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Review

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Review

# Assessing Dry Ports' Environmental Sustainability

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**Abstract:** Sustainable development and environmental issues related to ports and sea trade have highlighted the need to enhance transport and trade systems to include green practices, such as the realisation of dry ports. However, among the current studies investigating dry ports' implications, only few papers explore their environmental impacts. Moreover, these latter papers approach the argument in a general way, leaving the ecological concerns associated with dry ports under-researched or marginally explored. In light of these premises, with the present review, the authors aim to develop a new conceptual framework on the dry ports' environmental aspects in order to drive and support future academic research in this field. The methodology used by the authors is a systematic literature review on Scopus and Web of Science. They identified 107 relevant articles, of which 43 were included according to the authors' propositions. The main results show that (i) there is no coordination between the various studies and systemic debates on dry ports' environmental aspects; (ii) there are no standardised applicable tools; and (iii) there is no involvement among the various stakeholders. Additionally, a debate is also lacking under the lens of the Sustainable Development Goals of the Agenda 2030.

**Keywords:** dry port; inland terminal; freight village; interporto; environmental sustainability; systematic literature review



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## 1. Introduction

Historically, ports have been a privileged gateway for the sea-based trade of commodities, contributing to an area's economic and social development [1]. However, as containers have emerged on a global scale, their relationship with the respective hinterlands has been pointed out. Over time, concepts such as integrated logistics [2,3] and efficient supply chains [4], together with the growing concern for sustainable development [5,6] related to ports and sea trade [7], have highlighted the need to enhance transport and trade systems to include green practices, especially for people living in seaport areas [8,9]. Logistics, in general, has a negative impact on the environment, mainly due to emissions [10,11], so port operators have to meet very high standards of transport services in compliance with rigorous environmental requirements [12]. Therefore, there is ample opportunity to enhance the entire system's sustainability by tackling oil dependency, the impacts of increased railway transport [13], and the development of inland terminals near cities and regions [14].

In light of these premises, the development of intermodality [15,16] and dry-port use [17] may represent an answer to society's demand for more environmentally friendly transport [10]. In particular, dry ports were first investigated as a solution to reduce port congestion and were considered essential to redistributing sea-based commodity trade flows [18]. However, even though this concept dates back to the 1980s, there are still several ways to define it. The expression "dry port" was initially used to describe a facility useful for redistributing flows of goods arriving by sea. Currently, there is no univocal definition for dry ports and, in foreign languages, different terms are utilised to indicate

them, such as “inland terminal”, “freight village”, or “interporto” [19]. This situation makes several definitions available with small differences mainly related to the connection system considered between seaports and dry ports. In 1991, one of the first definitions was formulated by UNCTAD [20], as follows: “Dry port is located near inland from seaports. It is linked directly to seaport or, in the case of international land movement, is in contact with the sources of imports and destination of exports. Dry ports may be used either in a country that has seaports or in landlocked country, but only surface transport modes are involved in giving access to dry port”. Currently, according to Lamii et al. [21], the most cited definitions are those proposed by Roso et al. [10], Jaržemskis and Vasiliauskas [22], and Witte et al. [23], which include, as a possible type of connections, railway, rail plus road, and waterway, respectively. According to Nguyen and Notteboom [24], three main components characterise and distinguish dry ports: (i) they can be considered as cargo *unitisation*; (ii) they create and/or consolidate the durable link with seaports using high-capacity, frequent, and reliable inland waterway, rail, and/or road services; and (iii) they offer interchangeable services with seaports, such as customs services, cargo storage, or value-added services. Dry port services and their functionality represent the distinctive and peculiar differences compared with conventional inland intermodal terminals [10]. Some more specific elements are dry ports’ functioning, their vicinity to port hubs (i.e., close, medium distance, distant), and the networks linking seaports and hinterlands (i.e., roads, rails, or rivers). These solutions represent a fair trade-off between economic growth and environmental protection, improving rural areas [6], solving issues of geographical discontinuity [25], and increasing job opportunities along the entire logistics chain [26]. Thus, dry ports can be considered as an evolution of intermodal terminals, without forgetting their importance in the logistic management evolution.

However, and in line with Lamii et al. [21], Baydar et al. [26], and Khaslavskaya and Roso [27], it is possible to remark that among the current studies related to the growing importance of dry ports, only few papers concern environmental implications. Moreover, and as it will be better detailed in Section 5, these latter articles approach the argument in a general and often not a systematic way, leaving aspects of the environmental implications associated with dry ports and with the United Nations 2030 Agenda and its 17 Sustainable Development Goals (SDGs) unexplored or marginally explored. Consequently, it becomes crucial to fill in these gaps in academic research and, at the same time, to provide actions to support involved stakeholders toward more sustainable dry ports.

In this context, the present paper aims to develop a new conceptual framework on dry ports’ environmental aspects in order to drive and support future academic research in this field. To this end, after elaborating on some research propositions, a systematic literature review (SLR) was carried out to identify those variables that improve and facilitate a dry port’s environmental assessment and, consequently, its performance. The originality of the present research lies in its proposed framework and utility regarding its focus on the opportunities and strategies that could be implemented to concretely develop sustainable dry ports. This research provides useful insights for academics as well as practitioners and stakeholders, representing, to the best of the authors’ knowledge, one of the few studies investigating dry ports’ environmental sustainability.

The structure of this paper is as follows: Section 2 concerns the development of the theoretical background and research questions (RQs), and Section 3 clarifies the research methodology of this paper and introduces the PRISMA model. Thereafter, in Section 4, the results of the bibliometric and textual analysis are reported. A discussion regarding the research findings and future avenues of dry ports’ environmental sustainability is given in Section 5. Finally, Section 6 concludes this study by providing its limits and future research directions.

## 2. Theoretical Background and Research Questions Development

The proposed SLR is based on some theoretical assumptions useful to develop three RQs. In line with its definition [20], dry ports are receiving growing attention in terms of

transport and trade management [15–17], and several studies have investigated general concerns related to dry ports [18,19], but their environmental implications are quite under-researched. With these premises, and in order to facilitate the data collection and determine the direction and scope of the study, three RQs were developed by the authors. These RQs formed the foundation for the conceptual framework of dry ports' environmental sustainability reported in the final part of the study [28].

As dry ports can be considered a key element in the integration of “sea system” and dry land networks for better cargo handling, which is essential to achieve better environmental performance [19], it is important to verify this assumption. Therefore, the first research question is:

RQ1. Do dry ports serve as an ecological pathway in the logistics chain?

Furthermore, considering the chance to enhance the sustainability of logistics through the development of dry ports, it appears essential to establish how to account for (or monitor) their environmental performances, and which indicators can be implemented to measure them. It is well-known that environmental indicators are crucial to monitor goals, compare performance over time, disclose transparent results, and support private or public companies' management rather than national and international decision makers. They represent an adequate tool to plan and adopt new sustainable actions and/or policies [29]. Hence, the second RQ intends to investigate how to monitor dry ports' environmental sustainability, and which possible indicators have been used in the literature, as follows:

RQ2. How can dry ports' environmental sustainability be measured with indicators?

Lastly, since it is not possible to think about dry ports as an environmentally friendly logistics chain without considering all the relationships among the different stakeholders involved, the third question emphasises the need for an in-depth analysis of stakeholders' strategies regarding more efficient and sustainable dry ports [30–33]. Therefore, RQ3 is the following:

RQ3. What are the current strategies implemented for dry ports' environmental sustainability?

### 3. Methods

#### 3.1. Search Strategy

There are several ways to conduct a literature review (i.e., qualitative, quantitative, or mixed) depending on the aims and scope of the research, as Snyder [34] stated in her in-depth overview. Among these methods, the authors conducted a systematic literature review, which is a quantitative methodology to identify and evaluate the most important studies in a specific field collecting and examining the relevant data. Its aim is to detect themes, theoretical perspectives, or common clusters of research [35] by covering broad topics and various types of studies. Specifically, in this review, the authors adopted an explicit, transparent, and reproducible strategy [5,36,37] to ensure the review's objectivity and effectiveness. For this reason, the authors followed three steps: (a) the selection of the review criteria related to the aims and scope of the study and the identification of the subject areas (i.e., environmental sciences; social sciences; business, management, and accounting studies); (b) the screening of the research items; and (c) the analysis and interpretation of the selected papers according to content analysis [38]. Among the several standards and guidelines available to report and structure systematic reviews, the authors chose the PRISMA model, which allows for a study based on an evidence-based minimum set of items [39,40]. The authors conducted a structured TITLE-ABS-KEY search in Scopus and Web of Science and selected these databases due to their standardised approach, reliable reputation, and high quality in the field of scientific research [19,36,39]. Regarding the research timeline, the authors, in this first part of a more comprehensive study, performed a literature review of peer-reviewed articles published until 31 December 2020. In light of the significant repercussions that the COVID-19 pandemic had on the logistics system, the authors intend to investigate the years 2021 and 2022 separately, with the final aim to understand the COVID-19 influence on dry ports' sustainability.

Furthermore, as this is a recent topic, they decided not to include a specific starting point, including articles from the earliest publication date. Related to the keywords, to cover as many relevant aspects as possible, and due to the lack of a formal consensus on the definition of dry ports on a global scale [26], the authors decided to use the search terms “dry port” OR “inland terminal” OR “freight village” OR “interporto” in the title, abstract, and keywords. To avoid missing any articles, they included the Italian keyword “interporto” in its singular and plural (i.e., “interporti”) forms. From the subject areas in Scopus (physical, health, social, and life sciences) and 30 subtopics, the authors selected the following: environmental sciences; social sciences; and business, management, and accounting studies (Scopus). With this approach, studies were collected by matching the aforementioned keywords (i.e., “dry port”, “inland terminal”, “freight village”, “interporto/i”) with the truncated keywords “sustainability” OR “environment” OR “carbon footprint” OR “greenhouse gases (GHG) emissions”. However, although the term “environment” is polysemantic, it has not been considered in the context of competitive [11,41,42], urban [11], trade and business [9,43], natural [44], economic [42,45], rail [45], political [42], or technological environments [41]. Following the aforementioned approach, the authors organised the collected data in Microsoft Excel sheets, including authors’ names, articles’ titles, type of document (e.g., research and review articles, proceeding papers), authors’ keywords, abstract, authors’ affiliations, publishing journal, year of publication, DOI (i.e., digital object identifier), and research area (i.e., social science environmental science, engineering, and business and management). Then, these wide-ranging meta-data were reported in a PRISMA diagram (Figure 1). Successively, the authors identified, selected, and analysed the records to ensure their eligibility for the systematic literature review. The use of this model allows for substantial transparency and trustworthiness in the selection process of published articles [46]. Figure 1 presents the diagram of the 107 articles identified as eligible for data extrapolation. Although they are all significant, the authors excluded most of them according to the selected criteria. They removed a total of 42 papers because duplicate records (n = 16), conference proceedings (n = 14), without author names (n = 4), books or book chapters (n = 4), reviews (n = 2), or not written in English (n = 2). Therefore, the authors screened and then examined 65 papers. At the end of the screening stage, they included 43 articles for an in-depth review, excluding 22 articles because they were not in line with the aims and scope of the review.

Table 1 summarises the 43 selected contributions, including their year of publication and journal titles.

### 3.2. Analytical Approach

In line with the analytical approach proposed by D’Amore et al. [84] and Di Vaio et al. [85,86], the authors started the SLR with the bibliometric analysis, exploring general data regarding the research field. In this research, a quantitative approach was applied to synthesise the research structure and the development of the research field, based on the analysis of the selected publications. The second part of the analysis was content-based: the framework for this analysis evolved during the review of the papers by identifying themes selected according to thematic areas, identified by the RQ1, RQ2, and RQ3, which developed propositions.

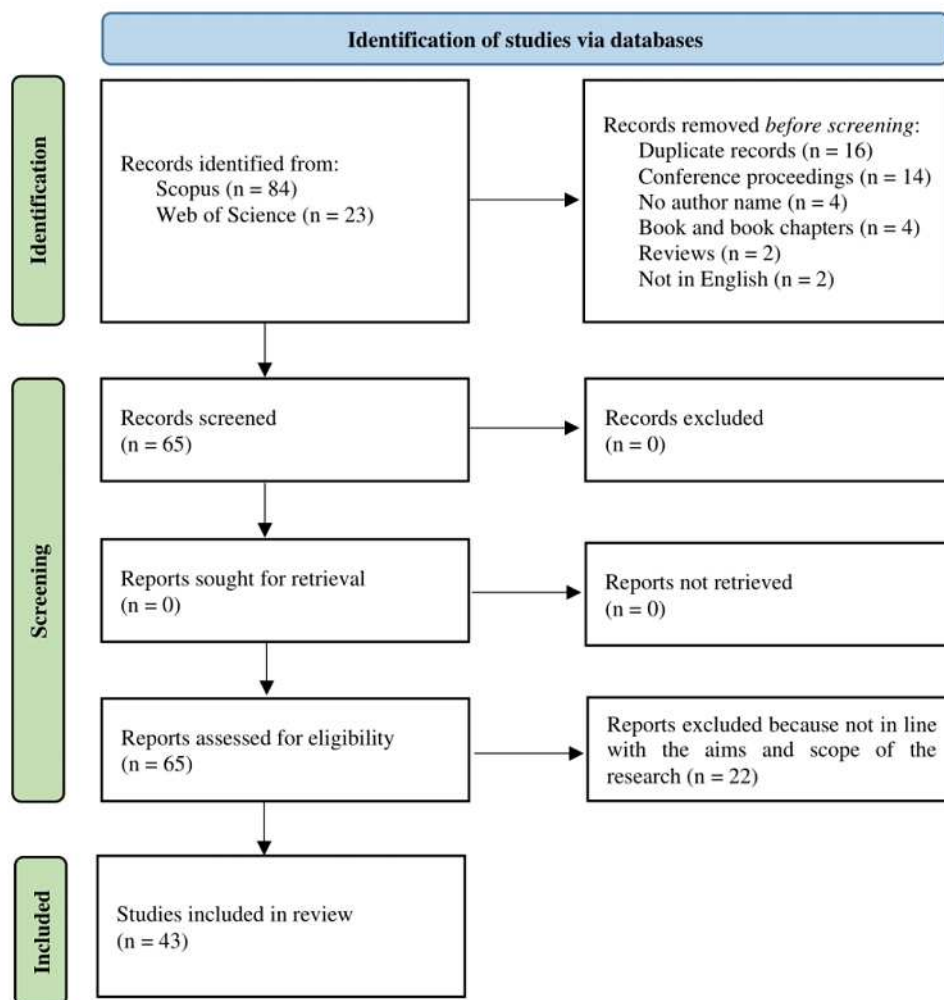


Figure 1. The PRISMA model. Source: personal elaboration by the authors on Page et al. [40].

Table 1. The list of the 43 selected contributions per author(s), year, and journal. Source: personal elaboration by the authors.

Author(s)	Year	Journal
Roso [47]	2008	International Journal of Physical Distribution and Logistics Management
Roso [48]	2009	World Review of Intermodal Transportation Research
Roso et al. [10]	2009	Journal of Transport Geography
Lima et al. [49]	2010	International Journal of Sustainable Development and Planning
Henttu and Hilmola [50]	2011	Research in Transportation Economics
Hanaoka and Regmi [51]	2011	IATSS Research
Ka [52]	2011	The Asian Journal of Shipping and Logistics
Iannone [53]	2012	Transportation Research Part A: Policy and Practice
Haralambides and Gujar [54]	2012	Maritime Economics and Logistics
Roso [55]	2013	World Review of Intermodal Transportation Research
Zeng et al. [45]	2013	Transportation Journal
Lättilä et al. [17]	2013	Transportation Research Part E: Logistics and Transportation Rev.
Wu and Haasis [56]	2013	Logistics Research
Regmi and Hanaoka [57]	2015	International Journal of Sustainable Transportation
Muravev and Rakhmangulov [58]	2016	Open Engineering
Molero et al. [59]	2017	Safety Science
Black et al. [60]	2018	Transactions on Maritime Science
Tsao and Linh [61]	2018	Journal of Cleaner Production
Wu and Haasis [11]	2018	Journal of Cleaner Production



Table 1. Cont.

Author(s)	Year	Journal
Xu et al. [62]	2018	Journal of Cleaner Production
Jachimowski et al. [63]	2018	Rocznik Ochrona Środowiska
Santarremigia et al. [64]	2018	Safety Science
Carboni and Dalla Chiara [65]	2018	Case Studies on Transport Policy
Qiu and Lam [66]	2018	Transportation Science
Pham and Lee [67]	2019	Asian Journal of Shipping and Logistics
Tsao and Thanh [68]	2019	Transportation Research Part E: Logistics and Transportation Review
Hui et al. [69]	2019	Sustainability
Kurtulus and Cetin [32]	2019	Sustainability
Li et al. [70]	2019	Sustainability
Baydar et al. [71]	2019	Journal of Cleaner Production
Digiesi et al. [72]	2019	Management and Production Engineering Review
Khaslavskaya and Roso [27]	2019	Maritime Economics and Logistics
Mata-Lima et al. [73]	2019	Environmental Quality Management
Wang and Zhu [74]	2019	Sustainability
Hervás-Peralta et al. [75]	2019	Sustainability
Aksoy and Durmusoglu [76]	2020	Maritime Policy and Management
Carboni and Orsini [77]	2020	European Transport Research Review
Gu et al. [78]	2020	Journal of Infrastructure, Policy, and Development
Facchini et al. [79]	2020	International Journal of Production Economics
Hervás-Peralta et al. [80]	2020	Case Studies on Transport Policy
de Souza et al. [81]	2020	Sustainability in Debate
Tadic et al. [82]	2020	Sustainability
Baccelli and Morino [83]	2020	Research in Transportation Business and Management

## 4. Results

### 4.1. Bibliometric Analysis

This section includes the main research findings of the literature review, including their descriptive analysis, and stresses some general considerations.

The earliest article was published in 2008 [47], and the latest ones were published in 2020 (eight articles). Scholars' interest in the subject has increased since 2018, with the peak reached in 2019 (11 articles). Figure 2 summarises the research timeline. Among the 29 journals in which the 43 selected papers were published (Table 1), only *Sustainability* and *Journal of Cleaner Production* present more than two contributions, with seven and five articles, respectively. They regard mainly environmental and sustainability issues in corporations, governments, education, regions, and societies. Five journals published two articles each, as Figure 3 shows, and the remaining 22 published only one.

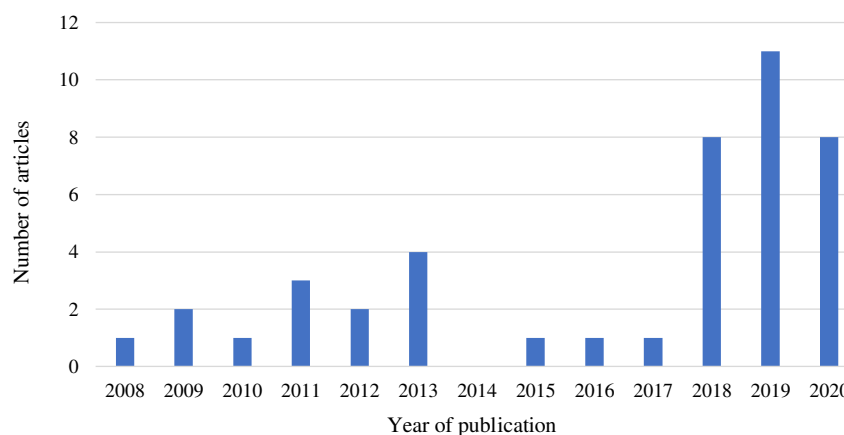


Figure 2. Research timeline. Source: personal elaboration by the authors.

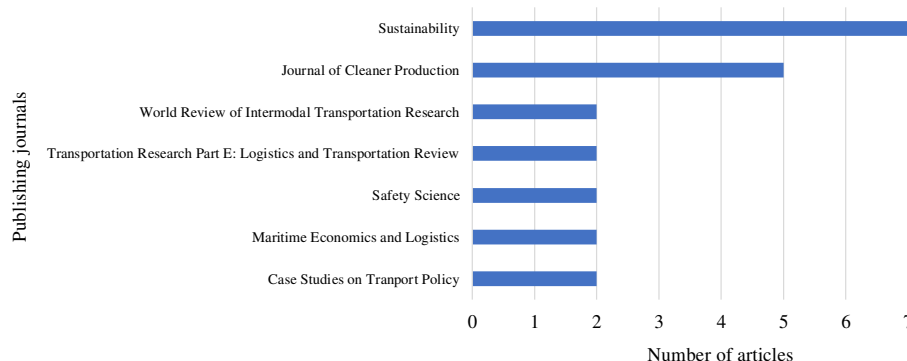


Figure 3. Publishing journals. Source: personal elaboration by the authors.

Further, regarding the corresponding authors’ geographical affiliations, Europe offers the most scholars, mainly six Swedish and Italian and four Spanish. Another region interested in this field is Asia, with five Chinese affiliations (Figure 4).

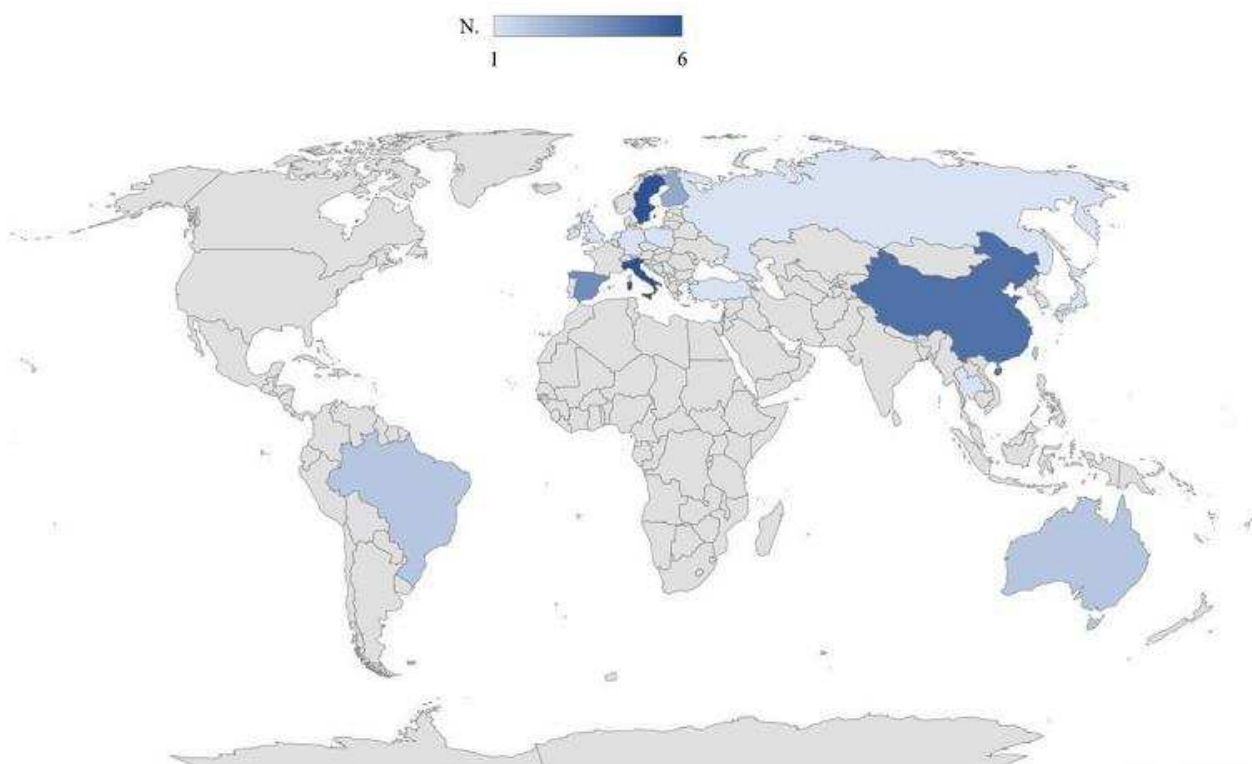


Figure 4. Geographical areas according to corresponding authors’ affiliations. Source: personal elaboration by the authors.

Specifically, according to this criterion, the Italian and Chinese contributions are mainly focused on their own local case studies, whereas the Swedish case studies are focused on foreign ones. In contrast, the Spanish articles are mostly linked to general issues instead of exploring a well-defined area.

Regarding the selected subtopics, Table 2 shows that 21 articles focus on one subtopic, of which 12 focus on social sciences; 5 on environmental sciences; 4 on business, management, and accounting; and 21 articles focus on two subtopics. Only one article focuses on environmental sciences; social sciences; and business, management, and accounting.



**Table 2.** Investigated subject and subtopics. Notes: PS = physical sciences; SS = social sciences; Source: personal elaboration by the authors.

References	Subtopics		
	Environmental Sciences (PS)	Social Sciences (SS)	Business, Management, and Accounting (SS)
Roso [47]		X	X
Roso [48]		X	
Roso et al. [10]	X	X	
Lima et al. [49]	X	X	
Henttu and Hilmola [50]		X	
Hanaoka and Regmi [51]		X	
Ka [52]		X	X
Iannone [53]		X	
Haralambides and Gujar [54]		X	
Roso [55]		X	
Zeng et al. [45]		X	
Lättilä et al. [17]		X	X
Wu and Haasis [56]	X		X
Regmi and Hanaoka [57]	X	X	X
Muravev and Rakhmangulov [58]	X		
Molero et al. [59]	X	X	
Black et al. [60]	X	X	
Tsao and Linh [61]	X		X
Wu and Haasis [11]			X
Xu et al. [62]	X		X
Jachimowski et al. [63]	X		
Santarremigia et al. [64]		X	
Carboni and Dalla Chiara [65]		X	
Qiu and Lam [66]		X	
Pham and Lee [67]		X	X
Tsao and Thanh [68]	X	X	
Hui et al. [69]	X	X	
Kurtulus and Cetin [32]	X	X	
Li et al. [70]	X	X	
Baydar et al. [71]	X		
Digiesi et al. [72]			X
Khaslavskaya and Roso [27]	X	X	
Mata-Lima et al. [73]	X		
Wang and Zhu [74]	X	X	
Hervás-Peralta et al. [75]		X	
Aksoy and Durmusoglu [76]	X		
Carboni and Orsini [77]		X	
Gu et al. [78]			X
Facchini et al. [79]			X
Hervás-Peralta et al. [80]		X	
de Souza et al. [81]	X	X	
Tadic et al. [82]			
Bacelli and Morino [83]		X	

Consequently, the prevalence of the subject of social sciences shows that the environmental performance of dry ports is only part of a larger analysis also including economic and social aspects. Indeed, only five contributions have been published in journals on the physical sciences, highlighting the central role of the related environmental assessment. Therefore, there is ample opportunity to conduct studies on this topic.

#### 4.2. Textual Analysis

As reported in the previous section, scholars have shown an increasing interest in the environmental aspects of dry ports, especially in the last few years. In what follows, a

textual analysis of the selected articles is provided to describe the content, structure, and functions according to the three research propositions.

#### 4.2.1. RQ1—Dry Ports as an Ecological Pathway in Logistics Chains

Dry ports have the potential to improve sustainability in logistics chains, as they could make the handling of goods more efficient and facilitate more organised port access. Obviously, when planning a dry port, one has to consider minimising the environmental, social, and economic costs [49,61].

Muravev and Rakhmangulov [48] assessed a series of parameters for strategic planning of a dry-port system, with the aim to ensure the improvement of the ecological situation in a port city. This effort entails considering a reduction in environmental pollution levels from carbon dioxide (CO<sub>2</sub>), noise in terminal areas, and solid domestic waste resulting from stuffing containers. Roso [47] also considered a decrease in traffic congestion, heavy use of local roads, the consequent risk of traffic accidents, and the issue of land use. Dry ports allow for a shift in freight flows from unimodal road transport to environmentally and socially friendly intermodal solutions, involving, for example, rail, inland waterway (by barge), and sea transport [11,53,60,63,67,78]. Black et al. [60] recognised, indeed, that intermodal transport (road-rail) generates various environmental benefits related to a direct rail connection between dry ports and seaports. Such transport requires coordination among all stakeholders: government planning agencies, regulatory authorities, terminal operators, freight forwarders, transport operators, and port authorities [60]. Therefore, the railway is advocated as a more sustainable traffic model by transport policies at various levels. In fact, it is often used in the inland transport of goods between seaports and dry ports instead of road transport used only in the final distance from/to dry ports. The results of this shift (from truck to train) undoubtedly include environmental benefits, mainly due to the decrease in energy consumption and congestion on the road network and at the seaport gate [27,60], and external environmental effects in the surrounding areas along the route [10,47,76]. The above-mentioned environmental benefits result in decreased CO<sub>2</sub> emissions along roads and seaports [27,54]. The analysed literature [32,59] endorses this statement and asserts that rail transport, compared with road transport, is not only less expensive but also more environmentally friendly: A “single train trip can substitute for 35 trucks” (Hui). For example, Khaslavskaya and Roso [27] examined the Skaraborg dry port case study to demonstrate an electrified railway’s efficiency in CO<sub>2</sub> reduction, showing a decrease of 80%. Other studies have shown smaller but still significant reductions, ranging from 10% to 45% [17,51,53,79]. Henttu and Hilmola [50] applied an efficient dry port model from Gothenburg (Sweden) to determine whether it was also appropriate for the logistics platform in Finland, which is characterised by an extensive coastline, where the large-scale diffusion of dry ports is still in its beginning stages. They concluded that increasing the number of dry ports to six would reduce transport costs and CO<sub>2</sub> emissions. Xu et al. [62] reported similar results, emphasising a strong correlation between the increasing number of dry ports and decreased CO<sub>2</sub> emissions. Regmi and Hanoaka [57] connected this reduction to the modal shift from road to rail freight transport and the development of a dry port. The results showed a significant amount of saving, which validates and encourages this eventual sustainable change. Additionally, Zeng et al. [45] and Li et al. [70] confirmed that it is possible to lower CO<sub>2</sub> emissions by 25% in China, even if hinterland shipping is conducted exclusively by road. They proposed extensive use of seaports connected to strategically selected dry ports. Facchini et al. [79] applied a model to evaluate the number of containers to be stocked in ports and/or in dry ports to minimise the overall running costs and carbon footprint. Their findings showed an 11–57% decrease in costs and a 3–86% in the carbon footprint. Digiesi et al. [72] discussed the same topics. Regarding the environmental aspects of trans-shipment devices, Jachimowski et al. [63] analysed the CO<sub>2</sub> releases from hybrid cranes, showing that they have a smaller environmental impact than electric or diesel ones. Their use, powered only by an electronic motor, is surprisingly not as environmentally friendly as it might seem. Kurtulus and Cetin [32]

confirmed that train scheduling and efficient empty-container management result in a slight decrease in GHG emissions. Baydar et al. [71] highlighted that dry ports have the potential to reduce emissions due to shared planning of trucks to the same destination (if no special consideration is required for delivery, such as cooling, safety, hazardous material, etc.). Carboni and Dalla Chiara [65] presented alternative solutions based on the services and location of inland terminals for railroad-combined transport. The opportunity to use electric and hybrid heavy-duty vehicles, powered by hydrogen fuel cells, might be a key element in long-distance transport, and plug-in electric vans may be useful, in economic and environmental terms, to cover short distances (approx. 100–200 km).

In short, all these authors have paid particular attention to the role of rail transport, identified as less expensive in terms of monetary and material (energy resources) costs and environmental impacts (CO<sub>2</sub> emissions), compared with road transportation. A further moderate GHG reduction can be achieved with improvement in train planning, empty-container management, and the adoption of hybrid cranes.

#### 4.2.2. RQ2—Indicators for Measuring Environmental Sustainability

Although dry ports are considered a green pathway in logistics chains, it is crucial to evaluate their environmental sustainability in terms of CO<sub>2</sub> emissions and atmospheric pollutants due to their activities.

Many researchers have proposed various integrated approaches linked to various criteria/indicators to measure dry ports' environmental performance. For instance, Haralambides and Gujar [54] suggested a new approach of data envelopment analysis (DEA) to evaluate the efficiency of 16 dry ports in India. This methodology takes into account environmental sources of CO<sub>2</sub> emissions. In this way, operators and policymakers can isolate the undesirable outputs and act on them. Qiu and Lam [66] calculated the carbon emission savings resulting from shippers sharing transportation services in a dry port, using a bi-level model. The results showed that these reductions increase if the distance between the dry port and the shipper is long or the distance between shippers is short. Moreover, Hervás-Peralta et al. [75] proposed an improvement in the terminal operating system, which is a tool that brings efficiency for each piece of cargo moved. They classified and prioritised its functionalities based on the contribution of 12 experts from various sectors. The improvement in system performance contributes to greater environmental sustainability in terms of decreased seaport congestion and GHG emissions, not only in dry ports but also in their surroundings. Regarding the indicators, Ka [52] suggested also considering a dry port's location. To this end, de Souza et al. [81] evaluated the spatial distribution of the most suitable locations for installing dry ports in Brazil. The authors combined two recognised methods for location definition, namely the spatial multicriteria analysis and the location-allocation problem, considering inputs from logistical, social, environmental (avoiding urban areas, hydrography permanent protect areas, and buffer zone of conservation units), economic, and competition elements. Wang and Zhu [74] instead considered only the energy consumption resulting from container loading in rail trucks as an environmental indicator to improve dry ports' energy efficiency. The results showed that the total handling time and energy consumption can be reduced with an optimised loading sequence. Hui et al. [69] increased the number of criteria considered to include the use of electricity and energy resources; water, waste, and air quality management; and GHG and noise emissions. They underlined the importance of elaborating this set of indicators in collaboration with stakeholders. Mata-Lima et al. [73] evaluated the process for identifying and ranking these environmental aspects, adopting a mixed-methodology approach. They found that the three most significant aspects are emissions into the air, resource consumption, and noise. Therefore, these elements have to be taken into account in the selection of proper, measurable indicators of environmental pressure usable to monitor the sustainability of dry ports' operations. Finally, in dry ports, dangerous and non-dangerous goods are warehoused at the same time, so the number of accidents is significant. Therefore, Santarremigia et al. [64] and Hervás-Peralta et al. [75] stressed the importance of designing

the layout of terminals in a proper and safe way, considering equipment performance, safety, and security as well as environmental protection. In particular, Molero et al. [59] focused on inland terminals for containers with dangerous goods (ITDGs) to determine which factors have to be considered in their design from a total safety management point of view in the earliest stages of the project. The authors used the SuperDecisions software and a panel of experts to this end. Specifically, in the environmental care area, five main criteria were recognised: location, design, management, construction, and emergencies. Among them, the main criterion was the ITDG's geographic location.

#### 4.2.3. RQ3—Strategies for Sustainable Dry Ports

The reviewed literature highlights the importance of evaluating all the available strategies and/or of including stakeholders in decision-making policies and understanding their requirements to ensure dry ports' environmental sustainability.

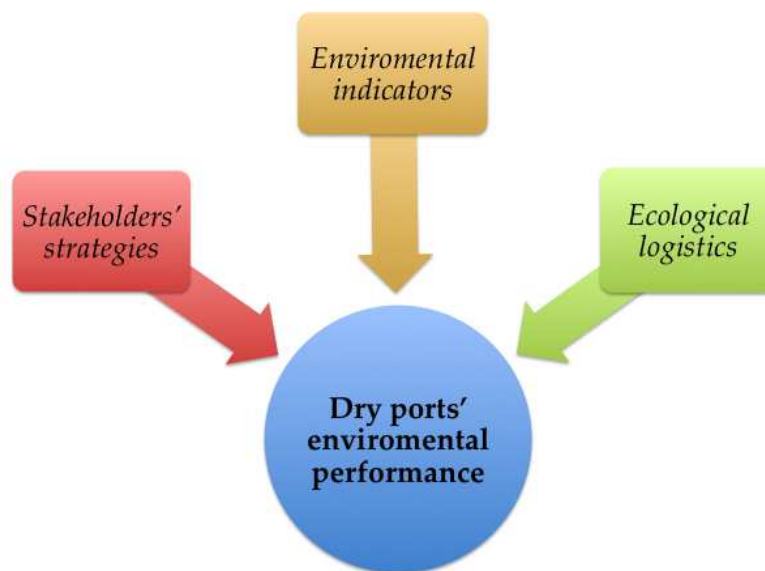
For example, Wu and Haasis [56] emphasised the need to include the natural environment as an essential stakeholder. Moreover, Black et al. [60] stressed the importance of solving environmental conflicts, especially in metropolitan areas, involving all public and private stakeholders. In particular, governments have a range of policies and tools that can be combined to counteract sustainability concerns in transport, thereby reducing external costs. To achieve environmental sustainability, governments have important tools, such as regulation; infrastructure policy; land use planning; and innovation, research, marketing, and information policy [53]. In contrast, private companies are mainly focused on the maximisation of profit and consider environmental aspects less important than other operational functions. Indeed, they consider sustainability measures "a burden and necessary evil" [69]. However, private logistics operators can encourage greening by focusing on new business models and, for example, implementing a corporate social responsibility strategy, which involves sustainable approaches to logistics and supply chain management [53]. Recently, researchers have proposed alternative methodological approaches. For instance, Tadic et al. [82] defined a new hybrid model of multicriteria decision making, which integrates Delphi, an analytical hierarchy process, and combinative distance-based assessment methods in a grey environment to classify dry port terminal locations considering various stakeholders' needs. The principal objective is environmental and social responsibility, aimed at improving mobility and accessibility as well as decreasing traffic congestion and accidents. Baccelli and Morino [83] readapted the multiactor and multicriteria analysis methodology, taking into account the stakeholders' perspectives, to study intermodal transport policies. They highlighted the importance and centrality of the coherence of public policies and private companies' strategies for the development of railway intermodality at all levels.

The role of stakeholders has been stressed to emphasise that improving dry ports' sustainability involves a high level of coordination among government planning agencies, regulatory authorities, terminal operators, freight forwarders, transport operators, and port authorities. Indeed, the strategies must include all stakeholders, public and private, because this cooperation offers the possibility to combine tools (regulations, policies, business organisation) to achieve a common goal without losing profits or social benefits.

## 5. Discussion

The previous findings provide a more robust synthesis to develop a new conceptual framework. It was built on the critical analysis of the authors, whose final aim was to investigate the current state of the art related to the assessment of dry ports' environmental sustainability. The results showed that there is a gap in this field, namely a weak and labile correspondence between the awareness of stakeholders and public authorities and their ability to make dry ports sustainable. Hence, the proposed innovative framework is relevant as a possible and useful tool to address new and specific studies and research, driving and supporting actions and policies toward a reduction in the environmental impacts of dry ports.

Specifically, it identifies the variables that affect the dry port's performance, and therefore, it highlights the need for better coordination among the different aspects (Figure 5). It was revealed that there is no coordination between the various studies and systemic debates on the dry port's environmental aspects, no standardised applicable tools, and no involvement among the various stakeholders. Additionally, a debate is also lacking under the lens of the SDGs of the Agenda 2030.



**Figure 5.** Conceptual framework and its variables derived from the SLR. Source: personal elaboration by the authors.

These results are in line with some other relevant and recent literature reviews published by some academic scholars. Indeed, all of them revealed that there is often a lack of data and an absence of research questions useful to develop a more systemic discussion; a lack of standardised performance indicators; very few publications based on surveys of shippers or transport operators; and many thematic areas on dry ports' research in the same article. For example, Baydar et al. [26] highlighted the need for more case-based studies and performance indicators analysed by scholars, as most publications on transport and logistics are from non-academic resources. They underlined that the studies on dry ports often focused on more than one aspect of sustainability. Khaslavskaya and Roso [87] observed that the environmental perspective is more in focus in recent studies, but very few publications consider the broader perspective of dry port sustainability. A variety of methods have been used, but research is predominantly represented by qualitative cases and quantitative modelling and optimisation studies. Most of the benefits identified in this review are of an economic nature, although the concept has gained popularity due to the range of environmental benefits identified. Additionally, Lamii et al. [21] found that different themes (optimisation, performance, concept, sustainability, environmental impact, risk management, and financial impact) are sometimes in the same article. It is only since the year 2010 that specific studies have been carried out on the dry port performance, according to economic, environmental, or social criteria. Nevertheless, they stressed the importance to further practical studies on the topic of dry ports and on some topics not adequately considered, e.g., their environmental impact.

Finally, it was found to be crucial to frame the issue of dry ports' environmental sustainability under the umbrella of UN Agenda 2030 and its relative SDGs. These goals aim to implement innovative digital technologies in port management and operations and to optimise physical port infrastructures for sustainability and resilience. From the environmental perspective, the SDGs aim to address air, dust, noise, and water pollution and to protect the environment through community and social-engagement programs [88].



Actually, the development of dry ports is a key enabler facilitating the achievement of some SDGs according to a sustainable transport approach. Indeed, it offers multimodal sustainable solutions such as the implementation of an integrated intermodal transport system, which brings together multiple stakeholders around shared objectives [89]. Such goals can be achieved only if the interconnections between logistics and SDGs are well-understood and deliberately used to solve trade-offs and to benefit from potential synergies [90]. Specifically, knowledge advancement about these interlinkages is crucial for developing and fostering the diffusion of dry ports; thus, academic scholars have to perform in-depth investigations on how the dry ports can meet SDGs, specifically those correlated to the environmental dimension. One of the first evaluations was carried out by Alamouh et al. [91], who revealed, even if generically, that this typology of multimodal transport sustains sustainable economic growth, builds resilient infrastructure (Goal 8: Decent Work and Economic Growth), supports inclusive and sustainable industrialisation and encourages innovation (Goal 9: Industry, Innovation, and Infrastructure), and guarantees sustainable consumption and production patterns (Goal 12). There are only a few references to the environmental aspect such as controlling emissions and pursuing energy-efficient building, Goal 3 (Good Health and Well-being) and Goal 13 (Climate Action), respectively [91]. Nevertheless, according to the findings of the present study, other goals can be met by dry ports' implementation: an increase in sustainable mobility and a reduction in traffic congestion (Goal 11: Sustainable Cities and Communities), as well as the protection of water quality (Goal 14: Life Below Water).

## 6. Conclusions

The authors conducted an SLR examining 43 articles to categorise the present literature on dry ports' environmental sustainability. In turn, this categorisation, according to the three research propositions, provided a conceptual framework useful for identifying important gaps in academic research and for suggesting linkages among the different aspects of this topic, which will become increasingly important in the facilitation of these types of studies. Additionally, these results could offer practitioners and stakeholders an overview of the existing tools and strategies to improve dry ports' environmental performance.

To summarise the main outcomes, even though many studies have been conducted on the importance of dry ports as an environmentally sustainable opportunity in logistics chains, only few of those studies concretely provide standardised rules for measuring dry ports' performance and strategies to be implemented, surely due to the availability of only some case studies. Furthermore, there is no coordination between the various studies and systemic debates on the dry ports' environmental aspects and no involvement among the various stakeholders. Additionally, a debate is also lacking under the lens of the SDGs of the Agenda 2030 even if this SLR showed that some efforts in this direction have been made (Goals 3, 8, 9, 12, and 13). Furthermore, this proposed SLR stressed that, in the context of dry ports, new strategies must be implemented to contribute also to Goal 11 (Sustainable Mobility) and Goal 14 (Water Quality Protection).

One of the main limits of this research is the only use of Scopus and Web of Science indexed databases (other relevant institutional documents and case studies related to the same topic could be collected by investigating other search engines) and the exclusion of studies published in 2021 and 2022 (up to 31 July).

Therefore, future research could focus on the evaluation of new additional data with a meta-analysis approach to weigh, compare, and identify patterns, disagreements, and relationships among them and mainly consider the years of the COVID-19 pandemic period and its implications on this topic.

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