Frontiers in Marine Science

TYPE Original Research
PUBLISHED 15 March 2023
DOI 10.3389/fmars.2023.1052128

Check for updates

OPEN ACCESS

EDITED BY
Ifesinachi Okafor-Yarwood,
University of St Andrews, United Kingdom

REVIEWED BY
Reza Karimpour,
University of Genoa, Italy
Eric Tamatey Lawer,
University of Ghana, Ghana

*CORRESPONDENCE
Dinah A. E. Ogara
d202013@edu.kaiyodai.ac.jp;
didi.adjoa@gmail.com

SPECIALTY SECTION
This article was submitted to Marine Conservation and Sustainability, a section of the journal Frontiers in Marine Science

RECEIVED 23 September 2022
ACCEPTED 10 February 2023
PUBLISHED 15 March 2023

CITATION
Ogara DAE, Morishita J, Davies PJ, Mbui M, Gamoyo M, Njoroge N, Chann IO, Igesa BS and Ochieng SO (2023) An indicator-based approach to assess sustainability of port-cities and marine management in the Global South.
Front. Mar. Sci. 10:1052128.
doi: 10.3389/fmars.2023.1052128

An indicator-based approach to assess sustainability of port-cities and marine management in the Global South

Dinah A. E. Ogara[1,2*], Joji Morishita[1], Peter J. Davies[3], Maina Mbui[4], Majambo Gamoyo[5], Nashon Njoroge[6], Isaac Otieno Chann[7], Benson Senelwa Igesa[8] and Stephen Odhiambo Ochieng[9]

[1]Department of Marine Policy and Culture, International Ocean Policy, Tokyo University of Marine Science and Technology, Tokyo, Japan, [2]Department of Spatial Planning and Design, The Technical University of Kenya, Nairobi, Kenya, [3]School of Natural Sciences, Faculty of Science and Engineering, Macquarie University, Sydney, NSW, Australia, [4]School of Natural Sciences, Faculty of Spatial Information Science, Macquarie University, Sydney, NSW, Australia, [5]Private Sector Development Department, Coastal and Marine Resource Development (COMRED), Mombasa, Kenya, [6]Center for Urban Studies, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya, [7]Institute of Mathematical Science, Faculty of Mathematics, Strathmore University, Nairobi, Kenya, [8]Kenya Institute of Public Policy Research and Analysis (KIPPRA), Nairobi, Kenya, [9]Department of Geomatic Engineering and Geospatial Information Systems (GEGIS), Jomo Kenyatta University of Science and Technology, Nairobi, Kenya

Ports and neighbouring cities function as connectors between land and water and have long accommodated a substantial flow of goods and services. Port cities in the Western Indian Ocean (WIO) region and the Global South (GS) are rapidly and inevitably expanding as the demand for global trade increases. However, this expansion has numerous impacts on the surrounding marine ecosystem and the socio-economic livelihoods of local communities. We propose a framework to evaluate the sustainability of port cities in the WIO region and more broadly for cities in the GS. Through an exploratory approach, a systematic literature review (SLR) was undertaken to identify existing themes on port city and marine ecosystem sustainability indicator frameworks. The results revealed a strong bias towards sustainability publications designed for port cities in Global North. The approach developed from this study focuses on the socio-economic and environmental attributes relevant to ports in the WIO region and for GS countries. This draws from the Drivers, Pressures, States, Impacts and Responses (DPSIR) framework and includes 78 indicators. The indicators are designed to identify and report on the complex land and sea interdependencies of port cities. To test the validity of these indicators their interdependencies were examined through a Causal Network (CN) structure which identified 12 priority DPSIR CN. These were also mapped to the UNSDGs enabling the wider applicability and transferability of the framework. The resulting framework enables port cities in emerging economies to establish robust sustainable reporting systems and provides a framework that offers a unique lens for evaluating interactions embedded in the land and sea continuum.

KEYWORDS
sustainability, Global South, marine ecosystems, land-sea continuum, port cities, Western Indian Ocean

1 Introduction

Currently, almost 80 percent of the world's trade is seaborne (Zheng et al., 2020). Port cities receive essential goods, and oceans provide the crucial ecosystem service of transport routes (Costanza, 1999; Haase, 2015; Wang et al., 2021). Globally, the ocean economy has been recognized as a critical driver of economic development. Oceans and coasts are considered development areas that can generate wealth and support human well-being by incorporating social, economic, and environmental benefits to achieve sustainable development (Okafor-Yarwood et al., 2020). Traditionally, ports have been considered the main drivers of economic development and employment in cities. Ports include logistic nodes for sustainable transitions and to enable a circular economy (Ernst et al., 2016) whose development and operations are key drivers of local economic growth within the host city (Shan et al., 2014). Furthermore, ports are an essential impetus for the development of surrounding cities (Liu J. et al., 2019). They promote port city prosperity by generating employment (Merk and Dang, 2013). The port facilitates import and export trade, and the city relies on industry and tourism (Couling and Hein, 2020). Port cities serve as maritime hubs, where the port acts as a junction point between land and sea transport networks (Jacobs et al., 2010; Hein, 2021). Moreover, the port city interface is an expression of the wider land-sea interrelationship, as it operates within coastal zones characterized by intense and complex interactions (Hoyle, 1989; Crossland et al., 2005). This land sea interface is a porous space dedicated to a mix of port and city functions (Couling and Hein, 2020; Moretti, 2021a).

The port city is comprised of closely intertwined entities that are mutually independent and influential (Zheng et al., 2020). A port city's function and configuration consist of two systems operating in a shared space that serves two purposes: 1) a port system is characterized by logistics, imports, exports, and mega-infrastructure projects driven by technology, efficiency, and competition; 2) its relationship with the city is characterized by social, ecological, and economic heterogeneity, that enables urban and regional infrastructure. Furthermore, the development of infrastructure and intensified spatial transformations such as land reclamation and extensions of port infrastructure, adds to the complexity of the "port-cityscape" (Couling and Hein, 2020) or "port city threshold" (Moretti, 2021a). This mutually independent focus results in port-related spaces becoming more urban and the city's urban complexes becoming more marine (Couling and Hein, 2020).

Africa's sea trade and seaport expansion have consistently grown resulting in an increase in port capacity and efficiency (Gidado, 2015; Olukoju, 2020). This has been aided through implementing global maritime technical advancements, attaining transportation efficiency, attracting international investment, and increasing global trade revenue streams. Simultaneously, there is an increasing demand for port cities to become more sustainable, while concurrently governments continue to invest in seaports that serve as maritime gateways, strategic economic points, and infrastructure nodes for their countries and regions. Unlike that in developed nations, in developing countries, and regions within Africa's Western Indian Ocean (WIO) remain challenged in terms adopting and implementing technological enhancements to improve productivity and sustainability (Hoyle, 2000; Gekara and Nguyen, 2020; Olukoju, 2020). Such practices serve as key friction points that pit economic outcomes against an emergence of greater environmental awareness and social pressures. The spectra of economic, social, cultural, and environmental challenges presented by port cities vary and often reflect their development trajectory that explain their degree of intimacy in functions over time (Couling and Hein, 2020; Lacalle et al., 2020; Hein, 2021; Moretti, 2021b) and the significant capital required to transition towards more sustainable practices.

Port and city systems have been studied in recent decades as dissociated entities (Hoyle, 1989; Hesse, 2018). Conventional port impact studies have two main shortcomings. First, they position port interactions as static entities that focus only on port impacts, ignoring the future effects of port development, changes in port operations (e.g., automation), and uncertainties (e.g., climate change impacts) influencing the port city system. Secondly, they overestimate the benefits of ports and their immediate social, economic, and environmental effects, while underestimating their negative impacts (Musso et al., 2011; Halpern et al., 2012; van den Houten, 2017; Couling and Hein, 2020).

More recently, the use of indicator-based approaches to assess and report on sustainability has emerged including frameworks for port cities. These methods are well-established and widely employed (Xiao and Lam, 2017; Lam and Yap, 2019). Common across many port city sustainability reporting approaches are Driving force-State-Response (DSR) and Pressure-State-Response (PSR) sustainability frameworks. In addition, the systems analytical framework (SAF) focuses on the port-city relationship. SAF is based on an integrated assessment of the port and city subsystems for a more holistic approach (Bossel 1997; Lundin 2003). The newer thematic-based frameworks incorporate indicators based on three main categories: economic, social, and environmental (Xiao and Lam, 2017). Such approaches align with globally recognized sustainability reporting tools including the CSD United Nations Commission of Sustainability Development (2007), Global Reporting Initiative (GRI) (2011) and Warhurst (2002). Moreover, according to Xiao and Lam (2017) and Lam and Yap, (2019), the utility of higher level sustainability reporting frameworks for assessing national and regional sustainability progress, is demonstrated by existing sustainability studies such as GRI, Millennium Development Goals (MDG) indicators (Global Reporting Initiative (GRI), 2011), Sustainable Development Goals (SDGs) (CSD United Nations Commission of Sustainability Development (2007)) and the OECD Key Environmental Indicators (OECD, 2004).

For marine and coastal sustainability, the DEDUCE project[1] by the European Union (Martí et al., 2007), uses indicators to measure sustainable coastal development from social, economic, and environmental perspectives. In the WIO region, the climate and ocean risk vulnerability index (CORVI)[2] measures ecological, financial, and political risks across 10 categories and 96 indicators to elucidate the climate risks and vulnerability issues that WIO region coastal cities face. These approaches reveal how indicators can drive actions to communicate and support more sustainable practices (Lundin, 2003). Therefore, in this study, we adopted a blended mix of the SAF approach as applied by Xiao and Lam (2017) in consideration of the SDGs, GRI, OECD, DEDUCE, and CORVI approaches for a port city framework centered on coastal and marine sustainability.

Customized indicator-based multidimensional port-city sustainability studies are well-established in developed countries (Bell and Morse, 2018). Research by Wang and Zhao (2016); Schipper et al. (2017); Xiao and Lam (2017), and Zheng et al. (2020) have been applied to specifically assess the sustainability of port cities in developed countries. Owing to the uniqueness of the port and city issues in the Global South[3], the knowledge from the Global North (GN) might not be extensively and widely transferable to Global South regions, despite its prevalent applicability. Sustainable development policies of the Global South often mirror those of the Global North (Zheng et al., 2020). Global South sustainability indicators have a myriad of varied territorial, historical, environmental, socioeconomic, sociocultural, and geographic settings (Leimgruber, 2018) that differ from their more wealthy and developed counterparts. Yet, critical scholarship assessing GS and Africa's port city and marine environment sustainability is still sparse. In addition, a majority of existing port city and port hinterland studies do not consider the land-sea continuum (Ducruet and Berli, 2018).

Port city development in the WIO region, Africa and the GS is an ongoing spatial and temporal process that impacts spatial, social, economic, and ecological dimensions. Large-scale infrastructure projects, such as port expansion for operational efficiency and competitive positioning (Hoyle, 2000) in port cities like Durban, South Africa (Foulds, 2015; Naicker and Allopi, 2015; Mpungose and Maharaj, 2022) and Mombasa, Kenya (Hoyle, 1999) are on the increase and will continue to do so. However, such plans have significant impact on the spatial configuration, socioeconomic development, and marine ecosystems of nearby cities. These impacts include rapid urbanization, and the proliferation of urban settlements, resulting in unplanned urban sprawl (Owei et al., 2010) as populations migrate to cities seeking employment and improved living conditions. This can have negative environmental effects on the host city and community, such as their impacts on land, coastal, marine and atmospheric pollution (Hiranandani, 2014; Hein, 2021; Hossain et al., 2021), making port and city sustainability studies imperative.

Based on this background, this study proposes an indicator-based approach that can identify a combination of relevant port city sustainability and marine management practice indicators in the WIO region and the GS. We aim to contribute to the literature on sustainable port and city indicator frameworks that exist but are currently limited (Hossain et al., 2021), especially in the WIO region and the GS. We argue that current sustainable 'port city development theories' are predominantly based on the GN perspectives, yet the GN and GS vary geographically and contextually. Limitations of adopting indices from the Global North to the Global South exist, given their differing ecological, political, and technological factors. Moreover, there is a paucity of research seeking to reveal the extent to which the port city's social, economic, and ecological aspects impact both its surrounding land and sea, in the WIO region of Africa, and within the Global South countries. The knowledge gap regarding differences in contexts and drivers in different regions of the Global South constitutes a major challenge for sustainable port city development (Morel et al., 2013; Lam and Yap, 2019) which underpins this paper.

2 Concept of sustainability

2.1 The concept of sustainable development

Sustainability is regarded as the concept that looks at the ability of the current generation being able to utilize resources to meet their needs whilst not compromising the ability of future generations to meet their needs as adopted from the Brundtland Report of 1987. It emphasizes the social, economic, and environmental aspects of development into a combined trilogy of desired outcomes. Thus, port cities must have a well-defined method of ensuring their sustainability is promoted and upheld. Concerning ports, the International Maritime Organization (IMO) has developed a series of conventions and protocols that regulate the operations of maritime vessels in the marine ecosystem.

The United Nations (UN) has played an essential role, working to help many countries to improve their situation and conquer the current and future challenges to sustainable development. In September 2015, the UN introduced a forward-looking approach: the Sustainable Development Goals (SDGs), to meet the increasingly serious opportunities and challenges in the field of global sustainable development (Raszkowski and Bartniczak, 2019). The SDGs establish three aspects of framework arrangements: global economic growth, social equity, and ecological protection with a set of 17 goals, 169 targets and 244 indicators to be achieved by 2030. Overall, the SDGs are intended to be universal with a shared common vision of progressing toward a safe, just, and sustainable operating space for human societies (Mair et al.,

1 DEDUCE meaning in full Développement Durable Des Zones Côtières Européennes.

2 Stuart. J, Yozell.S and Rouleau.T (2020). The Climate and Ocean Risk Vulnerability Index; Prioritizing areas of action for coastal cities

3 Global South- Broadly refers to a group of countries in regions of Latin America, developing parts of Asia, Africa and Oceania considered to be third world and low income (Dados and Connell, 2012). In this paper Global South refers to developing countries especially in the WIO region.

2018). Many studies that evaluate port and cityscape sustainable development, consider several sources on SDGs, mainly Goals 9,11,12, 14 and 15 (Verhoeven et al., 2020). Port cities play a key role in sustainability because they are not only centers of economic activity but also important hubs of the transportation network. Sustainable relations between ships and ports are an emerging development in discussions on port city sustainability. For port cities to be sustainable, ports must be sustainable. It is anomalous that processes for port sustainability are independent of their surrounding cities (Schipper et al., 2017; Karimpour et al., 2019; Kong and Liu, 2021). In recent years, attention to the sustainability of ports and port cities has increased. Ports are increasingly orienting their environmental endeavours toward energy issues and are pressured to reduce their global emissions (Bjerkan et al., 2021). The review of available frameworks for assessing sustainability was the object of articles and studies such as those of Huang et al., 2015.

2.2 Land-sea interactions: Sustainable port-city relationship

There has been an effort to understand the influence and interactions of ports and cities from a land-sea dimension given their coastal setting and their impacts on sustainability. Zheng et al. (2020) attempt to test the interconnected relationship between port activities, urban competitiveness and their impacts on marine environments. Reconceptualizing sustainable port cities and their hinterlands requires understanding the activities, states, and futures in the context of the land-sea interactions framework (Couling and Hein, 2020). Land, sea, and people are a trilogy of the characteristic of coastal communities and their environments (International Federation of Surveyors (FIG), 2010). Activities on land impact the sea and activities in the sea impact the land. Port and coastal cities are urban centers where terrestrial, marine and human resources have a high level of interaction (Chua et al., 2006). Ports and their surrounding urban regions, therefore, play a vital role in the ocean economy development. Kidd (2018) present a general framework for exploring issues in Land-Sea Interactions in ocean governance. LSI is a complex process involving dynamic processes across the land-sea interface (Kidd, 2018). This involves natural processes and their interrelationships between human activities in this zone. LSI can be addressed through reconciling development with the good ecological health of marine resources. Integrated Coastal Area Management (ICM/ICZM) and Marine Spatial Planning (MSP) are two key strategies that link environmental, social, and economic aspects within the land-sea continuum (Ehler and Douvere, 2007; Ehler et al., 2019). Conversely, Lainas, 2018; Ronco Zapatero, 2018; Friess and Grémaud-Colombier, 2021 have identified three broad categories for LSI evaluation namely environmental, socio-economic, and technical paradigms. These provide the scope in terms of maritime sectoral identification which are inputs in the marine spatial planning process.

Figure 1 illustrates the dynamics of LSI and relates to the ocean planning and governance arrangements, and what these interactions mean for landward communities and the marine ecosystem. These critical socio-economic interactions are both

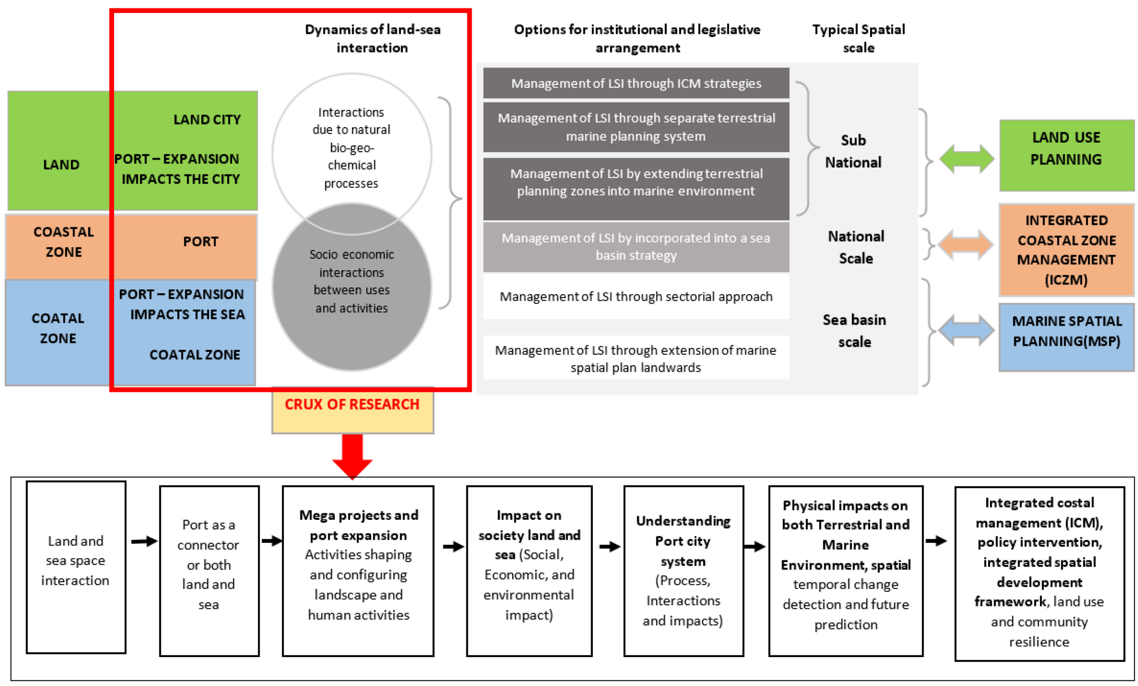

FIGURE 1
Conceptual framework of a port city in the embedded in the land and sea interaction.

land and sea based. Maritime uses such as ports and shipping, utilise land-based installations while their related utilities like port expansion extends into the sea. In order minimize potential use conflict and enhance synergies, sustainable ocean planning and governance requires understanding of associated individual and cumulative impacts of these intricate interactions as an integrated whole (Kondratyev and Pozdnyakov, 1996; Kidd, 2018).

Existing literature on assessing port city performance and progress towards sustainability, prescribes focusing on indicators that evaluate key functional and operational interactions occurring between aspects of the port development operations within the port and city systems (Merk, 2013). These systems are recently perceived as the port cityscape- a spatial unit of matted port related spaces in a port city region embedded in the land-sea continuum (Couling and Hein, 2020). Major recurrent thematic areas of port city performance include;1) *Port development* on issues such as port-throughput; value-added port area; efficiency index; 2) *Port-city development;* GDP per capita, population size and growth rate, unemployment rate; 3) *Transport;* transport spatial impact, motorway network density; railway network density; *4) Spatial development aspects*; coastal land occupation, the land surface of the port area, urbanized area; *5) Environment-* water pollution by port activities, waste generation and treatment, air quality and concentration of pollutants, CO_2 emissions per capita, population

TABLE 1 Port-city performance indicators in literature.

Indicator	Xiao and Lam (2017)	Merk and Ding (2013)
Port development	Productivity (cargo handled per resource usage)	Port throughput (mton)
	Port operation	Port throughput containers (m teu)
		Growth port throughput (m ton and/ or mteu)
	Trade facilitation	Value added port area (min USD)
		Efficiency index
Port-city development	GDP per capita	Metropolitan GDP per capita
	Income and profitability (household disposable income, gross savings)	GDP per capita growth
	–	Population
	–	Population growth
	GDP generation/value multiplier, commercial, activities, employment multiplier	Port-related employment (direct, indirect)
	Unemployment rate	Unemployment rate
Transport	Transport spatial impact	Motorway network density(km/ 1000km^2)
		Railroad network density(km/ 1000km^2)
Research and innovation	–	i.e total patent applications in region
Spatial development	Coastal and occupation	Land surface of port(km^2)
	Housing, shelter	Urbanized area(km^2)
Environment	Air quality & concentration of pollutants	CO_2 emissions per capita
		Population exposure to $PM_{2.5}$
	Water pollution by port activity	
	Waste generation and treatment	
Communication	–	Number of twitter followers
Heritage and cultural impact	(Maritime) heritage protection ad culture preservation	Cultural projects related to port
Institutional	Regulatory framework of port industry	–
	Political stability	–

Source: van den Houten, 2017.

TABLE 2 Criteria for sustainability evaluation of port-cities.

System	Variable	Unit	Reference
Port system	Berth length	m	Serebrisky et al. (2016); Chen and Lam (2018); Li et al, (2018a).
	Berth	EA	Chen and Lam (2018); Li et al, (2018a); Wanke et al., (2018).
	Crane	EA	Serebrisky et al. (2016); Chen and Lam (2018).
	Cargo throughput	10^4 Tons	Cui (2017); Chen and Lam (2018); Wanke et al., (2018); Lim et al., (2019).
	Container Throughput	10^4 TEU	Serebrisky et al. (2016);; Cui (2017); Chen and Lam (2018); Li et al, (2018a); Lim et al. (2019).
City System	Land	10^4 M^2	Chen and Lam (2018)
	Energy	10^4 Toe	Tan et al. (2017); Chen and Lam (2018).
	Labor	10^4	Zhang et al. (2011); Chen and Lam (2018)
	GDP	10^4 CNY	Zang et al. (2011); Tan et al. (2017); Ding et al. (2016); Xu et al. (2017); Li et al, (2018b); Yi et al. (2019).
	GHG	10^4 M^2	Ding et al. (2016); Chen and Lam (2018); Li et al, (2018b); Yi et al. (2018).

Source: Kong and Liu, 2021.

exposure to PM_2; 6) *Heritage and cultural impact*; 7) *Communication and 8) Institution and governance* (Merk, 2013; Merk and Dang, 2013; Xiao and Lam, 2017) (Table 1). Similarly, Kong and Liu (2021) posit that ports and cities have interrelations in the economy, land use, logistics, port-city spatial relationship, port-city economic development, and the port-city interface (Kong and Liu, 2021). These relations afforded the development of a two-stage interaction model of port cities with the overall goal being sustainable port city development as highlighted in Table 2. Moreover, the five World Ports Sustainability Program (WPSP) themes on sustainable ports aligned to the SDGs include; 1) Resilient infrastructure; 2) Climate and Energy; 3) Community outreach and port city dialogue; 4) Safety and Security and 5) Governance and ethics (Verhoeven et al., 2020) proved beneficial in the selection of port city sustainability indicators. In this paper, guided by the WPSP themes, the criteria in Table 1 and Table 2 were highly considered in the proposed port-city sustainability indicator framework.

2.3 Port city governance: Stakeholder perspectives and interests

Governance is an integral part of sustainable port city and marine management. The decision-making process within a port city system is complex (Lam and Yap, 2019). There are multiple conflicting interests and perspectives of actors operating within the port city interface embedded in the Land and Sea spaces (De Langen, 2006). These stakeholders can be profiled depending on their space of interest, thus land and sea (Crossland et al., 2005). The group's roles range from development issues at various authoritative levels. These stakeholders come from diverse backgrounds with multiple interests and competing resource uses and values (Crossland et al., 2005; Lam and Yap, 2019). Port city-related actors and stakeholder groups range from public sector, market players/cooperate bodies and community interest groups striving to achieve their multiple objectives through decision-making. Achieving sustainable port city management focuses on the interest of port city actors and stakeholders involved in the development of the port city interface and its marine environment, and the need for fostering lasting relationships and coalitions between them (Daamen, 2007; Matusiewicz and Rolbiecki, 2021).

3 Methodology

Exploratory methods were applied to comprehensively assess existing literature on the sustainability of port city systems and their marine environments. Thematic combinations were used to ascertain baseline priorities for top environmental management issues to link environmental impacts associated with port city activities and operations. From the literature, the causal relationship between the indicators was adapted using the Casual Network (CN) approach. This method is the most common framework for selecting and expressing the relationship between indicators and is a combination of a series of causal loops, such as the pressure–state–response (PSR) framework and its transformations: the driving force–state–response (DSR) and the driving force–pressure–state–impact–response (DPSIR) (Niemeijer and de Groot, 2008).

3.1 Systematic literature review

A systematic Literature Review (SLR) was utilized to identify and explore key factors to consider when selecting the indicators for the sustainable port-city indicator framework. The Cochrane Collaboration guidelines for qualitative research were followed to search, establish inclusion criteria and for data extraction (Booth et al., 2011; Noyes et al., 2011). The paper evaluates the importance of each indicator in the context of port cities in Africa's WIO region and Global South. Further, it suggests a support framework for making related sustainable decisions therein. The following criteria were used for selecting indicators: (a) scope (selecting indicators that fit into the main aim and targets of achieving port-city sustainability and marine management); (b) relevance (selecting the most suitable indicators for a specific study subject); (c) data availability (considering the accessibility of data); and (d) quantification (considering the quantification capacity of an indicator as a selection parameter or reference value for making comparisons).

Data collection and sampling strategy employed the STARLITE mnemonic (Booth, 2006; Moscou et al., 2016) meaning S-Sampling Strategy; T-Types of Studies; A-Approaches; R-Range of years; L-Limits; I- Inclusion and Exclusion criteria; T-Terms and E-Electronic Sources. A purposive sampling strategy was applied to determine the themes of interest to the study. All Types of studies peer-reviewed journals, grey literature, dissertations, organizational websites and reports, databases and websites on key related themes like port city sustainability and ocean stewardship were utilized. Approaches applied included scoping of internet searches, abstracts, citation searches and reviews, and thematic and comparative analysis. The range of years included information sourced from 1987-the initial timeframe of the concept of sustainable development to 2021. Limits-considered WIO region countries and developing countries and to port city sustainability indicator frameworks. Inclusion and exclusion criteria were used to identify articles included and excluded centered on relevance. Based on scoping review, major inclusions were abstracts, articles, documents, studies, website resources on sustainable development, sustainability indicator frameworks, port-city systems and WIO port-cities. Terms used include thematic aspects defined within the study. The following keywords were used for searching the literature: "Port city systems", "sustainability assessment of port city", "Sustainable development of port cities", "Land and Sea interactions for port city systems", and "Environmental monitoring of port city". Electronic sources based on internet data of published, peer-reviewed literature were mined from the Scopus database (Figure 2).

3.2 Sustainability dimensions and thematic combinations for port city indicators

Sustainability frameworks are often multidimensional synergizing the environmental, social, economic and governance aspects which enables a holistic process of development (Moussiopoulos et al., 2010). Adding governance as the fourth dimension of sustainability is fundamental to supporting coastal and marine management (Karnauskaitė et al., 2018). Ports have received increasing attention because of their environmental burdens. Therefore, green port policies are a major focus of sustainable port operations (Lawer et al., 2019; Lozano et al., 2019). (2020) highlight top environmental management areas and thematic contributions dealing with environmental impacts associated with port activities and operations. According to Bjerkan et al. (2021), for a port to achieve sustainability, top five baseline priorities in ports surveyed by ESPO 2020 (Table 3), were considered in this paper. These align with the five WPSP themes on sustainable ports (Verhoeven et al., 2020). Sustainability dimensions and thematic combinations were used for parameter and indicator measurement (Table 4).

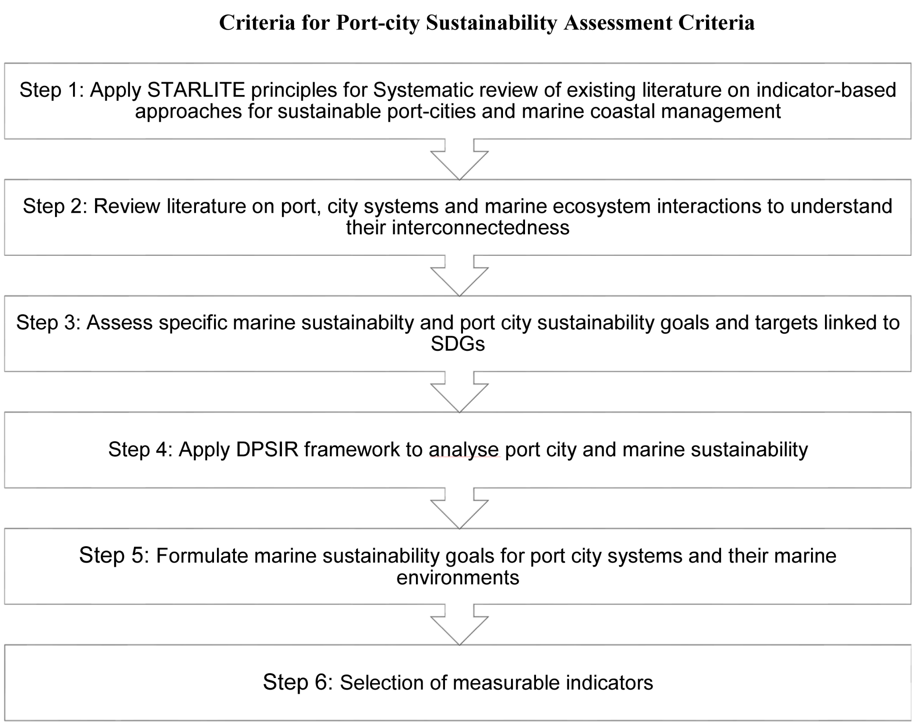

FIGURE 2
Workflow of criteria for port-city sustainability assessment criteria.

TABLE 3 Top Five Priorities in Ports Surveyed by ESPO (2020).

Rank	1996	2004	2009	2016	2020
1	Port development (water)	Garbage/port waste	Noise	Air quality	Air quality
2	Water quality	Dredging operations	Air quality	Energy consumption	Climate change
3	Dredging disposal	Dredging disposal	Garbage/port waste	Noise	Energy efficiency
4	Dredging operations	Dust	Dredging operations	Relationship with local community	Noise
5	Dust	Noise	Dredging disposal	Garbage/port waste	Relationship with local community

Source: Bjerkan, Hansen and Steen, 2021.

3.3 The causal network- structure and relationships for port city indicator selection

Determining a Causal Network (CN) association remains important for strategic actions; however, this can be challenging. Pakzad and Osmond (2016) reveal the dependency and interrelatedness of indicators. A causal network is a common framework of choice for indicator selection by various organizations such as the OECD (Pakzad and Osmond, 2016), which also supports result interpretation. To express the inherent indicator relationships and interactive process between the port city systems and their marine environments, thematic combinations used are converted into a causal network. We applied the CN to the DPSIR framework of the indicators to depict the innate relationship between indicators of the complex port-city-marine ecosystem connection. The sustainability dimensions and list of indicators were transformed into a CN diagram.

3.3.1 Drivers-pressures-state-impact-response framework

The DPSIR is a decision support tool that reflects the relationship between the environment and other factors such as society, economic development and human behaviour on the use of resources and the ecological environment (Gregory et al., 2013; Wang et al., 2018). The model has proved beneficial in illustrating internal relationships, connections and interactions among components (Jiao and Wang, 2020). The model can integrate sustainable indicators into several dynamic elements and explain the connection between them when used to evaluate ecological sustainability. To achieve the marine ecosystem-centered indicator-based approach proposed in this paper, the DPSIR has been used.

The analysis of the interactions employs the DSPIR conceptual framework that was developed by the European Commission in the 1990s. This is used to determine and assess the links between human pressures and state changes in marine and coastal ecosystems (Patrício et al., 2016; Wang et al., 2018). The framework seeks to link applied science and management of human uses to an ecosystem-based approach, specifically, the sea and coastal zones by extension (Gregory et al., 2013; Gari et al., 2015). Human activities along the coasts are considered the primary driving force of the change in the coastal ecosystem.

Determining and assessing the links between different SDGs and respective indicators in port cities remains a challenge. Although there are several conceptual frameworks for describing these links, the DPSIR framework has been widely adopted (Patrício et al., 2016). According to the framework, there is a chain of causal links starting with '*driving forces*' (economic sectors, human

TABLE 4 Parameters and Indicators Measured.

S/ No.	Sustainability Dimension	What was measured	Indicator used	Thematic Combinations
1.	Economics	Port development	-Port economic contribution -Port efficiency -Transport modes and intensity	-Resilient Infrastructure -Energy efficiency -safety and security
2.	Society and culture	Port-City development	-Port city population -Employment rates	-Community Outreach and port-city dialogue -Relationship with the local community
3.	Environment and Ecology (Ecosystems, Fisheries, climate)	Marine/Urban Ecosystem affected	-Port-related pollution (air, water, land) -Port-city related pollution (air, water, land) -Water quality -Waste management -Dredging	-Pollution Resilient Infrastructure -Climate change and energy
4.	Governance and politics	Legal Framework	-Available written policies and laws	-Governance and ethics

Source: Authors construction.

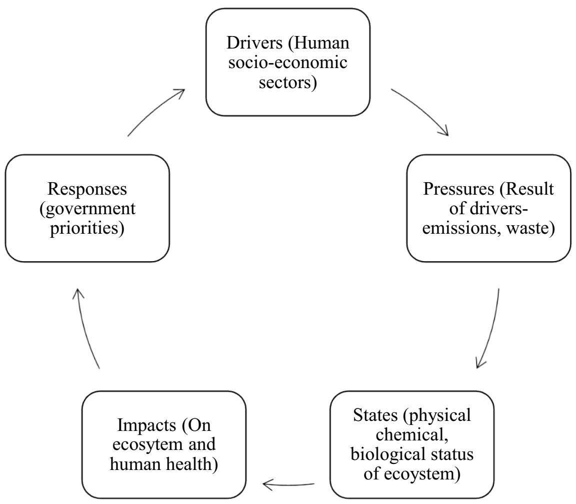

FIGURE 3
Interlinkages of the DPSIR framework components.

activities) through '*pressures*' (emissions, waste) to '*states*' (physical, chemical, and biological) and '*impacts*' on ecosystems, human health, and functions, eventually leading to '*responses*' (prioritization, target setting, indicators). These causal networks explain the balanced interaction between human activities and natural resources which demonstrates sustainability (Supplementary Table 1). By using the DPSIR framework to evaluate sustainability, it can integrate the sustainable indicators into different dynamic parts and can explain the interaction between each part (Figure 3).

The conventional way of analyzing port growth has always used the population and port cargo throughput as a benchmark. Most port development studies emphasize the economic aspects and logistical flows of port cities and often neglect the vital functions that oceans serve in forming urban and regional agglomerations (Couling and Hein, 2020). Concerning coastal areas, the DSPIR framework has previously been advanced concerning sustainable development. This, however, has gaps as it focuses on socio-economic constructs with little emphasis on green growth strategies that consider well-being (Gregory et al., 2013; Wang et al., 2018). The biophysical aspects of coastal systems are characterized by constant change. Both natural and anthropogenic drivers lead to material and resource fluxes across the land-sea interface (de Alencar et al., 2020). The result is the identification of a combination of sectoral categories that inform the identification and evaluation of coastal sustainability parameters as highlighted below (Figure 4) integrated into this paper.

4 Results

4.1 Systematic literature review results

A total of 1,666 articles were obtained from the Scopus database of which 52.6% were peer-reviewed research articles, 31.6% were conference proceedings, 7.3% were book chapters and 8.5% were other forms of publications including letters, notes, etc (Figure 5).

Using the keywords "Port city systems", "sustainability assessment of port city", "Sustainable development of port cities", "Land and Sea interactions for port city systems", and "Environmental monitoring of port city", a total of 1,934 publications were yielded. Port city systems 651 (34%), Sustainable development of port city 462 (24%), Land and Sea interactions for port city systems 268 (14%), Sustainability assessment of port city 223 (11%), Environmental monitoring in a port city 330 (17%) (Table 5).

Publications on port city systems and marine sustainability in the Global North and Global South are greatly varied. Most studies in this discourse are skewed toward the port city-systems of the Global North. Based on key search words "Port city systems by country" in the Scopus database used in this paper, top twenty-

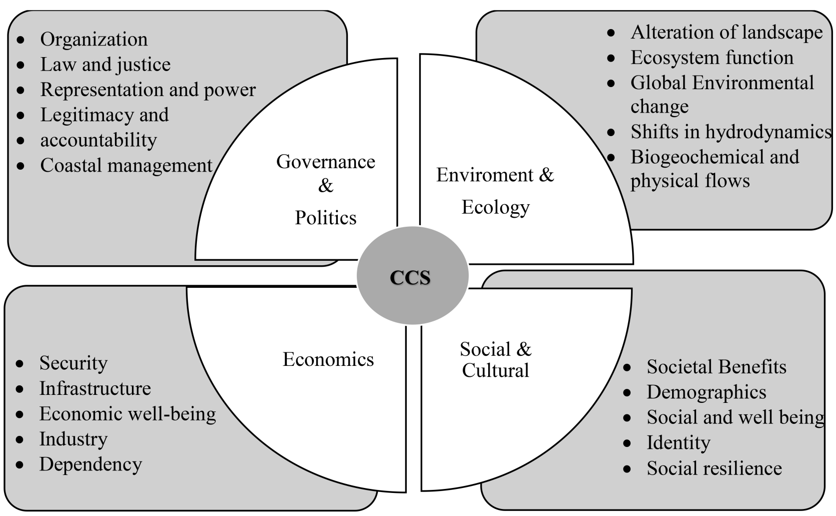

FIGURE 4
Combination of sectoral categories for coastal sustainability framework.

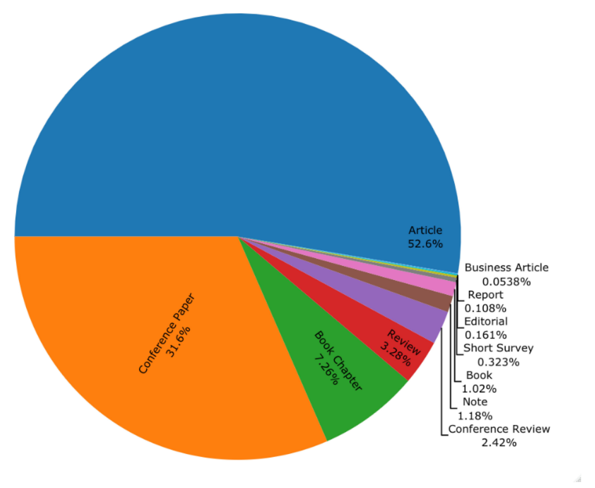

FIGURE 5
Results of scopus database search by publication type.

five (25) country port city systems emerged. Global North countries of USA (3312), China (1681), and Canada (894) emerged as the top three (3) most researched, while, on the other hand, Global South countries of Saudi Arabia (237), Chile (235) and Argentina (227) emerged as less researched (Supplementary Material Figure 1). In the WIO region, South Africa (441) dominated the publications. Similarly, with the search words “marine sustainability by country”, top (25) countries emerged. GN countries of USA (2993), Australia (1493), and England (1154) were the top three (3) most published by country while Chile (238), Greece (237) and Mexico (226) emerged as the bottom three (3) (Supplementary Material Figure 2). Among these publications, very few came from the WIO region with South Africa (287) leading having publications focusing on sustainability assessment, sustainability development and environmental monitoring in port city systems. The cutting revelation was that most of the publications were focusing on global north regions with fewer publications targeting global south regions in this category too. The implication is that there is limited knowledge of sustainable port city planning and marine sustainability, monitoring and management in countries and regions of the Global South. This presents an opportunity for Global South countries to explore research opportunities in this field and build on existing knowledge.

4.1.1 Challenges and opportunities to develop sustainable marine-centred port cities in the Global South

According to reviewed literature, the development of ports and port cities globally is a source of great social and economic potential however, they face challenges. In terms of the economic output of ports, one ton of port throughput is associated with USD 100 of economic value added. On the other hand, an increase of one million tons of port throughput is associated with an increase of 300 jobs in the port in the short term and an average of 220 to 1500 jobs per million tonnes of port cargo (Merk and Dang, 2013).

The negative impacts of the ports on the environment are presented through emissions, traffic congestion, pollution, land–use conflict, a threat to the bio-diversity-through release of ballast water, and strain on the social well-being of the port city. A study conducted in the more developed port-city of New York saw the cost of road congestion range between USD 0.3 and USD 0.8 billion per year due to a 6% increase in freight volumes in the Port of New York with the issue being more pronounced in developing countries and emerging ports (Merk and Dang, 2013). Importantly, the turnaround time of ships in a port has an implicit direct relationship to the negative environmental impacts within the port city where a higher ship turnaround time leads to greater environmental impacts. Seaport and city congestion is the most prevalent problem for ports in East and Southern Africa, given that many cities grew around ports with roads running through the city areas (Humphreys et al., 2019).

In the WIO region, port city growth has been and will continue to be on an upward trend due to globalization and international trade. Durban, Mombasa, and Dar es Salaam Ports are ranked the busiest respectively (Vickers, 2012; Ngangaji, 2019). However, this development comes with a fair share of challenges to the socio-ecological setting of their adjacent cities. Some of the major problems cited especially for the WIO region ports emanate from port expansion including berth widening and deepening which also drives land-use changes. Port expansion-related challenges compromise global and regional competitiveness, which is detrimental to trade and socio-economic development in the WIO region (Naicker and Allopi, 2015). For instance, as the ports of Durban (Bracking and Diga, 2015; Mpungose and Maharaj,

TABLE 5 Results of corresponding search words.

Key Search words	Number	Percentage (%)
Port city systems	651	34
Sustainable development of port city	462	24
Land and Sea interactions for port city systems	268	14
Sustainability assessment of port city	223	11
Environmental monitoring in port city	330	17
Total	1,934	100

Source: Authors construction.

2022) and Mombasa continue to expand, residential land uses are overtaken by port-related activities and functions such as truck yards and shipping garages. Spill over effects are felt in the adjacent city's spatial configuration, socio-economic development, and marine ecosystem (Mpungose and Maharaj, 2022). These include urbanization which inherently translates to socioeconomic vulnerability (Celliers and Ntombela, 2015). This contributes to ecological pressures such as atmospheric (noise and air) pollution, solid waste pollution, increase in sewage and effluents that harm the environment especially marine ecology (Mather and Reddy, 2011; Bond, 2014; Martel, 2016). Ecological degradation makes these cities the centers of biodiversity loss due to marine vessel emissions such as ballast waters and freight activities. Ballast waters carry invasive species to a new destination which can cause devastation to ecological species (Musso et al., 2011; van den Houten, 2017). City pollutants in the Port of Durban end up in the harbour port, after heavy rains as it comes through the storm water (Molelu and Enserink, 2018). Water pollution from dredging, accidental oil spills, accidental container spillage, and microplastics is a growing concern. Regulating pollution and waste management are within the local governments 'jurisdiction, however, the port also has laws regarding pollution that need to be adhered to. Moreover, for port cities in the WIO region, the proliferation of urban settlements resulted in urban sprawl as populations migrate to port cities seeking employment and improved living conditions. Increased traffic flows and congestion due to port functions (Browne et al., 2017) is also a challenge that comes with urbanization in port cities and affects the urban populations' quality of living (Merk and Dang, 2013; Knatz, 2017; Woxenius, 2017; Olusegun Onifade, 2020).

Moreover, port cities of the WIO region are at the frontline of climate change due to their location in the coastal zone. Their geographical position makes it necessary for them to build climate resilience due to their high exposure to climate extremes (Tsatsou, 2015). It remains a challenge for port cities in the WIO region to build resilience and adapt to climate change because of the complex infrastructural, environmental, social, ecological, economic, political, and planning perspectives that are present. Most coastal zone areas have been integrally termed as one of the most endangered areas in the world. Pollution, eutrophication, urbanization, land reclamation, overfishing, and exploitation continuously threaten the future of the coastal environment. This is further compounded by climate change uncertainties (Tsatsou, 2015).

In addition, port and city planning and governance face recurrent drawbacks due to the complex nature of stakeholders and institutional arrangements. The city operates at the sub-national scale where management is by local authorities while the port operates and is managed at the national scale. The sea basin management jurisdictions intersect between the local and the national authorities. This often results in conflict of co-ordination and co-operation of management and planning for port cities in the global south and WIO region (Molelu et al., 2021). Most WIO port and city plans are not complementary, and the situation is worsened by the urbanization and local government's capacity to provide infrastructure to support urban dwellers and port activities/ functions in the city. Odhiambo, 2018, noted that the growing scarcity of prime locations, increased environmental constraints, limited space for sustainable port expansion, and uncertainty about the impacts of climate and technological change remain fundamental challenges that require planning.

Globally port cities cut across global chains, especially in global trade and maritime sectors. The interconnectedness and unique nature of port cities of the global south countries, make it important to develop an indicator-based approach that can be used to assess their sustainability as they scale up their growth to match other developed port cities in the world. The collaboration of stakeholders in the port city interface, including public agencies, maritime stakeholders, port users and authorities, and parties responsible for land outside the port areas, needs to be better coordinated and formalized across ports in the developing regions.

4.2 Existing themes for sustainable port-city indicator framework

Themes as an analytical tool are used to generate knowledge about the complex nature of sustainability. The United Nations Commission on Sustainable Development (CSD) constructed a sustainability indicator framework that is divided between the four pillars of sustainable development for the evaluation of governmental progress toward sustainable development goals (Osborn et al., 2015), a similar approach applied in this paper. The priority thematic areas, as revealed by a systematic literature review on sustainable port-cities, consider the operations and functions of a port city system comprising two sub-systems: the port sub-system and the city sub-system. This approach helped shape the theoretical framework that this paper employed in identifying the indicators. Therefore, based on existing literature (Xiao and Lam, 2017; Darbra Roman et al., 2020; Zheng et al., 2020; Bjerkan et al., 2021; Kong and Liu, 2021) thematic categorizations and combinations were developed for this paper (Table 4).

The four sustainability dimensions by CSD (economy, society, governance, and environment) of port cities were adopted as summarized by various scholars (Figure 4). The analysis and coding of recurrent themes in the literature demonstrated three major outcomes that were consistent across the board: economic growth; environmental sustainability; and social wellbeing. Governance and politics were also viewed as an enabler of sustainable port-city development. Similarly, the causal factors for a sustainable index are tied to these sustainable development themes. They are structured in a manner that for one to qualify as a causal factor they:

i. Are imperative for national, regional, and local policy regarding sustainable development.
ii. Can promote port efficiency.
iii. Can impact the economy in the marine environment while considering principles of sustainable ocean governance and stewardship.
iv. Have the ability to contribute to climate change mitigation and adaptation.
v. Have ecological and social effects on development.

vi. Impact the quality of life within the port city.

The analysis and results reveal these aspects guided by the themes and their overall utility in indicator selection to bring about the causal relationship along the continuum.

4.3 The causal relationships for sustainable port-city indicator framework

A total of 78 multidimensional indicators were selected to assess port-city and marine sustainability in the context of the land-sea continuum. The fundamental structure of the causal network was based on measuring the basic causes that need to be considered for the development of an effective port city sustainability assessment indicator framework (Figure 6) within developing countries. The land and sea interactions approach were used as a major consideration for indicator identification and selection. Other considerations included SDGs and their targets. Central to this framework is the aspect of port volume growth, and expansion in the Global South, as a distinguishing driver of port city development. Other related key drivers included employment based on port and shipping industries, fisheries, tourism, population growth and port city culture and heritage (Supplementary Material Figure 3). For global south countries, ports are still experiencing growth and development. The selected indicators are derived from this narrative. The causes integrate four pillars: social-cultural, economic development, governance and politics, and environmental management. A causal factor to an indicator is defined as a cause with numerical value derived from actual measurements of pressure, state or ambient condition, exposure, or human health or ecological condition, over

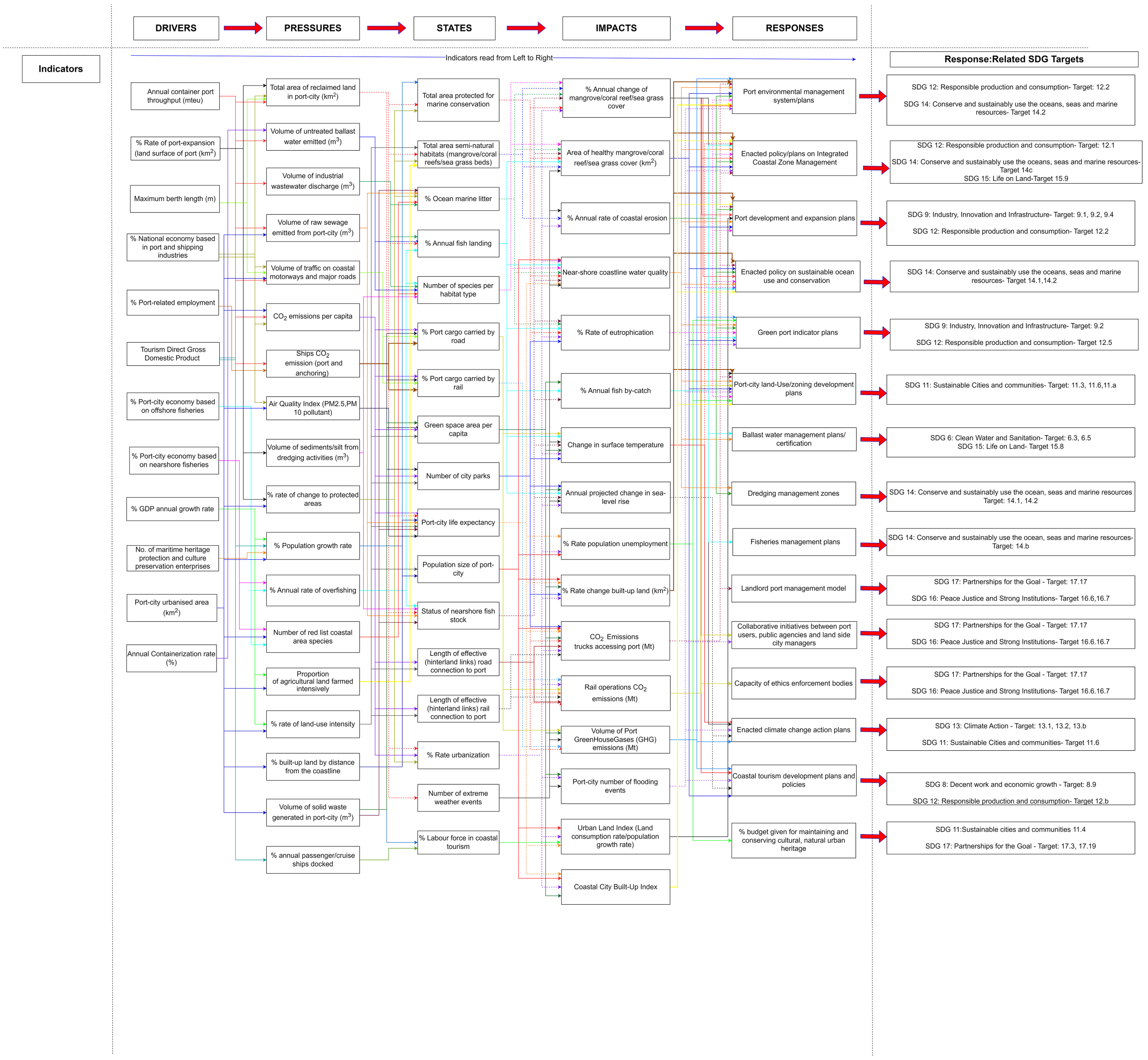

FIGURE 6
Sustainable port city indicator framework for Global South countries.

a specified geographic domain, whose trends over time represent or draw attention to underlying trends social, economic, and ecological conditions (Lundin, 2003; Singh et al., 2009). An informative choice of sustainability indicator cause would be the measure of the indicator or cause concerning the economic output (e.g., gross domestic product (GDP). There was a strong recognition of the social-cultural, economic, and environmental role port development plays in human health and wellbeing in the DPSIR framework (Singh et al., 2009). Dependent on data availability of the indicators in the proposed framework, this approach provides scope to assess the practical application and achievability of selected indicators to quantitatively assess sustainability performance across the uniquely varied yet similar coastal contexts of the GS port-cities.

4.3.1 Linking the DPSIR framework outcomes to land and sea interactions and SDGs

Policies and global development strategies are cognizant of the fact that there exists a close relationship between development and the environment. Port cities and the surrounding natural environment with urban cities exhibit tendencies to adapt and transform the natural interaction between land and sea (Couling and Hein, 2020). The current global debate on SDGs warrants consideration today and the future generations' requirements in current development strategies to achieve shared peace and prosperity. The DPSIR framework in this work illustrates a comprehensive approach that links its outcomes to LSI and SDGs. Notably, WIO countries fundamentally provide critical interaction between the development processes that engulf their ports surrounding environments. The increasing need to create interaction between land and sea and subsequent development is acknowledged in various policy documents. For instance, the European Union directive 2014/89/EU article 4 on Maritime Spatial Planning provisions commits that countries shall consider the uniqueness of the marine region's land-sea interactions, their related socioeconomic activities and consider the future uses and their impacts on the environment, as well as natural resources and enhanced cross-border cooperation, per relevant provisions. However, in reality, these interactions between SDGs and LSI result in co-benefits and synergies (Selomane et al., 2019). In practice, however, the interactions between SDGs often result in tradeoffs and tensions, Jiménez-Aceituno et al. (2020) which to a greater extent overrides sustainable development.

The analysis of this work takes a deeper dive into the connection the DPSIR framework outcomes and the LSI have and their nexus to various SDGs. Notably, the main drivers of port development according to the framework in the port cities of WIO countries are primarily organized around the growing pressure for economic growth leading to growth in maritime trade, and logistics activities which address the need for responsible production and consumption (SDG12) and need to conserve and use oceans resources sustainably (SDG 14). However, if not taken with caution this tends to have a negative effect on biodiversity loss in the sea and on land. The port expansion thus affects life on land (SDG15) and life under water (SDG14) respectively. These initiatives put in place by WIO countries to ensure increased annual container port throughput, expansion of their berth length and a national economy based on shipping and port-based industries have a direct negative impact on the surrounding port environments in general.

Moreover, WIO countries are endowed with underdeveloped port cities among other challenges include unemployment. These challenges of giving citizens decent work and economic growth (SDG 8), coupled with poverty eradication (SDG 1) are a result of port city urbanization pressure on achieving sustainable cities and communities (SDG 11). WIO countries have recently experienced a great quest to address these challenges leading to the progressive evolution of their economies thereby causing ecological challenges including pollution in their urban environment and surrounding oceans. Moreover, intensive industry, innovation, and infrastructure growth (SDG 9) tend to result in progressive loss of biodiversity on land (SDG 15) and water (SDG 14). Other challenges are seen in the achievement of SDG 11 on sustainable cities and communities at the ports due to overall environmental degradation. Collaborative initiatives between port stakeholders including public agencies in maritime authorities, city managers, and actors are essential (SDG 16). Other emerging challenges in achieving SDGs include the over-exploitation of ocean natural resources with the evolution in urban development that negatively impacts SDG 14, and SDG 15 on life below water and land respectively.

Conclusively the World Ports Sustainability report (2020) findings mirror similar views of the major findings in this work regarding linkages of the DPSIR framework and LSI with SDGs. The seventeen SDGs offered linkages of port city sustainability with SDG 9 on industry innovation and infrastructure, SDG 8 on decent work economic growth, and SDG 11 on sustainable cities and communities standing out high priority SDGs where globally ports feel more inclined to demonstrate actions and progress on sustainability.

5 Discussion

The main argument of this paper is that indicator-based approaches for port city sustainability assessment and marine management in developing countries and regions such as Africa and the global south are still minimally researched. The dearth of research in this area has created an overreliance on indicator-based sustainability frameworks, largely designed for the more developed countries of the global north. Therefore, this paper highly sought to understand the difference in the varied contextual nature of port-city systems between the northern and southern hemispheres of the globe. After this select a combination of indicators that best evaluate the sustainability of port cities in less developed countries and assess their ocean stewardship practices. Existing literature illustrates that numerous indicator-based port city sustainability frameworks exist, yet few combinations focus on the poorer developing countries, therefore opportunity exists to create such a framework, which underpins this paper. The United Nations exhibits that when it comes to the implementation of goals by different countries there is a special need to give different degrees of attention and effort to the different goals and targets, depending on where countries are economically at present, their differentiated responsibilities, and their different capabilities and endowments (Osborn et al., 2015). The clear distinction between developed and developing countries is key in bringing forward tangible approaches toward clear policies not only on ports and cities but other sustainable development aspirations. Country sovereignty and governance structure come to play when the management and administration of their ports and cities. Most ports and cities are at different levels of development and are dynamic depending on their location. Moreover, to capture contextual aspects of a given port-city system, the existing framework is largely rooted in the land-sea interactions framework. The intermediate character of the operational and functional aspects of the different sub-systems that constitute port operations and development, urbanization, port-city dialogue, and community outreach and their related marine environments, thus key considerations should be made to capture these aspects. However, the complex and dynamic nature of these systemic interactions compounds the process of formulating an indicator-based framework.

5.1 The utility of using the DPSIR

The application of the land-sea continuum conceptual framework proved useful and exemplary in capturing the intense yet fluid and porous interactions of port operations, neighboring coastal areas and port-city encroachments across the land and sea thresholds. Furthermore, the application of the DPSIR framework proved beneficial in illustrating a more comprehensive strategy that depicts the nexus of the social, cultural, economic and governance advancements that oceans fundamentally serve to better appreciate critical interactions between the development processes that engulf an ocean, port city and its surrounding hinterland areas.

The DPSIR model illustrates a major concept of port-city sustainable development with the port city evolution and countermeasures taken by the decision-making community (Mao et al., 2014). The DPSIR framework demonstrated a more practical basis to integrate the dynamic yet complex dimensions of port-city development in the context of the land-sea continuum, a fundamental thesis of this paper. The DPSIR framework in this work demonstrates the internal relationship and influences between components (Chen et al., 2004). The framework proved effective in capturing direct links and interdependencies between oceans and port-city regions. This approach moved away from classic land-based port and city development studies to a more recentered lens that employs a profound comprehension of the port city as a whole unit in relation to the sea space activities in a more networked approach (Couling and Hein, 2020). The most notable advantage of using the DPSIR model in the field of sustainable evaluation research is that it emphasizes the causal relationship between the port development, urban evolution pressure and the countermeasures by the five elements restraining and influencing each other, in this context.

Many prior researchers built the DPSIR indicators system based on previous research findings or experiences. These markers differ depending on the research case, the evaluation objectives, and the context such as Global North and Global South (Liu W. et al., 2019). These differences have resulted in numerous controversies regarding the continuity of model indicator selection when subsequent scholars use the DPSIR model based on subjective judgment. Therefore, to avoid this quagmire the United Nations Social Development Goals were used to provide programmatic guidance in the selection of the indicators based on the local context of the global south. The study of port city sustainability encompasses various components cutting across different SDGs.

5.1.1 Drivers level

Scholarship on port-city sustainability reveals that the main links of the driving forces (D) of port-city sustainability are the development of society, economy, and population. The indicators at this level are associated with the socio-economic dimension of sustainability. The interactions between ports and land use are also part of a complex framework that includes economic, cultural, political, demographic and technological changes. The integral anthropogenic driver of development in the port cities of developing countries is primarily organized around the growing demand for maritime trade, shipping and logistics activities. The growth of ports and port cities causes an increase in "Annual container ports throughout" and a change in the "Annual containerization rate". This leads to an increase in port and industrial expansion activities through land reclamation to extend berth lengths. Consequently, potential ecosystem and health effects arise from port expansion in global south countries which compromises port city sustainability. This implies a change and reduction in the total areas and health of critical biodiversity of semi-natural habitats such as mangroves, coral reefs, and seagrass beds. Ports and port cities of the global south are still developing. This is characterized by the growing influence of the existing maritime infrastructure which extends across the land-sea continuum. The land and sea relationship emerges as co-dependent. Infrastructure objects extend from both the land to the sea and sea to land. The port becomes more urban through alterations like land reclamation which encroach into the ocean. Moreover, growth in port-city and ports leads to an increased port-city economy based on offshore and on nearshore fisheries activities. This leads to a change in the "Annual rate of overfishing", which leads to a decrease in marine resources indicated by red list coastal area species. This alters the marine ecosystem's health by creating an imbalance.

5.1.2 Pressure level

The pressure (P) is the result of human activities on the marine ecosystem and safety. Some drivers are linked to multiple resultant pressures which create an interlink between the socio-economic drivers and the environmental pressures. The indicators at this level relate to the social-ecological dimension of sustainability. An increase in port expansion results in an increased "Total area of reclaimed land" in the port city and thereby "Volume of traffic on coastal motorways and major roads" is mainly driven by logistics-related enterprises. This impacts "CO_2 emissions per capita" on the landside primarily due to an increase in port cargo carried by rail and road which causes an environmental burden. "Volume of industrial wastewater discharge" is mainly driven by port industrial activity. On the seaside, as port expansion occurs, elongated berths imply an increase in the size of ships and the amount of cargo docking. This, in turn, causes an increase in the "Ship CO_2 emissions". Likewise, growth in ports and port cities has a correlation with port-city urbanization, which results in a "Change in land-use intensity", as well as an "Increased volume of solid and sewage waste generated from the port city". This leads to an increase in "Ocean marine litter" and a change in the "Status of nearshore fisheries". Similarly, as ports continue to expand, larger berths sizes are developed. This leads to an exponential increase in the number of larger vessels at the ports. This in turn results in an increased "Volume of ballast water" emitted. The "Number of species per habitat" is altered ultimately affecting the "Annual fish landings".

5.1.3 States level

The third level of the framework is the state (S). It is the resultant status of the environment due to the exerted pressures along the chain. It is aligned with the socio-ecology or social and environmental dimensions of sustainability. In this case, it is the urban environment of the port city and marine natural resources with the evolution of urban development, at the pressure level. The port cities' outcomes are because of port cities' drivers' activities and explorations. The DPSIR framework in this work emanates several resultant states mapped to the various pressures in the framework. Some of the states, just as in the case of pressures are caused by two or more related pressures due to the initial drivers' origin. Among the priority, links are "Total area protected for marine conservation" affected by "Total area of reclaimed land" in a port city and thus increased dredging activities. This has a bearing on the "Annual change and health of critical biodiversities such as mangroves, coral reefs, and seagrass cover". The sea becomes more urbanized through reclamation, there is an increase in the "Change in built-up land" of the port city. Also, the "Nearshore line water quality" is affected by the increased sediments or silt from dredging. This increased urbanization results in an increase in the "Population size of the port city" and built-up surfaces create a "Change in the coastal city built-up index". This makes the port city susceptible to "Increased extreme weather events" such as flooding, "Change in surface temperature" and "Annual projected changes in sea-level rise" as impacts of climate change.

5.1.4 Impact Level

The impact (I) is mostly socio-ecologically manifested because of various human activities linked to the preceding three components of the framework from drivers, pressures, and states. These impacts can either be on land or sea depending on the concertation of activity. For instance, from the DPSIR framework, the expansion of port cities and ports because of demand for space for such expansion, will have significant change that includes the "Increased annual change of mangrove/coral reef/seagrass cover" representing their loss and degradation cover in coastal regions due to overharvesting of wood products, human settlement, and overfishing. This leads to the loss of marine natural forest cover which causes an imbalance in the marine ecosystem. Moreover, port activities from various port cities sectors like transport constitute "CO_2 emissions from trucks accessing port", "Rail operations CO_2 emissions", and "Volume of Port Green House Gases (GHG) emissions", which are all associated as a portion of GHGs emissions from fossil-fuel combustion activities at the port and its expansion coupled with emissions from inland ships services, port operations, vehicles, and rail operations.

The "Increased urban population" at port cities and ports raises demand for goods and services which has a great impact on the marine ecosystem due to the "Increased rate of eutrophication". This is the rate of pollution that occurs in marine waters when they become over-rich in plant nutrients due to an increase in the proportion of agricultural land use; consequently, the sea water becomes overgrown with algae and other aquatic plants constitute this phenomenon. When these plants decompose, they rob the water of oxygen the marine water becomes lifeless. In addition, nitrate fertilizers that drain from the fields, nutrients from animal wastes, and human sewage are also significant causes of eutrophication. They cause environmental and natural resource degradations, such as air and water pollution, in the port cities and marine ecosystems.

On the other hand, sea-related priority impacts include the "Annual rate of coastal erosion" which is the process by which local sea level rises, strong wave action, and coastal flooding which wears down or carries away rocks, soils, and/or sands along the coastline. The expansion of ports and port cities has made this erosion more severe through its expansion and destruction of coral reefs. Port growth and expansion in addition to most developing economies have seen reduced "Annual fish by-catch" which is the amount of discarded catch of marine species due to unobserved mortality caused by direct encounters with fishing vessels around the ports. These unintentionally caught species often suffer injuries or die leading to their sudden population reduction. In conclusion, the impact level in the DPSIR framework of port cities' growth and expansion, and the effects of various drivers are felt as threats to the marine ecosystem. Each impact is a result of various states of the ecosystem that gives rise to the framework response to close the DPSIR framework tool.

5.1.5 Responses level

The response (R) spans the port city governance domain of the framework both on land and sea. The multiple perspectives, interests, and objectives of various groups within the port city are reflected in the spectra of the land and sea continuum. This level reveals the complex and competing interests of various port city actors and stakeholders within the port city interface. Ocean governance is concerned with integrating policy, actions, and affairs to protect the ocean environment, sustainable use of coastal and marine resources, and protection of biodiversity (Sujantoko et al., 2022). Measures taken by the various administrators involve examining the legal framework and institutional framework as a mechanism of implementation. These initiatives are usually in form of laws and regulations made for the smooth running and sustainable port city management. Some of these initiatives include “Enacted policy/plans on Integrated Coastal Zone Management” and conservation e.g: “Policy on marine spatial planning” such plans must consider the integrated nature of port cities thus the land-sea interface including governors and policy implementors and institutions to respond to these changes, such as the investment in environmental protection and urban protection and urban waste clearance rate, and pollutant treatment technology improvement. A single response could encompass several initiatives to combat various impacts. Some of the responses include, “Green port indicator plans”, “Port environment management system and plans”, “Port development and expansion plans” and many other policy initiatives that are initiated to guide framework administrators in the management and mitigation of impacts effects on port cities and their marine ecosystems.

5.2 DPSIR framework, LSI and SDG linkage opportunity

The main purpose of the DPSIR framework in this work is to promote sustainable development and to identify the utilization of land and sea space for different uses as well as to manage their harmonious interlinkages. The framework also aims at identifying and encouraging sustainable uses with great reference from SDGs provisions and following the relevant national policies and legislation, especially for WIO countries. To achieve this purpose, this work identifies guidelines for WIO countries to utilize and ensure that their port city planning processes result in a comprehensive framework identifying the different uses of maritime space and taking into consideration short, medium, and long-term changes such as climate change. The response level in the DPSIR framework provided an opportunity to link land and sea interactions with the Sustainable Development Goals (SDGs) as key governance actions required to achieve sustainable progress. These linkages serve as a guideline to monitor gains and gaps towards sustainable development. According to the United Nations 2015, the SDGs are intended to be universal in the sense of incorporating a universally shared common global vision of progress toward a safe, just, and sustainable space for all human beings to thrive on the planet (Osborn et al., 2015). To ensure conformity to these global set standards for sustainable development, the DPSIR framework in this paper draws on land and sea interaction and how ports and port city development impact coastal and marine environments. The framework mapped these indicators’ responses to several SDGs while considering the tradeoffs that should be noted in light of the practicality of cases across the board to avoid development frustrations (Lokrantz, 2020). Interconnection between the desired SDGs targets and the framework at large as response-related outcomes provides deeper insights and findings for this work. Overall, nearly all the seventeen (17) SDGs proved interlinked and showed nexus with the DPSIR framework and LSI. From the framework, however, “SDG 9 Industry innovation and infrastructure”, “SDG 11 Sustainable Cities and communities”, and “SDG 8 Decent work and economic growth” stood out as priority SDGs where ports feel more inclined to demonstrate actions and progress. Other priority SDGs include “SDG 6 Clean water and sanitation”, “SDG 12 Responsible production and consumption”, “SDG 13 Climate action”, “SDG 16 Peace Justice and strong institutions”, and “SDG 17 Partnerships for the goals” being of high prevalence. This work however highlights the aspect of an ideal world where the interactions between SDGs results in co-benefits and synergies as put forward by Folke et al. (2016). They note that in practice, the interactions between SDGs often result in tradeoffs and tensions, frustrating the achievement of sustainable development. Conversely, some of the main tradeoffs while striving to show progress, would be tendencies to loss in biodiversity both on land (SDG15) and in water (SDG14).

6 Conclusion and recommendations

Decision-making in areas of development in most global south regions faces complexity due to competing interests by stakeholders. Guided by the unique nature of ports and port-cities in Africa’s WIO region and the global south, economic development and rapid urbanization of cities will accelerate the consumption of urban land, energy, and natural resources. This will put a strain on the ecological environment, living space, and spatial comfort of urban residents. Therefore, the driving force (D), pressure (P), and impact (I) are all negatively correlated with urban sustainability. However, the state (S) is positive according to the DPSIR model while response (R) establishes the governance perspectives of all port city actors. By organizing and balancing these actors, this framework will aid and support effective decision-making input into public policy and bridge the science-policy gap based on the local context.

Moreover, the DPSIR framework illuminates the importance of the oceans as commons that provide an essential ecosystem service of trade and transportation. It illustrates the role and place of the ocean economy in our societies, and the need to better plan, prioritize and manage ocean resources and human activities such as port development and shipping activities in and around these spaces, for sustainable exploitation, utilization, and development. Numerous opportunities still exist for African oceans, and coastal port cities to develop and expand port operations. In doing so, secure a healthy ocean while creating wealth, and economic benefits for future generations through the formulation and implementation of a policy framework on port and port city-related waste management, port efficiency, and green port approaches.

To facilitate the development of sustainable port cities, it is important to adapt evidence-based approaches needed to measure and monitor marine health in the ocean systems, alongside the social and economic benefits and impacts, that must also be supported by robust governance processes. Presently, there is a limited but emerging awareness of the life-supporting roles that oceans play in the context of port city developments.

The sustainable port-city indicator framework developed shows the potential scope of considerations that can be useful in sustainable port city planning and development, particularly in developing countries. It is useful in operationalizing more synergistic, integrated, and holistic decision-making processes by considering all stakeholders across the four key dimensions (economics, governance, society, and environment) of sustainability.

At the drivers' level, the framework reveals twelve (12) drivers that show port-city sustainable management, the main driving forces of port-city sustainability are the development of society, economy, and a population whose processes occur in the natural space of the land-sea continuum. Thus, proper coordination and policy interventions need to be anchored on these drivers to guide sustainable port city development and management while sticking to globally accepted guidelines on sustainable development. Although port cities of the global south encounter inherent common processes and development dynamics, country-specific parameters need to be adhered to as each country and region has unique geographical, socio-cultural, and economic aspects that might differ.

At the pressure level, several challenges are faced by global south countries which are related to emissions and other related environmental burdens. These challenges are exerted on the port and cities' natural resources either on land and sea or in their neighborhood. In relative terms, pollution challenges exhibit the highest share of pressure with port and city growth. These challenges deprive ports and cities of sustainability in their quest for development and management. This speaks to the greater importance of multisector engagement in the policy dialogue on port and city development through the lens of ocean stewardship. Case by case approach to pressure management is key with borrowed experience from aspirator countries' approaches blended into their policies and regulations for better outcomes.

At the state level, it is apparent that the pressures cause a significant change in the original state of the ecosystem in global south ports and cities. As evidence, growth in the ports and cities attracts global attention for business and trade which has a vicious cyclical effect on the marine and neighborhood ecosystems. This points to the broader engagement between all stakeholders to dialogue on the possible sustainable approaches to investment commitments. This would then support long-term sustainability for ports and cities. Considering these challenges are socio-ecological, the solutions to them need to factor in this aspect to maintain the ecosystem balance.

At the impact level, relaxed management of the current states brings about both observed and unobserved impacts on the marine ecosystem. From the discussion, these impacts are felt in all four dimensions of sustainability. For instance, in the socio-economy dimension, solutions to impacts need to be mirrored based on how society and the economy interact at all levels and this applies to the other dimensions to have seamless solutions to the impacts. Planning and strategy with adequate resources offer the best approach toward impact evaluation and subsequent provision of necessary solutions.

Governance and affiliated institutions mandated with the responsibility of managing ports and cities prove to be vital in providing a needed response to impacts as a result of port and city development. At this level, it is necessary to assess the burden of the impact and task the relevant institution to give needed guidance in addressing the issue. Resource allocation to these institutions plays a vital role in achieving effective results. Policies and regulatory frameworks that support smooth interaction between state and non-state organizations that support port and city development need to be well formulated.

The analysis further reveals the multiple SDGs achievements and tradeoffs with targeted responses that span from the root drivers at the beginning of the framework. The pressure levels unveil the associated effects of the drivers spanning economic, social, environment and governance. These pressures guide policy initiatives to govern the port cities in a broader space. The states which are the deviations caused by the pressures from the original case equal the outcome because of the pressure on the available resources. Among the port city dependence, the pressures are quite high which automatically causes resource scarcity if not well mitigated. There will be a lapse in the sectors whether at the port city or beyond. It is conclusively inevitable that some of the highlighted sustainable development goals and targets need to be particularly shaped and callibrated to express the needs and aspirations of WIO countries and others should be cast to express the responsibilities of the developed world to aid the development process of ports and cities in the developing world. The need to strike a balance for all port city ecosystems yields the need to ease the impact of these pressures. This calls for the responses which are to be matched to the impacts to minimize tradeoffs while targeting sustainable development. Ports and cities in global south countries and their marine management have a vast array of players and stakeholder linkages which require a seamless policy blend across all the dimensions putting into consideration specific countries' unique economic, social and political statuses.

Future studies can explore the application of this proposed integrated port-city and marine sustainability framework to develop a composite index. The index offers an indicator-based assessment model to measure, quantify and monitor port-city sustainable development and ocean stewardship practices and their surrounding ecosystems of global south port cities.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Author contributions

DO - Substantial contribution in conceptualization, drafting and revising critical content of the work, methodology, analysis, and synthesis of discussions. JM - revising critical intellectual content. PD - revising critical intellectual content. MM - revising critical intellectual content. MG - drafting the work, and methodology. NN - drafting the work, and methodology. IC preparing the work, and methodology. SO - drafting the work, and methodology. BS- Logical Flow, writing and results interpretation of the manuscript. All authors consented to the publication of the work and agreed to be responsible for all aspects of the work. All authors contributed to the article and approved the submitted version.

Funding

This research was supported by WIOMSA under the Cities and Coasts Project (Grant number: Cities&Coasts/OP/2020/01), under the project "Spatial Planning Of Climate SMART And Resilient Port Cities In The WIO Region: A Case For Mombasa And Durban."

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2023.1052128/full#supplementary-material

References

Bell, S., and Morse, S. (2018). *Routledge handbook of sustainability indicators* (London and New York: Routledge: Taylor & Francis Group).

Bjerkan, K. Y., Hansen, L., and Steen, M. (2021). Towards sustainability in the port sector: The role of intermediation in transition work. *Environ. Innovation Societal Transitions* 40, 296–314. doi: 10.1016/j.eist.2021.08.004

Bond, P. (2014). "Collisions of community and capital in africa's armpit: South durban's contested port-petrochemical complex," in *Grassroots environmental governance: Community engagements with industrial development*, 1–24.

Booth, A. (2006). Brimful of STARLITE": toward standards for reporting literature searches. *J. Med. Library Assoc.* 94 (4), 421.

Booth, A., Noyes, J., Hannes, K., Harden, A., Harris, J., Lewin, S., et al. (2011). "Chapter 3: searching for studies," in *Supplementary guidance for inclusion of qualitative research in cochrane systematic reviews of interventions. version, 1.*

Bracking, S., and Diga, K. (2015). *Clairwood survey: Community views of the value of clairwood in the context of current development plans for Durban port expansion* (University of KwaZulu-Natal and Leverhulme Centre for the Study of Value).

Browne, M., Woexenius, J., Dablanc, L., Cherrett, T., and Morganti, E. (2017). "Port cities and urban logistics," in *LRN 2017 papers* (The Chartered Institute of Logistics and Transport).

Celliers, L., and Ntombela, C. (2015). *Urbanisation, coastal development and vulnerability, and catchments', Western Indian Ocean.*, 387.

Chen, Y. B., Chen, J. H., Li, C. X., and Feng, Z. Y. (2004). Evaluation index system of water resources carrying capacity of shenzhen city based on DPSIR model. *J. Hydraulic Eng.* 7, 98–103.

Chen, C., and Lam, J. S. L. (2018). Sustainability and interactivity between cities and ports: a two-stage data envelopment analysis (DEA) approach. *Marit. Pol. Manage.* 45 (7), 1–18. doi: 10.1080/03088839.2018.1450528

Chua, T.-E., Bonga, D., and Bermas-Atrigenio, N. (2006). Dynamics of integrated coastal management: PEMSEA's experience. *Coast. Manage.* 34 (3), 303–322. doi: 10.1080/08920750600686695

Costanza, R. (1999). The ecological, economic, and social importance of the oceans. *Ecol. economics* 31 (2), 199–213. doi: 10.1016/S0921-8009(99)00079-8

Couling, N., and Hein, C. (2020). *'The urbanisation of the sea: From concepts and analysis to design'.*

Crossland, C. J., Kremer, H. H., Lindeboom, H., Crossland, J. I. M., and Tissier, M. D. A. L. (2005). *Coastal fluxes in the anthropocene: the land-ocean interactions in the coastal zone project of the international geosphere-biosphere programme* (Springer Science & Business Media).

Cui, Q. (2017). Environmental efficiency measures for ports: An application of RAM-Tobit-RAM w-ith undesirable outputs. *Marit. Pol. Manag.* 44 (5), 551–564. doi: 10.1080/03088839.2017.1319982

CSD United Nations Commission of Sustainability Development (2007). *Indicators of sustainable development: Guidelines and methodologies* (New York, NY, USA: United Nations).

Daamen, T. (2007). "Sustainable development of the European port-city interface," in *ENHR-conference*. 25–28.

Dados, N., and Connell, R. (2012). The global south. *Contexts* 11 (1), 12–13. doi: 10.1177/1536504212436479

Darbra Roman, R. M., Wooldridge, C., and Puig Duran, M. (2020). *ESPO environmental report 2020-EcoPortsinsights 2020.*

de Alencar, N. M. P., Le Tissier, M., Paterson, S. K., and Newton, A. (2020). Circles of coastal sustainability: A framework for coastal management. *Sustainability* 12 (12), 4886. doi: 10.3390/su12124886

De Langen, P. W. (2006). Stakeholders, conflicting interests and governance in port clusters. *Res. Transportation Economics* 17, 457–477. doi: 10.1016/S0739-8859(06)17020-1

Ding, L., Shao, Z., Zhang, H., Xu, C., and Wu, D. (2016). A comprehensive evaluation of urban susta-inable development in china based on the TOPSIS-entropy method. *Sustainability* 8, 746. doi: 10.3390/su8080746

Ducruet, C., and Berli, J. (2018). *Measuring land-sea interactions at ports and cities : insights from geomatics and network analysis', Portus*, 35. Available at: https://shs.hal.science/halshs-01881554.

Ehler, C., and Douvere, F. (2007). *Visions for a Sea change: Report of the first international workshop on marine spatial planning* (Paris, France: Intergovernmental Oceanographic Commission and the Man and the Biosphere Programme UNESCO Headquarters).

Ehler, C., Zaucha, J., and Gee, K. (2019). "Maritime/marine spatial planning at the interface of research and practice," in *Maritime spatial planning* (Cham: Palgrave Macmillan), 1–21.

Ernst, L., de Graaf-Van Dinther, R., Peek, G., and Loorbach, D. (2016). Sustainable urban transformation and sustainability transitions; conceptual framework and case study. *J. Cleaner Production* 112, 2988–2999. doi: 10.1016/j.jclepro.2015.10.136

Folke, C., Biggs, R., Norström, A. V., Reyers, B., and Rockström, J. (2016). Social-ecological resilience and biosphere-based sustainability science. *Ecol. Soc.* 21 (3). doi: 10.5751/ES-08748-210341

Foulds, S. (2015). "Port of Durban: ports," in *Transport world Africa*, vol. 13 (1), 34–36.

Friess, B., and Grémaud-Colombier, M. (2021). Policy outlook: Recent evolutions of maritime spatial planning in the European union. *Mar. Policy* 132, 103428. doi: 10.1016/j.marpol.2019.01.017

Gari, S. R., Newton, A., and Icely, J. D. (2015). A review of the application and evolution of the DPSIR framework with an emphasis on coastal social-ecological systems. *Ocean Coast. Manage.* 103, 63–77. doi: 10.1016/j.ocecoaman.2014.11.013

Gekara, V. O., and Nguyen, X.-V. T. (2020). Challenges of implementing container terminal operating system: The case of the port of Mombasa from the belt and road initiative (BRI) perspective. *J. Int. Logistics Trade* 18 (1), 49–60. doi: 10.24006/jilt.2020.18.1.049

Gidado, U. (2015). Consequences of port congestion on logistics and supply chain in African ports. *Developing Country Stud.* 5 (6), 160–167.

Global Reporting Initiative, (GRI). (2011). *GRI 3.1 Sustainability Reporting Guidelines* (Amsterdam, The Netherlands: Global Reporting Initiative (GRI)).

Gregory, A. J., Atkins, J. P., Burdon, D., and Elliott, M. (2013). A problem structuring method for ecosystem-based management: The DPSIR modelling process. *Eur. J. Operational Res.* 227 (3), 558–569. doi: 10.1016/j.ejor.2012.11.020

Haase, D. (2015). Reflections about blue ecosystem services in cities. *Sustainability Water Qual. Ecol.* 5, 77–83. doi: 10.1016/j.swaqe.2015.02.003

Halpern, B. S., Longo, C., Hardy, D., McLeod, K.L., Samhouri, J.F., Katona, S.K., et al. (2012). An index to assess the health and benefits of the global ocean. *Nature* 488 (7413), 615–620.

Hein, C. (2021). Port city porosity: Boundaries, flows, and territories. *Urban Plann.* 6 (3), 1–9. doi: 10.17645/up.v6i3.4663

Hesse, M. (2018). Approaching the relational nature of the port-city interface in Europe: Ties and tensions between seaports and the urban. *Tijdschrift voor economische en sociale geografie* 109 (2), 210–223. doi: 10.1111/tesg.12282

Hiranandani, V. (2014). Sustainable development in seaports: a multi-case study. *WMU J. Maritime Affairs* 13 (1), 127–172. doi: 10.1007/s13437-013-0040-y

Hossain, T., Adams, M., and Walker, T. R. (2021). Role of sustainability in global seaports. *Ocean Coast. Manage.* 202, 105435. doi: 10.1016/j.ocecoaman.2020.105435

Hoyle, B. S. (1989). The port–city interface: Trends, problems and examples. *Geoforum* 20 (4), 429–435. doi: 10.1016/0016-7185(89)90026-2

Hoyle, B. (1999). Port concentration, inter-port competition and revitalization: the case of Mombasa, Kenya. *Maritime Policy Manage.* 26 (2), 161–174. doi: 10.1080/030888399286989

Hoyle, B. S. (2000). "Port development: Growth, competition and revitalization," in *Kenya Coast handbook: Culture, resources and development in the East African littoral.* Eds. J. Hoorweg, D. Foeken and R. A. Obudho (Hamburg: Lit Verlag), 373–390.

Huang, L., Wu, J., and Yan, L. (2015). Defining and measuring urban sustainability: a review of indicators. *Landscape Ecol.* 30 (7), 1175–1193. doi: 10.1007/s10980-015-0208-2

Humphreys, M., Stokenberga, A., Dappe, M. H., and Hartmann, O. (2019). *Port development and competition in East and southern Africa: Prospects and challenges.*

Jacobs, W., Ducruet, C., and De Langen, P. (2010). Integrating world cities into production networks: The case of port cities. *Global Networks* 10 (1), 92–113. doi: 10.1111/j.1471-0374.2010.00276.x

Jiao, L., and Wang, D. (2020). Carrying capacity of water resources in guilin city based on DPSIR framework and water footprint theory. *Sci. Soil Water Conserv.* 18 (3), 74–80. doi: 10.16843/j.sswc.2020.03.009

Jiménez-Aceituno, A., Peterson, G. D., Norström, A. V., Wong, G. Y., and Downing, A. S. (2020). 'Local lens for SDG implementation: Lessons from bottom-up approaches in Africa. *Sustainability Sci.* 15 (3), 729–743. doi: 10.1007/s11625-019-00746-0

Karimpour, R., Ballini, F., and Ölcer, A. I. (2019). Circular economy approach to facilitate the transition of the port cities into self-sustainable energy ports–a case study in Copenhagen-malmö port (CMP). *WMU J. Maritime Affairs* 18 (2), 225–247. doi: 10.1007/s13437-019-00170-2

Karnauskaitė, D., Schernewski, G., Schumacher, J., Grunert, R., and Povilanskas, R. (2018). Assessing coastal management case studies around Europe using an indicator based tool. *J. Coast. Conserv.* 22 (3), 549–570. doi: 10.1007/s11852-018-0597-x

Kidd, S. (2018). "Land-Sea interactions and the ecosystem approach in ocean planning and governance," in *The ecosystem approach in ocean planning and governance* (Brill Nijhoff), 140–159.

Knatz, G. (2017). How competition is driving change in port governance, strategic decision-making and government policy in the united states. *Res. Transportation Business Manage.* 22, 67–77. doi: 10.1016/j.rtbm.2016.08.003

Kondratyev, K., and Pozdnyakov, D. V. (1996). Land-ocean interactions in the coastal zone: The LOICZ project. *Il Nuovo Cimento C* 19 (3), 339–354. doi: 10.1007/BF02509293

Kong, Y., and Liu, J. (2021a). Sustainable port cities with coupling coordination and environmental efficiency. *Ocean Coast Manag* 205, 105534.

Kong, Y., and Liu, J. (2021b). Sustainable port cities with coupling coordination and environmental efficiency. *Ocean Coast Manag* 205. doi: 10.1016/j.ocecoaman.2021.105534

Lacalle, I., Belsa, A., Vaño, R., and Palau, C. E. (2020). Framework and methodology for establishing port-city policies based on real-time composite indicators and IoT: a practical use-case. *Sensors* 20 (15), 4131. doi: 10.3390/s20154131

Lainas, I. (2018). Land-sea interactions and maritime spatial planning guidelines in the context of European union. the case of Greece. *RELAND: Int. J. Real Estate Land Plann.* 1, 365–376.

Lam, J. S. L., and Yap, W. Y. (2019). A stakeholder perspective of port city sustainable development. *Sustainability* 11 (2), 447. doi: 10.3390/su11020447

Lawer, E. T., Herbeck, J., and Flitner, M. (2019). Selective adoption: How port authorities in Europe and West Africa engage with the globalizing 'Green port'idea. *Sustainability* 11 (18), 5119. doi: 10.3390/su11185119

Leimgruber, W. (2018). *Between global and local: marginality and marginal regions in the context of globalization and deregulation* (Routledge).

Li, J., Jiang, B., and Lin, N. (2018a). A study on the influence mechanism of port environmental carrying capacity. *Asian J. Ship. Logistics* 34 (3), 191–197. doi: 10.1016/j.ajsl.2018.09.002

Lim, S., Pettit, S., Abouarghoub, W., and Beresford, A. (2019). Port sustainability and performance: A systematic literature review. *Transport. Res. Transport Environ.* 72, 47–64. doi: 10.1016/j.trd.2019.04.009

Li, W., Yi, P., and Zhang, D. (2018b). Sustainability evaluation of cities in northeastern china usi-ng dynamic TOPSIS-entropy methods. *Sustainability* 10 (12), 4542. doi: 10.3390/su10124542

Liu, W., Sun, C., Zhao, M., and Wu, Y. (2019). Application of a DPSIR modeling framework to assess spatial–temporal differences of water poverty in China. *J. Am. Water Resour. Assoc.* 55 (1), 259–273. doi: 10.1111/1752-1688.12724

Liu, J., Zhou, J., Liu, F., Yue, X., Kong, Y., and Wang, X. (2019). Interaction analysis and sustainable development strategy between port and city: the case of liaoning. *Sustainability* 11 (19), 5366. doi: 10.3390/su11195366

Lokrantz, A. J. (2020) *SDGs | biosphere futures.* Available at: https://www.biospherefutures.net/sdgs (Accessed 4 December 2022).

Lozano, R., Fobbe, L., Carpenter, A., and Sammalisto, K. (2019). Analysing sustainability changes in seaports: Experiences from the gävle port authority. *Sustain. Dev.* 27 (3), 409–418. doi: 10.1002/sd.1913

Lundin, M. (2003). *Indicators for measuring the sustainability of urban water systems: A life cycle approach* (Citeseer) (Gothenburg, Sweden: Chalmers University of Technology).

Mair, S., Jones, A., Ward, J., Christie, I., Druckman, A., Lyon, F., et al. (2018). "A critical review of the role of indicators in implementing the sustainable development goals," in *Handbook of sustainability science and research*, 41–56.

Mao, X., Wang, X., Chen, Q., and Yin, X. (2014). A PSR-framework-based health assessment of ulansuhai lake in China. *Polish J. Environ. Stud.* 23 (6), 2093–2102.

Martel, P. (2016). *An examination of the knowledge production process in a spatial planning exercise: the case study of the Back of Port Project in Durban, South Africa.* PhD Thesis.

Martí, X., Lescrauwaet, A.-K., Borg, M., and Valls, M. (2007). *Indicators guidelines: to adopt an indicators-based approach to evaluate coastal sustainable development.*

Mather, A., and Reddy, K. (2011). Expansion plans for the port of Durban: What are the issues for the city of Durban? *J. Shipping Ocean Eng.* 1 (1), 30–45.

Matusiewicz, M., and Rolbiecki, R. (2021). The tendency of city stakeholders to implement sustainable logistics measures using the port city of Gdynia as an example. *Zeszyty Naukowe Akademii Morskiej w Szczecinie* [Preprint].

Merk, O. (2013). *The competitiveness of global port-cities: synthesis report.*

Merk, O., and Dang, T.-T. (2013). *The effectiveness of port-city policies: A comparative approach.*

Molelu, O., and Enserink, B. (2018). *Tensions in durban's city-port: The governance of the social and ecological impacts of planning and development.*

Molelu, O., Mbwana, M., Charo, T. J., Wanyonyi, I., and Nato, G. (2021). *Reasons why co-design and planning are important in WIO port-cities: Case study of Mombasa, Kenya.*

Morel, G., Lima, F. R., Martell-Flores, H., and Hissel, F. (2013). Tools for an integrated systems approach to sustainable port city planning. *urbe. Rev. Bras. Gestão Urbana* 5, 39–49. doi: 10.7213/urbe.05.002.SE03

Moretti, B. (2021a). "Beyond the port city," in *Beyond the port city* (JOVIS Verlag GmbH).

Moretti, B. (2021b). *Beyond the port city* (JOVIS Verlag GmbH).

Moscou, K., Kohler, J. C., and MaGahan, A. (2016). Governance and pharmacovigilance in Brazil: a scoping review. *J. Pharm. Policy Pract.* 9 (1), 1–15. doi: 10.1186/s40545-016-0053-y

Moussiopoulos, N., Achillas, C., Vlachokostas, C., Spyridi, D., and Nikolaou, K. (2010). Environmental, social and economic information management for the evaluation of sustainability in urban areas: A system of indicators for thessaloniki, Greece. *Cities* 27 (5), 377–384. doi: 10.1016/j.cities.2010.06.001

Mpungose, A., and Maharaj, B. (2022). "Megaprojects in the context of neoliberalism: Socio-economic and spatial impacts of the proposed dig-out port in Durban, south Africa," in *Urban forum* (Springer), 173–195.

Musso, E., Benacchio, M., Ferrari, C., and Haralambides, H. E. (2011). "On the economic impact of ports: Local vs. national costs and benefits," in *Proceedings of the 9th World Conference on Transport Research*, Seul (Corea del Sur.

Naicker, R., and Allopi, D. (2015). The need for expansion of the Durban container terminal. *Int. J. constructive Res. civil Eng* 1 (2), 33–38.

Ngangaji, M. M. F. (2019).

Niemeijer, D., and de Groot, R. S. (2008). Framing environmental indicators: moving from causal chains to causal networks. *Environment Dev. sustainability* 10 (1), 89–106. doi: 10.1007/s10668-006-9040-9

Noyes, J., Booth, A., Hannes, K., Harden, A., Harris, J., and Lewin, S. (2011). "5: Extracting qualitative evidence," in *Supplementary guidance for inclusion of qualitative research in cochrane systematic reviews of interventions*, vol. 2011a. Eds. J. Noyes, A. Booth, K. Hannes, A. Harden, J. Harris and S. Lewin In. Version, 1.

Odhiambo, J. (2018). *Sustainable port development in the WIO region.*

Environment Directorate, Organisation for Economic Cooperation and Development (2004). *OECD key environmental indicators.* (Paris, France: OECD).

Okafor-Yarwood, I., Kadagi, N. I., Miranda, N. A.F., Uku, J., Elegbede, I. O., and Adewumi, I. J. (2020). The blue economy–cultural livelihood–ecosystem conservation triangle: The African experience. *Front. Mar. Sci.* 7, 586. doi: 10.3389/fmars.2020.00586

Olukoju, A. (2020). African Seaports and development in historical perspective. *Int. J. Maritime History* 32 (1), 185–200. doi: 10.1177/0843871419886806

Olusegun Onifade, A. (2020). New seaport development-prospects and challenges: Perspectives from apapa and calabar seaports, Nigeria. *Logistics* 4 (2), 8. doi: 10.3390/logistics4020008

Osborn, D., Cutter, A., and Ullah, F. (2015). Universal sustainable development goals. *Understanding Transformational Challenge Developed Countries.* (OCEANS 2016-Shanghai: IEEE), pp. 1–8.

Owei, O. B., Obinna, V. C., and Ede, P. N. (2010). "The challenges of sustainable land use planning in Nigerian cities. The case of port Harcourt," in *Proceedings of the ISOCARP congress*(Nairobi, Kenya), 19–23.

Pakzad, P., and Osmond, P. (2016). Developing a sustainability indicator set for measuring green infrastructure performance. *Procedia-social Behav. Sci.* 216, 68–79. doi: 10.1016/j.sbspro.2015.12.009

Patrício, J., Elliott, M., Mazik, K., Papadopoulou, K.-N., and Smith, C. J. (2016). DPSIR–two decades of trying to develop a unifying framework for marine environmental management? *Front. Mar. Sci.* 3, 177.

Raszkowski, A., and Bartniczak, B. (2019). On the road to sustainability: Implementation of the 2030 agenda sustainable development goals (SDG) in Poland. *Sustainability* 11 (2), 366. doi: 10.3390/su11020366

Ronco Zapatero, J. (2018). *Maritime spatial planning in the EU–achievements and future development*.

Schipper, C. A., Vreugdenhil, H., and De Jong, M. P. C. (2017). A sustainability assessment of ports and port-city plans: Comparing ambitions with achievements. *Transportation Res. Part D: Transport Environ.* 57, 84–111. doi: 10.1016/j.trd.2017.08.017

Selomane, O., Reyers, B., Biggs, R., and Hamann, M. (2019). Harnessing insights from social-ecological systems research for monitoring sustainable development. *Sustainability* 11 (4), 1190. doi: 10.3390/su11041190

Serebrisky, T., Sarriera, J.M., Su´arez-Alem´an, A., Araya, G., Brice˜no-Garmendía, C., and Schwartz, J. (2016). Exploring the drivers of port efficiency in latin america and the caribbean. *Transport Pol.* 45, 31–45. doi: 10.1016/j.tranpol.2015.09.004

Shan, J., Yu, M., and Lee, C.-Y. (2014). An empirical investigation of the seaport's economic impact: Evidence from major ports in China. *Transportation Res. Part E: Logistics Transportation Rev.* 69, 41–53. doi: 10.1016/j.tre.2014.05.010

Singh, R. K., Murty, H. R., Gupta, S. K., and Dikshit, A. K. (2009). An overview of sustainability assessment methodologies. *Ecol. Indic.* 9 (2), 189–212. doi: 10.1016/j.ecolind.2008.05.011

Sujantoko, S., Pratikto, W. A., Prastianto, R. W., Maulana, M. I., and Vibriyanti, A. (2022). Study of changes in coastal morphology due to utilization of the Surabaya city coastal area. *Int. J. Mar. Eng. Innovation Res.* 7 (1). doi: 10.12962/j25481479.v7i1.12029

Tan, S., Yang, J., Yan, J., Lee, C., Hashim, H., and Chen, B. (2017). A holistic low carbon city indicator framework for sustainable development. *Appl. Energy* 185, 1919–1930. doi: 10.1016/j.apenergy.2016.03.041

Tsatsou, A. (2015). *Port-city relationship and climate change: Actions for resilience*.

van den Houten, J. (2017). *A system dynamics exploration of port-city development: The case of tema, Ghana*.

Verhoeven, P., Michail, A., Shieh, V., and Van Loo, F. (2020). "World ports sustainability report," in *World ports sustainability program*. Https://Sustainableworldports. Org/Wpcontent/Uploads/WORLD-PORTS-SUSTAINABILITY-REPORT-2020-FIN. Pdf.

Vickers, B. (2012). "Towards a new aid paradigm: South Africa as African development partner," in *Cambridge Review of international affairs*, 25 (4), 535–556.

Wang, C. N., Nguyen, N. A. T., Fu, H. P., Hsu, H. P., and Dang, T. T. (2021). Efficiency assessment of seaport terminal operators using dea malmquist and epsilon-based measure models. *Axioms* 10 (2). doi: 10.3390/axioms10020048

Wang, W., Sun, Y., and Wu, J. (2018). Environmental warning system based on the DPSIR model: A practical and concise method for environmental assessment. *Sustainability* 10 (6), 1728. doi: 10.3390/su10061728

Wang, D., and Zhao, Y. (2016). "Research on quantitative evaluation indicator system of seaport sustainable development," in *OCEANS 2016-shanghai* (IEEE), 1–8.

Wanke, P., Nwaogbe, O. R., and Chen, Z. (2018). Efficiency in nigerian ports: handling imprecise data with a two-stage fuzzy approach. *Marit. Pol. Manage.* 45 (5), 699–715. doi: 10.1080/03088839.2017.1410588

Warhurst, A. (2002). Sustainability indicators and sustainability performance management. *Mining Minerals Sustain. Dev. [MMSD] project Rep.* 43, 129.

Woxenius, J. (2017). *Mombasa: options for the port city interface – final report*. World Bank.

Xiao, Z., and Lam, J. S. L. (2017). A systems framework for sustainable development of Port City: Case study of Singapore's policies. *Res. Transp. Bus. Manag.* 22, 255–262. doi: 10.1016/j.rtbm.2016.10.003

Xu, X., Hao, J., and Deng, Y. (2017). Industry interdependence dynamics and structure change causal analysis: An empirical study on China's shipbuilding industry. *Sustainability* 50, 1–8. doi: 10.1016/j.scs.2019.101529

Yi, P., Dong, Q., and Li, W. (2019). Evaluation of city sustainability using the deviation maximization method. *Sustain. Cities Soc.* 22, 255–262. doi: 10.1016/j.rtbm.2016.10.003

Yi, P., Li, W., and Li, L. (2018). Evaluation and prediction of city sustainability using MCDM and stochastic simulation methods. *Res. Transp. Bus. Manag.* 10 (10), 3771. doi: 10.3390/su10103771

Zhang, H., Uwasu, M., Hara, K., and Yabar, H. (2011). Sustainable urban development and land use change–a case study of the yangtze river delta in china. *Sustainability* 2 (7), 1074–1089. doi: 10.3390/su2071074

Zheng, Y., Zhao, J., and Shao, G. (2020). Port city sustainability: A review of its research trends. *Sustainability* 12 (20), 8355. doi: 10.3390/su12208355