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SUSTAINABILITY AT MARITIME MOBILITY: COMPARING OPEN DATA ECOSYSTEMS AND COLLABORATIVE MARITIME PLATFORMS

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Original Article

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ABSTRACT

Maritime transport is a critical component of global supply chains and sustainable mobility systems. Ports, as interfaces between maritime and land transport, influence urban congestion, emissions, and environmental performance. Open Data Platforms (ODP) and Open Data and Collaborative Platforms (ODCP) can support transparency, data-driven decision-making, and coordination among port and urban stakeholders.

This study examines the role of ODP and ODCP in the maritime port sector and their contribution to sustainability and sustainable urban mobility. A multi-stage methodology combines bibliometric analysis with an empirical assessment of platforms associated with the world's Top 50 Container Ports. The analysis considers publication trends, sustainability dimensions, platform functions, and levels of development.

The findings indicate that research in this field remains recent, fragmented, and only partially focused on sustainability. Existing platforms vary considerably in maturity and scope, prioritizing data provision and environmental monitoring, while collaborative functions and integrated economic, environmental, and social dimensions are less consistently developed. Based on these findings, the study proposes a structured framework for evaluating and designing maritime ODP and ODCP.

The study contributes to the literature on port–city integration, sustainable mobility, and data-driven governance, while offering practical guidance for port authorities, policymakers, and platform developers.

Keywords: *open data platforms, collaborative platforms, maritime ports, sustainable mobility, port–city integration, sustainability*

1. INTRODUCTION

Maritime transport is a fundamental pillar of global trade, carrying more than 80% of the total volume of goods transported worldwide (Vu et al., 2024). Its predominance reflects its capacity to move large volumes over long distances at relatively low cost. It also offers advantages in terms of energy efficiency and environmental impact per unit transported. However, maritime transport necessarily depends on intermodal operations, as goods must be transferred between ports and inland transport networks (Mansoursamaei et al., 2023).

As a result of their central role in global trade, ports have evolved from traditional loading, unloading, and storage facilities into complex logistics hubs that coordinate and integrate supply-chain activities (Han, 2018). This transformation has increased both the number and diversity of stakeholders involved in port operations, making effective collaboration and transparent communication increasingly important (Ali et al., 2022b).

In parallel, decision-making processes are becoming more data-driven. Open Data Platforms (ODP) and Open Data and Collaborative Platforms (ODCP) support data access, transparency, innovation, and coordination across governmental and organizational contexts (Kassen, 2018). Data are considered open when they can be freely used, reused, and redistributed, including for commercial purposes, without substantial legal or technical restrictions (Ali et al., 2022a). ODP and ODCP provide digital infrastructures through which users can discover, access, exchange, and apply open data. Common examples include CKAN, DKAN, Socrata, OpenDataSoft, GitHub, Google, and Kaggle (Ali et al., 2022b).

The growing operational and institutional complexity of port systems further increases the need for shared and standardized data infrastructures (Pachiyappan et al., 2026). Contemporary ports involve port authorities, logistics operators, shipping companies, municipalities, regulatory bodies, and local communities, all of which generate and use data for planning, operations, and decision-making. Without accessible and interoperable data systems, the capacity of ports to coordinate responses to operational, environmental, and social challenges remains limited. In this context, ODP and ODCP can improve information exchange, transparency, and cooperation across organizational and institutional boundaries.

Despite the increasing importance of digitalization in the maritime sector, the literature provides limited systematic analysis of ODP and ODCP in port environments. This research gap is particularly relevant to sustainable mobility. Ports are major nodes within urban and interurban transport networks and directly affect traffic flows, congestion, emissions, noise, land use, and the integration of maritime and land-based transport. As interfaces between global supply chains and local mobility systems, they significantly influence the environmental and social performance of surrounding urban areas.

Against this background, the study identifies and analyses ODP and ODCP used in the maritime port sector. It maps their scope, focus, functions, and practical applications and develops a structured framework for comparing and designing such platforms. The study also reviews the literature on open data and collaborative platforms in maritime contexts, with particular attention to economic, environmental, and social sustainability. In doing so, it identifies major research gaps, implementation challenges, and opportunities for future development.

The paper is organized as follows. Section 2 presents the theoretical background. Section 3 describes the materials and methods, including the literature review and bibliometric analysis. Section 4 reports the bibliometric findings, assesses existing platforms, and introduces the proposed comparison framework. Section 5 discusses the implications for sustainable mobility and port operations, as well as the main limitations and challenges. Section 6 concludes the paper and outlines practical implications and directions for future research.

2. THEORETICAL BACKGROUND

This section presents a structured review of the literature on ODP and ODCP, with particular attention to their application in complex socio-technical systems and, more specifically, in the maritime port context. The review aims to synthesize existing research on the characteristics, challenges, and benefits associated with these platforms, highlighting how open data and collaborative approaches have been conceptualized, implemented, and evaluated across different domains. By consolidating contributions from both general and sector-specific studies, this section establishes the theoretical foundations for the analytical framework proposed in this research.

In addition, the literature review emphasizes sustainability-related aspects and the role of data-driven platforms in supporting coordinated decision-making and stakeholder interaction (Shojaei et al., 2026). By examining methodological approaches, evaluation models, and empirical findings reported in prior studies, the review identifies key gaps in the literature, especially regarding the integration of sustainability dimensions and the limited focus on maritime port applications. This synthesis provides a coherent basis for the methodological choices adopted in this study and justifies the need for a structured analysis of ODP and ODCP tailored to the maritime sector.

2.1. OPEN DATA / OPEN DATA AND COLLABORATIVE PLATFORMS ANALYSIS

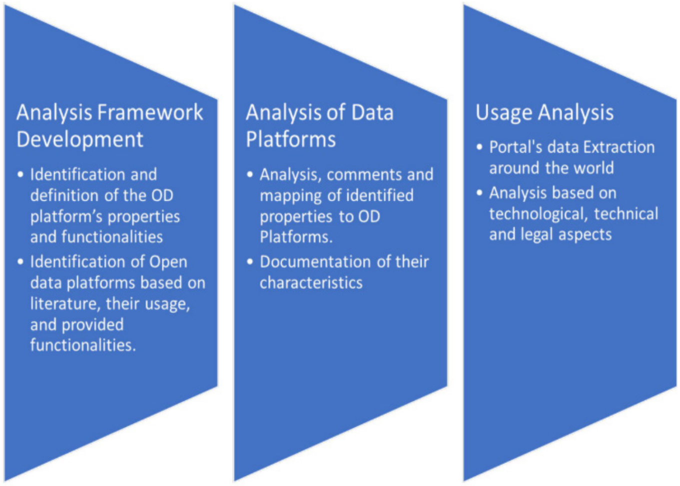
Beyond their technical architecture, ODP and ODCP should be understood as components of broader open data ecosystems shaped by governance structures, institutional arrangements, data standards, and user communities (Van Loenen et al., 2021). Their effectiveness therefore depends not only on data availability, but also on stakeholder coordination, governance quality, and the integration of sustainability principles into platform design. Value is generated primarily through the reuse, linkage, and combination of heterogeneous datasets across organizational and sectoral boundaries (Bauer & Kaltenböck, 2012). Accordingly, platforms should be assessed not only by the data they publish, but also by their capacity to support integration, reuse, and downstream applications.

Platform maturity represents a further analytical dimension. Open data platforms range from basic repositories supporting one-way data publication to advanced collaborative environments enabling real-time interaction, shared data curation, and multi-stakeholder decision-making (Alexopoulos et al., 2014). This distinction underpins the difference between ODP, which primarily facilitate data dissemination, and ODCP, which incorporate participatory and collaborative functions. Identifying a platform's position along this maturity continuum is therefore essential for systematic comparison.

Interoperability and user engagement are also critical. Interoperability refers to the capacity to exchange, integrate, and reuse data across heterogeneous systems, standards, and institutional settings (Ali et al., 2022a). Without it, open data cannot fully support coordinated decision-making or cross-sector collaboration. User orientation is equally important, as platforms that fail to address accessibility, trust, usability, and stakeholder needs tend to achieve lower levels of adoption and impact (Kassen, 2018).

Together, ecosystem embeddedness, data reuse, platform maturity, interoperability, and user engagement provide the theoretical basis for analysing maritime ODP and ODCP. These dimensions complement the structured methodology proposed by Ali et al. (2022b), presented in Figure 1, and provide a coherent framework for evaluating and comparing platforms across different application domains.

Figure 1 - A proposed methodology for the analysis of ODP



Source: (Ali et al., 2022b)

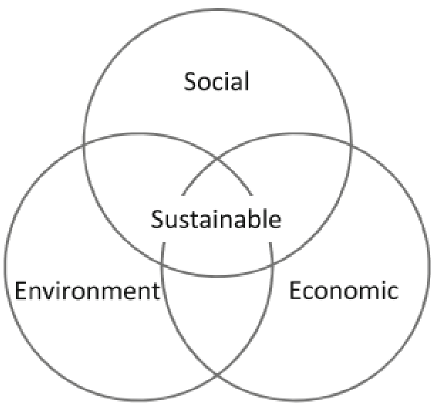
2.2. SUSTAINABILITY ANALYSIS IN ODP AND ODCP

Sustainability has become a central concern in contemporary policy, planning, and research, particularly in sectors characterized by complex socio-technical systems and substantial environmental impacts. However, sustainability considerations remain insufficiently integrated into most existing open data platforms, which are typically designed to prioritize data availability and technical interoperability rather than sustainable outcomes (Van Loenen et al., 2021).

This limitation is particularly evident in the port and maritime sector, where empirical research on the sustainability implications of ODP and ODCP remains scarce. Consequently, establishing a coherent method for evaluating sustainability within data-driven port platforms represents an important methodological challenge.

To address this gap, the study adopts the framework developed by Jiang et al. (2019) for assessing the sustainability performance of government open data platforms. The model conceptualizes sustainability through three dimensions: economic, environmental, and social (Figure 2). In the absence of a domain-specific framework for maritime open data platforms, this established multidimensional model provides an appropriate basis for analysing and comparing ODP and ODCP from a sustainability perspective.

Figure 2 - Typical representation of sustainability as three intersecting circles



Source: (Jiang et al., 2019)

2.3. BARRIERS FOR ODP AND ODCP

Previous studies have identified a wide range of barriers that must be addressed for open data platforms to fulfill their intended role as fundamental enabling tools (Ferreira et al., 2025). These barriers span multiple dimensions, including technical, organizational, and human-related challenges, and collectively constrain the effective use and impact of ODP. Issues related to data quality and standardization, legal constraints, data privacy and security, strategic business considerations, technical complexity, and user literacy have been shown to significantly limit the full potential of open data platforms (Beno et al., 2017).

Beyond these structural and technical limitations, several authors have highlighted the practical difficulties associated with implementing and the everyday use of open data platforms, often resulting in lower-than-expected levels of adoption and utilization (Folmer et al., 2019; Hyseni & Bexheti, 2022). From the perspective of end users, such difficulties lead to usability constraints, reduced confidence in the data, and challenges in incorporating platform outputs into decision-making.

Addressing these barriers represents a considerable challenge for platform developers and system designers, who must balance technological sophistication with accessibility and usability (Slobodova, 2020; Vítor et al., 2022). The literature suggests that overcoming these obstacles requires not only technical solutions but also organizational alignment, capacity building, and user-oriented design approaches. Consequently, several aspects have been identified as critical to enhancing the success and long-term viability of open data platforms, reinforcing the need for structured evaluation frameworks that account for these diverse dimensions (Ali et al., 2022b).

Millette, C. and Hosein, P. (2016) highlighted the main requirements of open data platforms to best serve the needs of the public: (a) highly available data, (b) reusable and distributive data, and (c) universally consumable. They also identified seven principles that a data platform solution must address to meet developers' and consumers' needs: completeness, primacy, timeliness, accessibility, machine-readability, non-discrimination, and non-proprietary.

2.4. BENEFITS OF ODP AND ODCP

Collaborative platforms enhance interaction, coordination, and knowledge exchange among geographically dispersed stakeholders. By supporting real-time communication and multiple content formats, including text, audio, video, and images, they enable more flexible and responsive forms of collaboration. When integrated into organizational processes, these platforms can improve productivity, facilitate feedback, and strengthen collective problem-solving (Andriessen et al., 2023).

In the maritime sector, digitally enabled collaboration has considerable potential to improve the efficiency, sustainability, and safety of port operations (Alexopoulos et al., 2014; Gupta et al., 2022). Combining open data with collaborative functionalities supports coordinated decision-making, aligns operational strategies, and increases transparency among port stakeholders.

These benefits extend beyond individual ports to cross-sectoral partnerships and international cooperation. Shared data environments enable stakeholders to exchange best practices, compare performance, and jointly address operational and sustainability challenges. Data-sharing agreements, collaborative research, and digital cooperation platforms further promote knowledge diffusion and collective learning, reinforcing the strategic value of ODP and ODCP in the maritime port sector (Gupta et al., 2022; Herrera-Cubides et al., 2023).

2.5. ODP AND ODCP AS ENABLERS OF PORT–CITY INTEGRATION AND SUSTAINABLE URBAN MOBILITY

Ports are not isolated logistics hubs. As crucial interfaces between maritime supply chains and land-based transport networks, they shape and directly impact traffic flows, congestion patterns, air quality, noise levels, land use, and the integration of multiple modes of transport within and around urban areas. Addressing sustainability in maritime transport, therefore, requires analytical tools and data infrastructures that explicitly capture this port-city link and support coordinated decision-making across organizational and institutional boundaries.

In this context, ODPs and ODCPs emerge as important facilitators of port-city integration. By facilitating access to standardized, interoperable, and real-time data among diverse stakeholders - including port authorities, municipal governments, logistics operators, transport agencies, and local communities - these platforms can support the kind of systemic and multilateral coordination that sustainable urban mobility demands (Seisenbekov et al., 2026). However, the extent to which existing platforms are designed to perform this integrative function remains underexplored in the literature.

Vaca-Recalde et al. (2024) offer a relevant perspective on this potential through their proposal for a connected and intelligent framework for vehicle automation in smart ports. Their work demonstrates how integrated data platforms in port environments can support real-time coordination between port operations and the surrounding transportation infrastructure, contributing to more efficient logistics flows. Essentially, the framework extends beyond the port perimeter, encompassing the interfaces between automated port vehicles, urban road networks, and intermodal transfer points - a design that reflects the inherently hybrid, port-city nature of modern port operations.

Menegon et al. (2023)integrated and efficient planning of coastal and marine spaces at macro-regional level. This research presents the Geoportal of the Adriatic-Ionian Region (GAIR offer a complementary perspective on Maritime Spatial Planning. The development of a geoportal for the Adriatic-Ionian region illustrates how spatially integrated data platforms can support coordinated governance in maritime and coastal environments, reconciling competing uses of marine and coastal space - including those that directly affect urban and peri-urban areas. The geoportal's emphasis on data interoperability, multi-stakeholder access, and regulatory compliance provides a concrete model of how the ODP and ODCP can operationalize the environmental and social dimensions of sustainability at the port-city interface.

From a platform design perspective, Vítor et al. (2022) demonstrate the technical feasibility of scalable smart-city data platforms that integrate real-time data streams from heterogeneous urban sources. Their architecture, designed to support real-time processing and data sharing in a smart city environment, is directly relevant to the challenge of port-city integration: ports generate continuous operational data - ship movements, gate transactions, container flows, emissions - which could, in principle, be integrated into urban mobility management systems, provided there is an adequate platform infrastructure.

The user-oriented perspective of Millette and Hosein (2016) reinforces this point. The authors emphasize that the value of open data platforms ultimately lies in their accessibility and usability for end users. Their identification of seven design principles (completeness, primacy, timeliness, accessibility, machine readability, non-discrimination, and non-proprietary access) provides a normative benchmark for evaluating maritime platforms. This is particularly relevant in the context of port-city data sharing, where diverse and technically heterogeneous user communities must be served simultaneously.

Taken together, these contributions suggest that the effectiveness of the ODP and ODCP as instruments of port-city integration and sustainable urban mobility depends on at least three interrelated conditions: the platform's ability to integrate heterogeneous data sources into the port-city interface, including real-time operational and environmental data; the platform's design to enable access by multiple stakeholders, ensuring that the data can be used by actors with different technical skills and institutional roles; and the platform's alignment with urban mobility governance frameworks, allowing its results to contribute to decisions regarding land use planning, transportation policy, and environmental management. These conditions are not consistently met by existing platforms, as revealed by the empirical analysis presented in Sections 4.2 and 4.3, and inform the port-city integration dimension explicitly incorporated into the comparison framework proposed in Section 4.4.

3. MATERIALS AND METHODS

This study employed a multi-stage methodology combining a structured literature review, bibliometric analysis, and empirical assessment of maritime open data and collaborative platforms.

First, a literature search was conducted in the Web of Science database using two query strings: (a) ("open data platform" OR "collaborative platform*") AND maritime*, and (b) ("open data platform" OR "collaborative platform*") AND (maritime AND sustainab*). The search yielded 110 records. After restricting the sample to peer-reviewed scientific articles, 57 publications remained.

The 57 articles were then screened to identify studies explicitly addressing sustainability in maritime platforms. This process yielded 10 documents, including six published scientific articles. These six studies were examined in detail to assess how sustainability was conceptualized across the economic, environmental, and social dimensions proposed by Purvis et al. (2019), as well as to identify the main challenges and solutions discussed in the literature.

Two bibliometric analyses were subsequently conducted using VOSviewer. The first covered the full set of 57 articles on maritime ODP and ODCP, while the second focused on the sustainability-related subset. This enabled comparison of publication trends, thematic structures, and relationships among research topics.

The empirical phase examined ports included in the World Shipping Council's Top 50 Container Ports ranking (2024). The analysis identified ODP and ODCP associated with these ports, either directly or through secondary research, and assessed their data coverage, availability, quality, functionality, and usability.

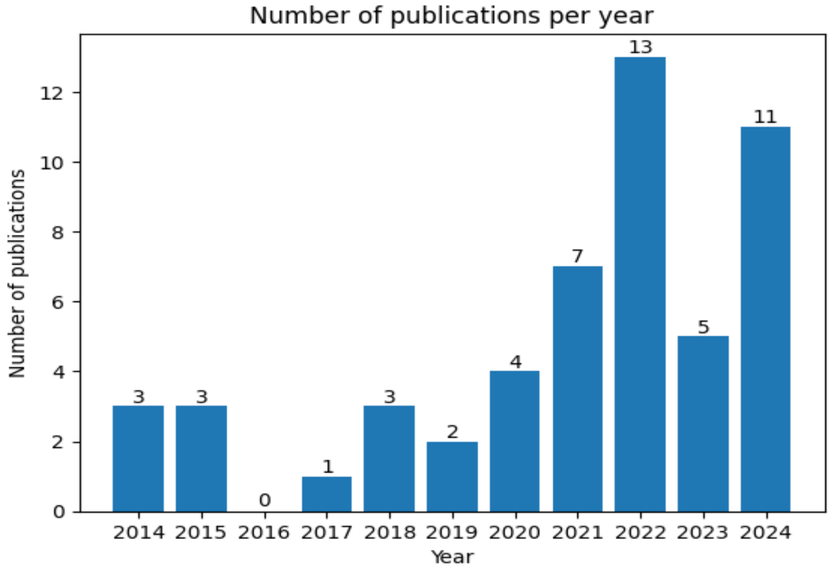
In total, 39 maritime-related platforms were identified and evaluated. The combined findings from the literature review, bibliometric analyses, and empirical assessment formed the basis for the comparative framework for maritime ODP and ODCP proposed in this study.

4. RESULTS AND DISCUSSION

4.1. BIBLIOMETRIC ANALYSIS OF ODP AND ODCP IN THE MARITIME CONTEXT

This subsection presents the results of the bibliometric analyses conducted to examine the scientific literature on ODP and ODCP in the maritime context. The analysis aims to provide an overview of research trends, publication patterns, and thematic relationships within existing literature, and to assess the extent to which sustainability-related aspects have been addressed. By visualizing the volume, distribution, and connections among published studies, the bibliometric results provide a contextual foundation for interpreting subsequent findings and for identifying research gaps in the maritime port domain.

Figure 3 - Temporal distribution of scientific publications on maritime ODP and ODCP



Source: Own elaboration using VOSviewer

Figure 3 shows that research on maritime ODP and ODCP remained limited and irregular between 2014 and 2019, with no indexed publications recorded in 2016. Publication activity increased from 2020 onward and peaked in 2022. Despite a slight decline in 2023, the high output recorded in 2024 indicates sustained and growing academic interest. These trends confirm that maritime ODP and ODCP constitute a relatively recent but expanding research field.

Figure 4 illustrates the multidisciplinary distribution of publications across research areas. Oceanography and Environmental Sciences account for a substantial share of the literature, reflecting the importance of open and interoperable data for monitoring and managing marine and environmental systems. Engineering disciplines, particularly Marine Engineering and Ocean Engineering, are also strongly represented, highlighting the technical and operational relevance of these platforms.

Contributions from Electrical and Electronic Engineering, Telecommunications, Computer Science, and Information Systems further emphasize the role of digital infrastructure, sensor networks, data management, and platform integration. However, the comparatively limited representation of social sciences and information systems suggests that research remains predominantly technical and domain-specific. This imbalance highlights the need for more interdisciplinary approaches that integrate technological, organizational, governance, and sustainability perspectives in port and maritime ecosystems.

Figure 4 - Categorization by activity areas that have published articles about maritime ODCP

Source: Own elaboration using VOSviewer

The results presented in Table 1 indicate a decentralized research landscape in which no single organization dominates scientific production on maritime ODP and ODCP. Although the University of Lisbon and Leiden University appear at the top of the table by publication count, the overall volume of articles per organization remains relatively low. This distribution suggests that research on maritime ODP and ODCP is dispersed across multiple institutions rather than concentrated in a small number of leading research centers, reflecting the field's emerging, exploratory nature.

In contrast, several organizations are represented by a single publication yet have a high number of citations. This pattern is particularly evident among research institutes, governmental bodies, and specialized organizations such as the Alfred Wegener Institute, NOAA, and various marine research centers. The high citation counts associated with these contributions suggest that, although limited in number, these studies have had a significant scientific impact, often serving as key references within the field.

The presence of both academic institutions and applied research organizations reflects the interdisciplinary and practice-oriented nature of research on maritime ODP and ODCP. Universities tend to contribute through broader conceptual or methodological studies, while research institutes, governmental agencies, and consultancy-oriented organizations often provide highly influential, domain-specific insights grounded in empirical data or operational experience. Overall, the distribution shown in Table 1 highlights a research domain characterized by institutional diversity, dispersed contributions, and a mix of exploratory academic work and high-impact applied studies, reinforcing the relevance of maritime ODP and ODCP for both research and practice.

Table 1 - Leading organizations contributing to research on maritime ODP and ODCP

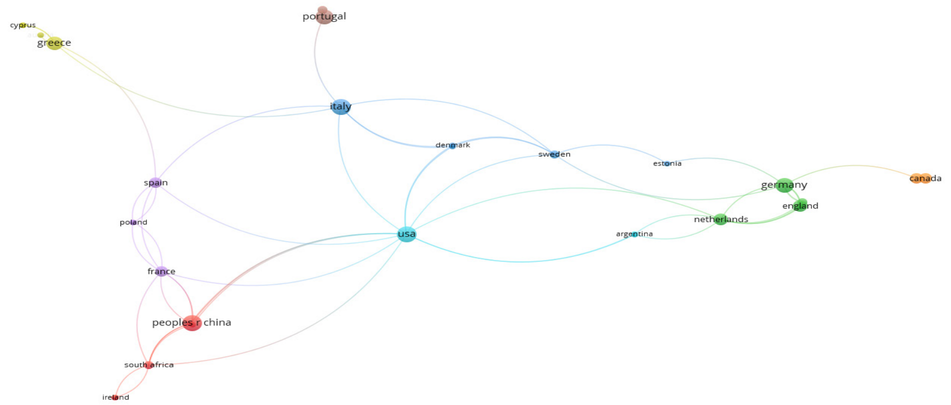
Organization	Documents	Citations	Total Link Strength
univ lisbon	3	19	7
leiden univ	3	4	4
noaa	2	13	7
alfred wegener inst	1	31	12
carl von ossietzky univ oldenburg	1	31	12
cefas lowestoft lab	1	31	12
deep seas environm solut ltd	1	31	12
ecap consultancy grp	1	31	12
oil & gas uk	1	31	12
scottish assoc marine sci	1	31	12
seascape belgium	1	31	12
univ aberdeen	1	31	12
univ edinburgh	1	31	12
univ glasgow	1	31	12
wageningen marine res	1	31	12
wageningen univ	1	31	12
cafoscari univ venice	1	5	8
earthx	1	0	8
emilia romagna geol seism & soil survey	1	5	8
hellen ctr marine res	1	5	8

Source: Own elaboration using VOSviewer

The collaboration network, shown in Figure 5, reveals an emerging, moderately fragmented pattern of international cooperation in maritime ODP and ODCP research. A small number of countries, particularly the United States and Italy, serve as central hubs connecting regional clusters, while several others remain more peripheral. Although European collaboration is relatively strong, especially in Northern and Western Europe, cross-regional and intercontinental links remain limited.

Overall, the network structure suggests significant potential to strengthen international collaboration and support a more integrated, globally oriented research landscape.

Figure 5 - Connections between countries that publish more articles related to maritime ODCP

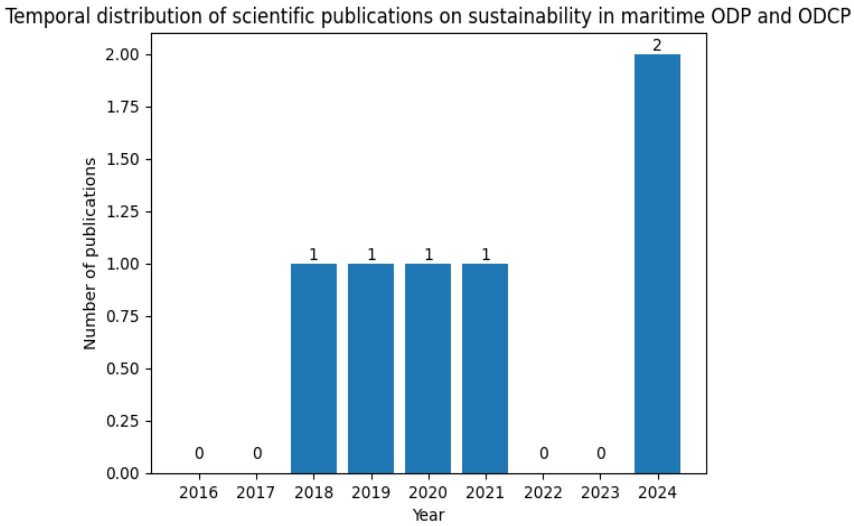


Source: Own elaboration using VOSviewer

This study also examines scientific publications that explicitly address sustainability-related aspects in the context of maritime ODP and ODCP. This analysis explores how sustainability has been conceptualized and operationalized across existing studies, with particular attention to its economic, environmental, and social dimensions.

Figure 6 presents the temporal distribution of scientific publications on sustainability on maritime ODP and ODCP. The results indicate a limited and irregular scientific production on sustainability in maritime ODP and ODCP. Research in this area only emerged after 2018, remains discontinuous over time, and shows a slight increase in 2024. Moreover, the limited number of available studies limits the ability to identify robust trends or draw definitive conclusions, highlighting sustainability as an underexplored dimension in this research domain.

Figure 6 - Temporal distribution of scientific publications on sustainability on maritime ODP and ODCP



Source: Own elaboration using VOSviewer

The distribution of scientific publications by activity areas, as shown in Figure 7, highlights the disciplinary profile of research addressing sustainability in the context of maritime ODP and ODCP. Environmental Sciences and Environmental Studies emerge as the most represented areas, accounting for most of the identified publications. This predominance reflects the strong association between sustainability concerns and environmental monitoring, impact assessment, and ecosystem management, areas in which data availability and interoperability play a central role.

Figure 7 - Categorization by activity areas that have published articles about maritime ODCP linked to the sustainability theme

Source: Own elaboration using VOSviewer

Building on the sustainability assessment model proposed by Jiang et al. (2019), which conceptualizes sustainability as a multidimensional construct comprising three main dimensions - economic, environmental, and social -this study analyzed the selected articles addressing sustainability in the context of maritime ODP and ODCP according to these three dimensions. In the absence of domain-specific evaluation frameworks tailored to maritime data platforms, the adopted approach provided a consistent and widely accepted basis for structuring the analysis.

Accordingly, each article was examined to identify its primary focus and contributions within the economic, environmental, and social dimensions of sustainability. The results of this analysis are summarized in Table 2, which evidences not only the distribution of articles across the three dimensions, but also the recurrent application domains within each pillar.

These shared application domains provide insight into prevailing research priorities and illustrate how sustainability has been operationalized in existing studies on maritime ODP and ODCP.

Table 2 - Sustainability dimensions and application domains of published maritime ODP and ODCP studies

Dimension	Application Domains	Articles
Economic	Sustainable Blue Economy development	(Kyvelou & Ierapetritis, 2019; Menegon et al., 2023; Murray et al., 2018; Spadon et al., 2024; Van Vranken et al., 2020)
	Costs reductions	(Kyvelou & Ierapetritis, 2019; Vaca-Recalde et al., 2024; Menegon et al., 2023; Murray et al., 2018; Kyvelou & Ierapetritis, 2019; Spadon et al., 2024)
	High investments needed	(Vaca-Recalde et al., 2024)
Environment	Overexploitation or degradation prevention	(Menegon et al., 2023)
	Environment risks prevention	(Menegon et al., 2023; Murray et al., 2018; Spadon et al., 2024)
	Biodiversity and habitat protection	(Menegon et al., 2023; Murray et al., 2018; Kyvelou & Ierapetritis, 2019; Spadon et al., 2024)
	Efficient use of resources	(Vaca-Recalde et al., 2024; Van Vranken et al., 2020)
	Climate impacts of changing processes	(Murray et al., 2018; Spadon et al., 2024)
Social	Stakeholder engagement	(Menegon et al., 2023; Kyvelou & Ierapetritis, 2019; Van Vranken et al., 2020; Spadon et al., 2024)
	Conflicts resolution	(Menegon et al., 2023; Kyvelou & Ierapetritis, 2019; Van Vranken et al., 2020)
	Quality of life	(Menegon et al., 2023)
	Labor impacts	(Vaca-Recalde et al., 2024; Murray et al., 2018)
	Safety and security improvements	(Vaca-Recalde et al., 2024; Spadon et al., 2024)

Source: Own elaboration

From an economic perspective, the analysed studies primarily examine efficiency gains, cost reduction, and the optimization of maritime and port operations. ODP and ODCP support data-driven decision-making, reduce duplication of effort, and improve resource allocation. Economic sustainability is also linked to innovation, competitiveness, and the development of data-enabled maritime services. The most frequently reported benefits concern lower labour costs (Vaca-Recalde et al., 2024), the avoidance of duplicated process-optimization studies (Murray et al., 2018), more efficient use of maritime resources (Kyvelou & Ierapetritis, 2019; Van Vranken et al., 2020), and reduced data-management costs (Menegon et al., 2023; Spadon et al., 2024).

Within the environmental dimension, the main application areas include environmental monitoring, risk prevention, biodiversity protection, and the efficient use of natural resources. Open and interoperable data support environmental assessment, impact analysis, regulatory compliance, and integrated environmental management. In particular, ODCP can help identify biodiversity hotspots and support the protection of natural habitats (Kyvelou & Ierapetritis, 2019; Menegon et al., 2023; Murray et al., 2018; Spadon et al., 2024). They also facilitate the centralization and standardization of data used to detect patterns, model contaminant dispersion, and assess environmental risks (Menegon et al., 2023; Murray et al., 2018; Spadon et al., 2024).

The social dimension is mainly associated with stakeholder engagement, governance, conflict resolution, safety, and quality of life. The reviewed studies emphasize the role of ODP and ODCP in promoting transparency, enabling participatory decision-making, and strengthening collaboration among stakeholders within maritime and port ecosystems.

The social dimension mainly points to the stakeholders' engagement, both as a challenge and a benefit, lightening the need to involve the community as a whole, relieving the importance of local communities (and their cultural heritage), and transboundary cooperation (Kyvelou & Ierapetritis, 2019; Menegon et al., 2023; Spadon et al., 2024; Van Vranken et al., 2020). The potential to use the data to resolve conflicts, ensure coexistence among traditional sectors, and improve fairness in resource allocation is also enhanced (Kyvelou & Ierapetritis, 2019; Menegon et al., 2023; Van Vranken et al., 2020).

Overall, the table illustrates that sustainability-oriented research on maritime ODP and ODCP tends to associate each sustainability dimension with specific application domains, reinforcing the need for integrated approaches that address economic, environmental, and social objectives in a coordinated manner.

4.2. OPEN DATA AVAILABILITY IN THE TOP 50 CONTAINER PORTS

Following the literature review and bibliometric analyses, this subsection presents the results of a systematic assessment of open data availability among the world's leading container ports. The analysis focused on the ports included in the worldwide Top 50 Container Ports list, published by the World Shipping Council (2024). The objective was to map the current state of ODP and ODCP adoption at the port level.

For each port, the assessment followed a two-step procedure. In a first step, the official port authority website was examined directly to identify any linked or embedded open data platform. In cases where no platform was immediately visible, a second check was performed through standardized web searches combining the port name with terms such as "open data", "data portal", and "data platform", as well as a review of relevant governmental or regulatory portals associated with the port's national or regional jurisdiction.

The results (Table 3) reveal that open data provision is far from universal among the world's major container ports. Of the 50 ports analysed, 28 - corresponding to 56% of the total - were found to have some form of open data available for access or sharing. The remaining 22 ports had no identifiable platform: 18 had no platform, or none that was visible and easy to find through the procedures described above, while 4 did not have a direct, dedicated website for the port authority itself and instead provided only static information, such as sustainability reports or news. Table 3 provides a full overview of the 50 ports analysed and their corresponding data availability status.

These findings suggest that, despite the growing relevance of data-driven approaches in the maritime sector, the systematic provision of open data at the individual port level remains limited. The absence of platforms in a significant share of the Top 50 ports, which represent some of the most resource-intensive and strategically significant nodes in global supply chains, underscores a clear implementation gap between the recognized potential of ODP and ODCP and their actual deployment in port environments.

Table 3 - Open Data Availability in the Top 50 Container Ports

Port Identification	ODP/ODCP Status
Shangai, China	Not available
Singapore, Singapore	Available
Ningbo -Zhoushan, China	Not available
Shenzhen, China	Available
Guangzhou Harbor, China	Available
Busan, South Korea	Available
Qingdao, China	Available
Hong Kong, China	Available
Tianjin, China	Available
Rotterdam, The Netherlands	Available
Jebel Ali, Dubai, UAE	Available
Port Klang, Malaysia	Available
Xiamen, China	Available
Antwerp, Belgium	Available
Kaohsiung, Taiwan, China	Available
Dalian, China	Not available
Los Angeles, USA	Available
Hamburg, Germany	Available
Tanjung Pelepas, Malaysia	Not ODP, only static information
Laem Chabang, Thailand	Available but not at the port site
Keihin Ports, Japan	Not ODP, only static information
Long Beach, USA	Available
Tanjung Priok, Indonesia	Not available
New York-New Jersey, USA	Available
Colombo, Sri Lanka	Available
Ho Chi Minh City, Vietnam	Available
Suzhou, China	Not available
Piraeus, Greece	Not available
Yingkou, China	Available
Valencia, Spain	Not available
Manila, Philippines	Not available
Taicang, China	Not available
Hai Phong, Vietnam	Not available
Algeciras, Spain	Available
Jawarharlal Nehru Port (Nhava Sheva), India	Available
Bremen/Bremerhaven, Germany	Available
Tanger Med, Morocco	Available but not at the port site
Lianyungang, China	Not available
Mundra, India	Not available
Savannah, U.S.A	Available
Tokyo, Japan	Not available
Rizhao, China	Not available
Colon, Panama	Available
Santos, Brazil	Available
Salalah, Oman	Available
Dongguan, China	Not available
Guangxi Beibu, China	Not available
Cai Mep, Vietnam	Not available
Yingkou Bayuquan, China	Not available
Port Said, Egypt	Available

Source: Own elaboration

4.3. REFERENCE PLATFORMS FOR MARITIME ODP/ODCP

Complementing the port-level assessment, this subsection examines maritime-relevant ODP and ODCP operating at the sector level. Rather than focusing on platforms formally associated with individual port authorities, the analysis identifies platforms supporting maritime operations, research, and governance across the wider data ecosystem.

A total of 39 platforms were assessed. These included sector-specific solutions for maritime and port activities, such as NXTPort, EMSA, Sea Traffic Management–PortCDM, and MarineTraffic; multi-domain platforms used by maritime stakeholders, including Eurostat, OECD iLibrary, and Esri; and thematic platforms focused on ocean observation, environmental monitoring, and transport policy, such as EMODnet, the World Ocean Database, and the ITF. This broader ecosystem approach follows Ali et al. (2022b), who emphasize that open data ecosystems in complex sectors include both dedicated and cross-sectoral platforms.

Each platform was evaluated according to its thematic focus, supported data types and formats, access conditions, collaborative functions, sustainability features, and web performance. Table 4 summarizes their main objectives, functionalities, and application areas.

The findings show that most platforms prioritize data provision and information access, particularly in maritime monitoring, safety, environmental observation, and transport performance. Environmental and oceanographic data are especially prominent, reflecting the importance of these platforms for ecosystem monitoring, environmental assessment, and regulatory compliance. By contrast, fewer platforms support operational coordination, logistics integration, or multi-stakeholder decision-making.

Collaborative functions are also unevenly developed. Although some platforms enable user interaction, data sharing, and integration with external systems, many remain focused on one-way data publication. This suggests that collaboration, despite its prominence in policy and conceptual discussions, has not yet become a central design feature of many maritime platforms.

Overall, existing maritime ODP and ODCP remain fragmented and specialized, with strong capabilities in data provision and environmental monitoring but limited support for integrated collaboration and cross-domain decision-making. These findings, together with the bibliometric and port-level results, informed the framework presented in the following subsection.

Table 4 - Maritime-related platforms focus

39 Maritime-Related Platforms	Focus or Topic
Blue Cloud	Maritime Open Platform
European Marine Observation and Data Network (EMODnet)	Maritime Data Provider
Admiralty	Marine Geospatial Data
NXTPort	Smart Data Sharing Platform
ESRI	Geospatial Data
UN Sustainable Development Goal 14	Maritime Sustainability
UNCTAD	Maritime Transport Data
Eurostat	Generic Statistical Data
U.S. Bureau of Transportation Statistics (BTS)	Governmental
Lloyd's List Intelligence	Maritime Services
Digital Transport and Logistics Observatory (DTLO)	Transport Digitalization
European Maritime Safety Agency (EMSA)	Service/Assistance Provider
World Bank Port Performance Indicators	Consulting and Reporting
Electronic Quality Shipping Information System (EQUASIS)	Maritime Safety Promotion
Global Container Database (GCO)	Container Technical Information
Greenhouse Gas Emissions from Shipping (IMO GHG Data)	Maritime Transport Regulation
World Maritime University Port Database (WMU Port Database)	Education

39 Maritime-Related Platforms	Focus or Topic
International Transport Forum (ITF)	Transport Policy Think Tank
OECDilibrary	Generic Statistical Data
EuroOcean	Ocean Promotion (ONG)
European MSP Platform	Maritime Spatial Planning
CoastObs	Maritime Data Provider
Collaborative Land-Sea Integration Platform (Coastal)	Rural-Coastal Development
EuroGOOS	Marine Data and Standards
JERICOri	Maritime Data Provider
EuroSea	Ocean Research
International Association of Ports and Harbors (IAPH)	Global Trade Association
Sea Traffic Management – PortCOM	Real-Time Maritime Data
European Commission's Port Services Regulation Database	Legal and Regulation
International Tanker Owners Pollution Federation	Maritime Technical Assistance
European Short Sea Shipping Information System (ESSSIS)	Shortsea Shipping Information
European Maritime Transport Environmental Report (EMTER)	Environmental Report
Marine Traffic	Ship Tracking
Vessel Finder	Ship Tracking
World Ocean Database (WOD)	Ocean Open Data
National Data Buoy Center (NDBC)	Meteo/Ocean Open Data
openAQ	Air Quality Open Data
Saildrone Data Explorer	Real-Time Ocean Information
Integrated Marine Observing System (IMOS Data Portal)	Australia Ocean Data

Source: Own elaboration

Considering the literature previously reviewed and based on the analysis of port websites and collaborative and open data platforms, it was concluded that the most relevant features or functions of these solutions are as follows:

- Community Engagement and Collaboration: Features like discussion forums, user feedback mechanisms, and collaborative data curation tools, such as version control systems and annotation features, enable users to collaborate directly on datasets.
- User Authentication and Authorization: Secure authentication and authorization mechanisms control access to sensitive or restricted datasets. Authentication should be integrated with partner platforms to enable seamless collaboration among organizations and stakeholders.
- Data Licensing and Usage Policies: Clear licensing and usage policies define how the data can be accessed, used, and shared, leaving no room for ambiguity.
- Governance and Sustainability: Establishing clear governance structures and sustainability plans ensures the platform's long-term viability.
- Documentation and Support: Comprehensive documentation and support services help users navigate the platform. Every interaction on the platform should be thoroughly documented. User support services enable quick responses and stakeholder satisfaction, improving the quality of the experience.

4.4. MARITIME OPEN DATA COLLABORATIVE PLATFORMS FEATURES FRAMEWORK

The main findings of this study were synthesized to identify and consolidate a comprehensive set of essential features for maritime open data and collaborative platforms. This synthesis draws on three complementary sources of evidence: (1) the systematic literature review and bibliometric analysis reported in Section 4.1, which identified the dominant research themes, sustainability dimensions, and knowledge gaps in existing scholarship; (2) the port-level availability assessment reported in Section 4.2, which revealed the current state of ODP and ODCP deployment among the world's major container ports; and (3) the inventory and characterisation of 39 maritime-relevant reference platforms reported in Section 4.3, which provided a broad empirical basis for identifying the features and functionalities most consistently present or absent in existing solutions. By integrating these complementary perspectives, the analysis moves beyond isolated observations to provide a structured understanding of the key characteristics underpinning effective ODP and ODCP in the maritime context.

Based on this integrated analysis, the results were formalized into a structured framework (Table 5) that organizes the identified features into coherent dimensions. The proposed framework is intended to serve both as an evaluation instrument and as a practical design guide. On the one hand, it can serve as a checklist to assess and compare existing maritime platforms; on the other hand, it offers guidance to developers, port authorities, and decision-makers for the design and implementation of new ODP and ODCP, with particular attention to sustainability, interoperability, and long-term viability.

Table 5 - Framework to maritime Open Data and Collaborative Platforms (ODCP)

<table>
<tr><td colspan="3">Key Features / Properties</td></tr>
<tr><td rowspan="14">Data Properties</td><td rowspan="4">Periodicity</td><td>Annual</td></tr>
<tr><td>Monthly</td></tr>
<tr><td>Real-Time (RT)</td></tr>
<tr><td>Near RT</td></tr>
<tr><td rowspan="10">Data Formats</td><td>CSV</td></tr>
<tr><td>JSON</td></tr>
<tr><td>XML/XMLS</td></tr>
<tr><td>Databases</td></tr>
<tr><td>PDF</td></tr>
<tr><td>Images (jpeg, png, tiff, svg, ...)</td></tr>
<tr><td>Audio (wav, mp3, flac, ...)</td></tr>
<tr><td>Video (mp4, avi, av1, ...)</td></tr>
<tr><td>GIS</td></tr>
<tr><td>Others (specify)</td></tr>
<tr><td rowspan="8">Access and Management</td><td rowspan="2">API</td><td>API Access</td></tr>
<tr><td>Documentation</td></tr>
<tr><td rowspan="4">Deployment</td><td>Desktop App</td></tr>
<tr><td>Android</td></tr>
<tr><td>iOS</td></tr>
<tr><td>Browser</td></tr>
<tr><td rowspan="2">Integration</td><td>Devices</td></tr>
<tr><td>Platforms</td></tr>
</table>

Key Features / Properties		
Security and Compliance	Open data standard compliance	Government Entities
		Researchers and Developers
		None
	Authentication	No login / Open
		Single Sign-on (SSO)
		Multifactor Auth (MFA)
		Third-party Auth. (Google/JUL)
Features and Functionalities	Search/ Searchability	Search
		Categories & Sorting
		Onsite
	Data Visualization Tools	Offsite
		Third-party
		File Upload
	Data Insertion Tools	API
		Database
	Data Linkage	Linking with other platforms
Costs and Pricing	Free Access	Free Access / Open Data
	Licensing	Clear license terms
	Subscription Fees	Subscription
		Service Levels / User Types
	Purchasing	Pay per Item / Shop Cart
		Pay per Service / Feature
		Pay per API calls
	Custom	Pricing under consultation
Sustainability	Environmental management	Certifications, Terms of Service
		Environmental Compliance (regulations)
	Infrastructure and Hosting	Sustainable Cloud Providers
		Energy-Efficient Hardware
		Data Center Cooling Technologies
	Sustainable Data Practice	Data minimization strategies
		KPI for energy consumption (transaction/ query)
UI/UX Evolution	Changes over time	Interface
		Functionality
		Others (*specify*)
Community and Support	Documentation	Guides, tutorials, API docs
	Community Support	Forums, user groups, etc.
	Professional Support	Professional support services

Key Features / Properties		
Port–City Interface & Urban Mobility Integration	Multimodal Connectivity	Land-side transport data (road, rail, inland waterways)
		Intermodal transfer point data
	Operational Data Sharing	Operational data (vessel movement, gate transaction, cargo flow)
		API-compatible with urban transport systems
	Spatial & Coastal Planning Support	Port boundary and land use data
		Coastal zone geospatial data
		Maritime Spatial Planning (MSP) tools
		Multi-layer GIS analytical tools
	Regulatory Compliance Support	MSP directive compliance documentation
		Integrated coastal management reporting
	Multi-stakeholder Accessibility	Maritime sector users
		Transport agencies and local authorities
		Urban planners and researchers
		Civic/public access (non-discriminatory)
	Environmental Monitoring	Environmental data (port emissions, noise level, water quality)
		Biodiversity and habitat indicators
5-star model	Assessment of the level of openness and accessibility of data on the Web	
PageSpeed Insights	Assessment of the digital accessibility of the platform interface	

Source: Own elaboration

When analyzing Maritime ODP, various criteria were considered to assess its effectiveness and suitability. These criteria encompass different aspects of the platform's functionality, accessibility, security, and support. Key criteria considered in the assessment include:

- Data Properties: The types and formats available on the platform were evaluated, including whether it provides periodic data updates, such as annual or monthly reports, and whether the data is available in real-time or near real-time. Additionally, various supported data formats were considered, including CSV, JSON, XML, databases, images, audio, video, GIS data.
- Access & Management: Checking how users can access and manage the data, including the availability of API and documentation for developers, as well as the deployment and integration options such as desktop applications, mobile apps for Android and iOS, or browser-based access.
- Security and Compliance: Verifying the platform's adherence to open data standards and compliance with relevant regulations. Authentication methods, including single sign-on, multi-factor authentication, and third-party authentication, are also considered to ensure data security and user privacy.
- Features and Functionalities: Investigate the platform's search capabilities, data visualization tools, data insertion tools, data linkage with other platforms, and data evaluation tools to assess its usability and effectiveness in handling and presenting data.
- Costs and Pricing: Analysing the platform's pricing model, including options for free access, licensing terms, subscription fees, and purchasing options such as pay-per-item or pay-per-service (Parker & Van Alstyne, 2018).

- Sustainability: Verify specific dimensions that address each platform's environmental impact to evaluate its commitment to this theme. Information in this regard can come from certifications such as ISO, membership in sustainability organisations, transparency about how data is stored and managed, the type and amount of energy spent on these processes, or the commitment of the various suppliers.
- UI/UX Evolution: using an Internet Archive tool named Wayback Machine (Internet Archive, 2001), track changes in the platform's user interface and user experience over time to evaluate its evolution and responsiveness to user feedback and technological advancements.
- Community and Support: Considering the availability of documentation such as guides, tutorials, and API documentation, as well as the level of community support through forums and user groups. Professional support services are also considered to assess the platform's overall support infrastructure.
- Port–City Interface & Urban Mobility Integration: Assessing the extent to which the platform supports data sharing and coordination at the interface between port operations and urban mobility systems. As ports function as critical nodes in urban and interurban transport networks, their operational data have direct implications for congestion, emissions, land use, and multimodal transport integration in surrounding areas (Vaca-Recalde et al., 2024). This criterion evaluates whether the platform provides land-side transport data - covering road, rail, and inland waterways - and data on intermodal transfer points to enable coordination between maritime and urban transport flows (Vaca-Recalde et al., 2024). It also examines whether operational data such as vessel movements, gate transactions, and cargo flows are available, and whether the platform offers API-compatible outputs suitable for integration with external urban transport management systems (Vítor et al., 2022). The spatial and regulatory dimensions are assessed through the availability of geospatial data on port boundaries, coastal zones, and land use, as well as tools supporting Maritime Spatial Planning and compliance with integrated coastal management frameworks (Menegon et al., 2023). Finally, the criterion considers the platform's accessibility to a diverse range of stakeholders beyond the maritime sector - including transport agencies, urban planners, researchers, and the general public - following the open data design principles of completeness, accessibility, non-discrimination, and non-proprietary access (Millette & Hosein, 2016), as well as the availability of environmental monitoring data relevant to the port–city interface, including emissions, noise, water quality, and biodiversity indicators (Menegon et al., 2023; Vaca-Recalde et al., 2024).
- 5-star model: This criterion aims to analyse the five classification levels for the available data on a web platform based on the 5-Star Model for ODP (Tim Berners-Lee, 2010). This is a framework developed by Tim Berners-Lee, the inventor of the World Wide Web, to assess the level of openness and accessibility of data on the Web. The model aims to encourage organizations to make data available in a way that maximizes its potential for re-use and interoperability and consists of five progressively more open levels, or "stars," each representing a higher degree of openness and usability.
- Performance: To standardize the evaluation of each ODP's digital accessibility and web performance - understood as the technical quality and responsiveness of the platform's web interface - a Google tool called PageSpeed Insights was used (Google, 2010). PageSpeed Insights is a widely adopted web performance analysis tool that evaluates the loading speed, responsiveness, and quality of the user experience of web pages, returning a standardized score on a scale from 0 to 100, where higher values indicate better performance. It should be noted that this metric captures the

digital accessibility of the platform interface and is not intended to measure maritime operational performance or logistics efficiency.

Several limitations of this study should be acknowledged to properly contextualize the findings and inform their interpretation. First, the port-level analysis is restricted to the 50 ports included in the WSC Top 50 Container Ports ranking, which, while representative of the world's largest container traffic volumes, does not capture the full diversity of smaller, regional, or specialized port contexts. The findings regarding ODP and ODCP availability may therefore not be generalized beyond the major container port segment.

Second, the platform assessment relied exclusively on publicly visible and accessible information, without access to internal platform documentation, usage statistics, backend functionalities, or organizational data. Platforms that restrict access to registered or institutional users may have been partially assessed or classified as less functional than they are in practice.

Third, the study does not incorporate end-user perspectives. The assessment of platform characteristics reflects the research team's structured observation rather than the experience, perceptions, or reported satisfaction of port operators, logistics professionals, urban planners, or other platform users. User-side evaluations would likely reveal adoption barriers and usability gaps that the present methodology does not capture.

Fourth, although the platform assessment covered multiple dimensions - including data properties, access, security, functionalities, costs, sustainability features, and web performance - the per-platform results of this assessment are not individually reported in this article. The analysis informed the framework's development but was not presented as a comparative matrix, limiting the reader's ability to verify or replicate the evaluation for individual platforms.

Fifth, the sustainability-focused bibliometric subset comprised only six peer-reviewed scientific articles, which constrains the robustness of trend analyses in that dimension and reflects the early-stage nature of sustainability-oriented research in the maritime ODP and ODCP domain rather than a limitation of the search procedure.

Finally, the study adopts an exploratory and descriptive research design. While this approach is appropriate for mapping an emerging and fragmented field, it does not allow for the establishment of causal relationships between platform characteristics and sustainability or operational outcomes.

5. CONCLUSION

This study examined the role of ODP and ODCP in the maritime port sector, with particular emphasis on their contribution to sustainability. By combining a bibliometric analysis with an empirical assessment of existing platforms, the research provides an integrated overview of how open data and collaborative approaches are currently being applied in maritime contexts and how they support economic, environmental, and social objectives.

The results demonstrate that, although ODCP holds significant transformative potential, its current level of implementation and maturity varies considerably across platforms. Most of the analysed solutions remain primarily focused on data provision and operate at a relatively low level of openness and integration, limiting their ability to fully exploit the potential of open data. This fragmentation reinforces the need for structured and standardized approaches, such as the framework proposed in this study, to support both the evaluation and the design of maritime ODP and ODCP.

From a sustainability perspective, the findings confirm that ODCP can contribute meaningfully across the three pillars. Economically, these platforms support cost reductions and operational efficiency by improving data accessibility and reducing duplicate work. Environmentally, data centralization and standardization facilitate resource optimization, environmental monitoring, and biodiversity protection. Socially, ODCP enhances stakeholders' engagement, transparency, and fairness in decision-making processes, particularly in complex port ecosystems involving multiple actors.

Importantly, these contributions extend beyond the port perimeter and are directly connected to broader challenges of sustainable urban mobility. As critical nodes in urban and interurban transport networks, ports influence traffic flows, congestion patterns, emissions, land use, and interactions between maritime and land-based transport modes. In this context, ODCP can support better coordination between port operations and urban mobility systems, enabling more integrated planning, improved intermodal connections, and data-driven strategies to mitigate the negative externalities of freight transport in urban areas.

Several challenges remain. The lack of harmonized data standards, limited integration capabilities, and low levels of user literacy continue to hinder the effective adoption and widespread diffusion of ODCP. In addition, the bibliometric analysis revealed that sustainability-oriented research in the context of maritime ODCP remains limited and discontinuous, highlighting clear opportunities for further investigation.

Several directions for future research emerge from this study. Building on the framework proposed here, future work could apply the evaluation criteria to generate individual platform assessments and present the results in structured comparative form — a matrix or scoring table that would allow direct comparison across the 39 platforms analysed and beyond. This would transform the present exploratory study into a replicable benchmarking instrument. The framework itself could also be validated and refined through expert consensus methodologies, such as the Delphi method, or through empirical application in smart port case studies, testing whether the proposed dimensions and criteria reflect the priorities of maritime practitioners and platform developers (Vaca-Recalde et al., 2024; Vítor et al., 2022).

A second line of future inquiry concerns the integration of operational key performance indicators. Extending the comparative analysis to incorporate metrics such as vessel turnaround time, fuel consumption per TEU, idle time, cargo loss rates, or emissions in port areas would allow researchers to evaluate how effectively platforms translate data availability into measurable sustainability and operational gains. The use of established sector indices - such as the World Bank Logistics Performance Index or the UNCTAD Liner Shipping Connectivity Index - as contextual benchmarks for assessing port-level platform performance would also strengthen the analytical rigor of future comparative studies (Vaca-Recalde et al., 2024).

A third direction concerns the port–city interface and sustainable urban mobility dimension, introduced in Section 2.5 and incorporated into the framework proposed in Section 4.4. Future research should empirically test this dimension by examining whether and how existing platforms provide data relevant to urban transport management, multimodal planning, and port–city governance, and by engaging municipal authorities and urban planners as user communities alongside maritime stakeholders (Menegon et al., 2023; Millette & Hosein, 2016; Vítor et al., 2022).

Finally, future studies could explore the business models, governance arrangements, and long-term funding structures that underpin successful maritime ODP and ODCP, and examine how platform design choices affect user adoption, data quality, and sustained engagement across diverse stakeholder communities. Longitudinal studies tracking platform evolution over time - for instance, through repeated application of the Wayback Machine methodology used here (Internet Archive, 2001) - would provide valuable insights into the lifecycle dynamics of maritime open data ecosystems.

Realizing the full potential of ODP and ODCP requires coordinated effort across policymakers, port authorities, urban planners, industry, researchers, and local communities. By fostering collaboration and shared understanding across these domains, the maritime and urban mobility sectors can enhance resilience, support sustainable development, and respond more effectively to the challenges posed by increasingly interconnected transport systems.

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Conflicts of Interest

The authors declare no conflicts of interest. The funders had no role in the study's design; in the collection, analyses, or interpretation of data; in the writing of the manu-script; or in the decision to publish the results.

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