technological development, land and infrastructure use, location and optimization issues, infrastructure development and availability, stakeholder interests and investments, and a competitive business environment [12]. Countries that have fully implemented dry ports are benefiting from improved cargo movement, reduced environmental congestion, and economic benefits [69]. The logistics terminal of Saint Petersburg Seaport is deemed a pilot of the dry port concept under Russian Act No. 510. Russia saw significant improvements in the development of dry ports to serve seaports such as Saint Petersburg, Novorossiysk, and Vladivostok. There are three options for increasing seaport productivity: physical expansion, modifying container yard management, or constructing hinterland terminals. It is noteworthy that when a dry port is built, the seaport capacity is raised by 2.5 times, as opposed to 1.5 when the seaport is physically expanded [70].

The use of Free Trade Zones (FTZ) is also a prevalent postponement and added value technique in American inland ports. Inland ports follow the landlord model, in

which a real estate promoter seeks revenue production through a relationship with a rail operator, creating logistical activities in co-location with the rail terminal [71]. Hui et al. [66] introduced a multi-criteria decision analysis method for rating the sustainability of dry ports based on the fact that the economic, social, and environmental ramifications are inextricably linked to the dry port's geographic location. Major dry ports and their sustainability initiatives [66] are presented in Table 6.

Table 6. Sustainability Initiatives.

No	Dry Port	Sustainable Initiatives	KPIs'
1.	Moorebank (NSW)	Renewable energy installation The application of passive design techniques HVAC system that is extremely efficient Electricity rather than LPG Rainwater harvesting Basins for on-site detection Air conditioning equipment that is cooled by air Materials with low toxicity Dedicated space for garbage recycling Complete garbage recycling Facilities for cyclists Criteria for sustainability	Produce 50,000 MWh per year from renewable sources. 110,000 tones of CO_2 emissions are reduced. Sydney's heavy truck movements have been reduced by around 3000.
2.	Somerton (VIC)	Climate change and energy Water Biodiversity	Reduce energy intensity by 39%. Cut CO_2 emissions by 57% Increase recycling from 29% to 40% 44% reduction in water intensity
3.	Duisburg (Germany)	Sustainability Noise Water and Light protection Frugal use of raw materials Reduction of pollutants Modern waste management Own solar facility Reduction of consumption of fossil fuels	Reduce no. of trucks by 100,000 a year Traffic management system that reduces emissions by 30%
4.	Centrepoint (USA)	Energy efficiency Roof retrofits Warehouse lot light fixture replacement Solar panels Hydrogen fuel cells Brownfield development Previously contaminated properties USGBC-LEED-certified buildings	Not applicable

4.3. Gaps in the Sustainable Dry Port Studies

4.3.1. Patterns of Research in Dry Port Sustainability

A dry port was traditionally characterized as an inland terminal where shipping companies could issue bills of lading to and from [25]. Subsequently, it has been demonstrated that cooperation among dry ports in supply chains improves prospects for cargo flow processing by redirecting cargo shipments from overburdened dry port terminals to those with reserves and processing capacity [72]. The majority of dry port research findings are represented by qualitative cases and optimization studies that cover many areas of dry ports and are focused on location, functions, services, ownership, and maturity level difficulties [12]. Despite the fact that the research subject is new and distinct, considerable research is needed on dry port development, environmental impact, economic impact, social impact, performance impact, and dry ports from a network perspective [11,61].

4.3.2. Research Themes and Level of Analysis

Considerable scientific attention has been directed towards inland port research, with many publications influenced by an outside-in paradigm where the seaport is frequently considered the leader and the inland port the follower. However, there is growing scientific interest in inside-out techniques, where inland ports take the lead [73,74].

Sustainable dry port studies address broad issues related to economics, social, and environmental concerns, contributing to the development of dry ports. Following the bibliometric analysis, the researchers explored the potential research direction for the future. The structure and development trends of the journals were investigated through a comprehensive examination.

The analysis and mapping revealed that most of the themes covered several regions, including Asia, North America, Europe, Latin America, Australia, and Africa, although with varying degrees of exposure in each country. The research shows an increase in publications, a growing interest in dry port studies, and a more extensive array of authors. The findings highlight that the majority of articles are published in China and Europe.

The majority of dry port research focuses on dry port location analysis using multi-actor multi-criteria, the Delphi method, linear ranking, simulation, and related issues, despite the fact that dry ports are essential for connecting both industries and seaports, especially for landlocked countries. There is less emphasis on the sustainability of dry ports, the relationship between internal sustainability, external collaboration, and the quality of port services [13,28]. Limited attention has been directed towards these areas, which should cover a broader scope of research on sustainability management. Consequently, this study presents a distinct theoretical and methodological contribution to dry port investigations. A bibliometric review/analysis of dry port literature revealed that scholars mostly concentrated on theoretical issues like dry port sustainability and often lacked comprehensive empirical data. This research contributes to the body of knowledge by highlighting significant topics that are rarely discussed by academics, such as the sustainability of dry ports in the context of landlocked nations.

5. Conclusions

This study conducts a bibliometric analysis of sustainable dry port operations from 2000 to 2023 using VOSviewer and BibExcel. The analysis primarily focuses on research dispersion over time, authors, locations, and scientific mapping. Notably, the number of publications has been continuously increasing since 2005. Asia is the leading contributor to research on this topic, with China contributing the most publications. Some of the well-known authors in this field are Roso Violeta, Jeveevan Jagan, Wilmsmeier Gordon, Monis Jason, and Notteboom Theo.

The connections between dry ports and sustainability were analyzed. The findings revealed that sustainability issues were not well contextualized within the dry port. The distance (link) between dry port and sustainability in the VOSviewer is too far, and it is not well researched together.

Dry port research has predominantly focused on various distinct topical areas, discussing the definitions, functions, policy and governance, ownership, dry port-seaport interaction, dry port performance, dry port location, and multimodal transportation [24,28,71]. Researchers do acknowledge that issues such as sustainable dry port operations, internal dry port sustainability, trade supply chain networks, stakeholder collaboration, and service quality have not been thoroughly researched nor given priority [46]. Nonetheless, these issues play a significant role in ensuring dry port sustainability. Despite the relatively recent attention to dry port sustainability issues, they remain among the most crucial areas of study in the context of sustainability due to the nature of the sector.

Dry ports are vital linkages between producers, transporters, clearing agents, and seaports [75]. Dry ports' contribution to the economy is significant, and their selection is critical to improving the performance of a company and their trade supply chain. Therefore, evaluating its effectiveness from all relevant perspectives, such as economic sustainability, social sustainability, and environmental sustainability, is critical for shippers, logistics service providers, modal carriers, and legislators [76]. Dry ports have the potential to improve the sustainability of transportation and warehouse systems, but the realization of this potential demands significant adjustments to the logistics chain. Researchers have identified sustainability indicators and scored them using multi-criteria decision-making

for location analysis. However, addressing sustainability concerns requires numerous indicators from diverse stakeholders in the dry ports, with each variable needing rigorous scientific testing and measurement [66].

The number of studies on dry port sustainability issues is limited compared to topics like "sustainable supply chain management" or "green sea port". This study highlights a significant gap in research on dry port sustainability issues, emphasizing the need to prioritize studies connecting port sustainability with sustainable development goals. There is a need to focus research on the sustainability of dry ports, the connection between internal sustainability and external collaboration, dry port sustainability, and the quality of dry port operations.

5.1. Future Research Directions

Through a comprehensive bibliometric and network analysis, the study presents fresh insights into research themes in dry port sustainability, thereby broadening coverage of sustainability-related issues. Although academics and practitioners are becoming more interested in the area of dry port, research incorporating structured analysis and a thorough evaluation of relevant literature in sustainability metrics remains limited. More specifically, in the context of land-locked countries, there is a significant lack of the scientific community's effort to connect internal sustainability, external stakeholder collaboration, sustainability performance, and port service quality with dry port sustainable performance. The study identifies these as current research interests as well as potential future study areas.

5.2. Limitations

The researchers attempted to gather research studies from the Scopus, Web of Science, and university databases. They gathered research studies and exported them to Mendeley before conducting bibliometric analysis with VOSviewer and BibExcel. It is acknowledged that other published research that is not indexed in the Web of Science and/or Scopus is not included. Moreover, some research works published by publishers with indexes in Web of Science and/or Scopus might have slipped through due to the keyword criteria employed in the study.

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Abbreviations

AHP	Analytic Hierarchy Process
BNs	Bayesian Networks
CO_2	Carbon dioxide
CODAS	Combinative Distance-based Assessment
HVAC	Heating, Ventilation and Air Conditioning
LEED	Leadership in Energy and Environmental Design
LPG	Liquefied Petroleum Gas
MCDA	Multi-Criteria Decision Analysis
MGh	Megawatt Hour
NSW	New South Wales
R2	R-squared
SD	Sustainable Development
SDGs	Sustainable Development Goals
SEM	Structural Equation Modeling
SJR	Scimago Journal Rank
SLR	Systematic Literature Review
TBL	Triple Bottom Line
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution

USA United States of America
USGBC United States Green Building Council

Appendix A. H-Index Documents (26 or More Citations)

Authors	Journal	Publication Year	Citations	Areas
Woxenius et al. [77]	Journal of Transport Geography	2009	771	Intermodal Transport
Rodrigue and Notteboom [78]	Maritime Policy & Management	2009	480	Terminalisation of Supply Chains
Wilmsmeier, Monios, and Lambert [79]	Journal of Transport Geography	2011	240	Intermodal corridor
Roso [80]	Transportation Research Part D: Transport and Environment	2007	232	Seaport Inland Access
Roso and Lumsden [18]	Maritime Economics & Logistics	2010	222	Dry Port Concept
Roso [4]	International Journal of Physical Distribution & Logistics Management	2008	218	Intermodal Terminal
Monios [81]	Research in Transportation Economics	2011	125	Inland Terminal Development
Bask, Roso, Andersson, and Hämäläinen [82]	Journal of Transport Geography	2014	120	Seaport–Dry Port Dyad
Jeevan, Chen, and Lee [6]	The Asian Journal of Shipping and Logistics	2015	94	Container Seaports
Roso [83]	World Review of Intermodal Transportation Research	2013	81	Intermodal Transport
Khaslavskaya and Roso [12]	Maritime Economics & Logistics	2020	66	Intermodal Transportation
Nguyen and Notteboom [84]	Maritime Policy & Management	2019	65	InlandTerminal
Roso [85]	World Review of Intermodal Transportation Research	2009	59	Environment; Intermodal Terminal
Tadic, Krstic, Roso, and Brnjac [86]	Sustainability	2020	58	Dry Port Location
Roso, Brnjac, and Abramovic [87]	Transportation journal	2015	58	Intermodal Terminal
Khaslavskaya and Roso [28]	Sustainability	2019	50	Supply Chain Outcomes (SCO)
Awad-Núñez, González-Cancelas, Soler-Flores, and Camarero-Orive [88]	Transport	2015	44	Dry Ports Location
Chen and Notteboom [89]	Journal of International Logistics and Trade	2012	42	Distribution Center; Value-Added Logistics
Nguyen and Notteboom [90]	Journal of International Logistics and Trade	2016	36	Intermodality; SWOT Analysis
Awad-Núñez, González-Cancelas, Soler-Flores, and Camarero-Orive [68]	Transportation Research Procedia	2016	26	Dry Ports Location

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