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Circles of port sustainability: A novel method combining global comparability and local relatability in performance assessment

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ABSTRACT

Ports are increasingly 'greening' operations to protect their 'license to operate' by integrating social-environmental considerations into their management and reporting on their sustainability performance. In this research, we develop a novel method for port sustainability performance (PSP) assessment that combines science-based knowledge with place-based contextualisation. Specifically, we address a recognised challenge of combining global ('top-down') techno-scientifically oriented indicators with place-based locally relatable ('bottom-up') contexts in sustainability performance, in addition to addressing limitations encountered in empirical verification. First, a critical evaluation of the international literature on port sustainability assessments is undertaken to distil commonalities in global performance indicators, and to identify typical frames used in the design of sustainability performance indices. We apply this learning, together with place-based experiential knowledge, to develop a science-based framework for a Port Sustainability Performance (PSP) Index that is explicitly aligned with the Sustainability Development Goals (SDGs). We then apply a co-design process to demonstrate local customisation of the index to derive place-based quantifiable measures and targets. Further, for easy-to-use empirical verification, a simple spreadsheet is applied to develop a flexible weighted scoring matrix. The matrix uses place-based rating systems for selected measures and associated targets, and aggregates allocated scores into informative outputs. Finally, the concept of *Circles of Sustainability* is adapted for ports to visually display sustainability performance, in alignment with related SDGs. This research contributes to bridging the science-practice divide in reporting on port sustainability performance.

1. Introduction

Ports are critical trade facilitators in the global economic system. They have undergone phenomenal growth over the past decades.

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In their earliest forms ports could operate cost-effectively and safely without competition in uncontested seascapes (Kaliszewski, 2018; Lee et al., 2018). However, with rapid coastal urbanization, competition for depleting natural resources and increasing stakeholder empowerment and regulatory demands (Burt 2014; Riekhof et al., 2019) ports are increasingly forced to pursue 'greening' of their operations and activities, not only for economic growth and environmental competitiveness, but also to protect their 'license to operate' (Lam and Van de Voorde, 2012; Roh et al., 2016; Haezendonck and Langenus, 2019). In addition, climate change necessitates more sustainable practices in ports, both in mitigating for and adapting to risks associated with increased storminess, sea level rise and other climate related factors (Stein and Acciaro, 2020). It is in response to these challenges that the concept of 'Green Ports' emerged, primarily focused on balancing *economic and environmental sustainability* in port systems (Lam and Notteboom, 2014; Maritz et al., 2014; Bergqvist and Monios, 2019). The concept of 'Sustainable Port Development' built on that of 'Green Ports' to include consideration of *social sustainability*, in essence advocating long-term ports security through balanced economic growth, environmental protection and social progress (Hiranandani, 2014). Indeed, ports can no longer secure their 'license to operate' without addressing both societal and environmental concerns – the so-called 5th generation ports (Kaliszewski, 2018).

With the adoption and establishment of the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs), monitoring and assessment of progress towards achieving sustainable development have become a necessity, giving rise to the process of sustainability assessment (Sala et al., 2015). The primary purpose of sustainability assessment is to inform policy development and management decision-making towards achieving the SDGs (Sala et al., 2015; Villeneuve et al., 2017), and to flag areas where improvements are required. Sustainability assessment can also assist individual ports in reporting in terms of their corporate social responsibility and compare their sustainability performance against other ports (Schipper et al., 2017; Lim et al., 2019).

James (2015) identified various forms of sustainability performance assessment. These include formal top-down methods where sustainability is assessed against a set of standardised indicators - popularly applied by organisations to publicly communicate their performance. These methods typically use frameworks to provide structure to an assessment. Global examples include the Global Reporting Initiative, ISO14031 and AA1000 (James, 2015), and the Sustainable Development Analytical Grid, part of the United Nation's SDG Acceleration Toolkit (UNDG, 2019). However, formal top-down approaches come with challenges. Sustainability may mean different things to different people, and it is often difficult for top-down, techno-scientifically oriented definitions of sustainability to be universal, comprehensive, comparable, or defensible across place-based local or smaller-scale contexts (James, 2015; Bell and Morse, 2018). Such complex, techno-scientifically oriented approaches can also discourage truly participatory efforts towards consensus and action (James, 2015). The process of improving organizational sustainability rests on terms defined by an organization itself, but within an objectifiable and generalised framework, thus spanning place-based and general contexts (James, 2015). Furthermore, effective uptake and implementation of sustainability reporting systems require empirical verification (Stein and Acciaro, 2020). Such empirical verification has as often been limited or lacking (Laxe et al., 2016; Schipper et al., 2017).

Unsurprisingly, sustainability performance assessment is starting to be applied in port management globally (Geerts et al., 2021), and it has been the subject of numerous research studies. These range from the selection of port-specific indicators or criteria (e.g., Peris Mora et al., 2005; Shiau and Chuang, 2015; Lu et al., 2016; Roh et al., 2016; Puig et al., 2017; Roos and Neto, 2017; Fobbe et al., 2020; Stein and Acciaro, 2020) to performance assessment methods (e.g., Lirn et al., 2013; Chiu et al., 2014; Asgari et al., 2015; Chen and Pak, 2017; Laxe et al., 2017; Schipper et al., 2017; Xiao and Lam, 2017; Oh et al., 2018; Brunila et al., 2023). The analytical hierarchy process (AHP) analysis (e.g., Lirn et al., 2013; Chiu et al., 2014; Asgari et al., 2015) and Delphi technique (e.g., Chen and Pak, 2017) have been popular in 'green port' performance assessment, largely drawing on qualitative expert opinions obtained through questionnaires. However, in their review, Laxe et al. (2016) established that there was little empirical verification within the broader context of sustainability performance. Subsequently, they developed a method to assess relative performance across social, institutional, economic, and environment dimensions in Spanish ports using data captured in mandatory sustainability reports (Laxe et al., 2017). Schipper et al. (2017), also in response to the lack of empirical verification, developed a scoring index for inter-port comparison specifically focusing on the likely contribution of port *planning initiatives* in securing future sustainability outcomes. Stein and Acciaro (2020), however stressed the importance of including *operational effectiveness* in achieving sustainable value creation, reflected, for example, in the status of environmental quality, social cohesion and economic competitiveness.

In the literature, the concept of *Circles of Sustainability* has been introduced to visualise sustainability performance in areas such as urban planning (James, 2015) using a relatively simple radar diagrams, to provide more than just *'high-sounding words'* (page xvii, James, 2015). This concept has also been applied in coastal management (de Alencar et al., 2020; Bryant and Elliot, 2021), and it potentially offers an opportunity for visualising port sustainability performance, as coasts and their management are the broader domain within which ports are nested (Taljaard et al., 2021).

Considering the above-mentioned challenges, the purpose of this study is to develop a novel method for sustainability performance assessment in ports that combines global ('top-down') techno-scientifically oriented indicators with place-based locally relatable ('bottom-up') contexts (James, 2015; Bell and Morse, 2018), and which is supported by an easy-to-use empirical verification system. It is envisaged that this will enable port authorities to monitor their own sustainability trajectory over time, or to compare performance spatially across different ports (Laxe et al., 2016).

This introduction is followed by a theoretical background which frames the scientific context of the study (Section 2). The research method, presented in Section 3, adopts a design science approach to develop a novel method for assessing a globally comparable ('top-down') and locally relatable ('bottom-up') sustainability performance index for ports. The results and discussion (Section 4) describe the development process, comprising: (i) the identification of globally representative sustainability indicators, (ii) the development of a science-based framework for a port sustainability performance (PSP) Index, (iii) a co-design process to identify locally relatable performance measures and targets, (iv) the development of an easy-to-use empirical validation system using a simple spreadsheet, before lastly (v) adapting the concept of *Circles of Sustainability* to visually communicate sustainability performance outputs from the

PSP Index. Conclusions stemming from this research are presented in Section 5.

2. Theoretical background

To establish the need for a port sustainability assessment framework that is integrated within organisational procedures and supported by appropriate science-based technologies and tools, relevant background theory is highlighted. First, the conceptual underpinning of sustainability assessment is described, before the use of indicators and the considerations and requirements in developing indicators for sustainability assessment are addressed. This is followed by a section on port governance, included so that the reader can situate the requirements of port officials in reporting on sustainability within the context of different port governance models.

2.1. Concept of sustainability

One of the most widely popular definitions of sustainability is 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987). However, opinions still diverge on how this can be achieved. A first attempt was the systems approach, characterising sustainability as the optimisation of goals spanning the environmental, economic, and social systems (Barbier, 1987). The complexity and the multidimensional nature of sustainable development increasingly challenged science, leading to the emergence of a new discipline called sustainability science (Kates et al., 2001). Based on a review, Sala et al. (2015) derived four key definitions of sustainability science: (i) an advanced analysis of complex systems using analytical-descriptive tools to improve understanding on conditions in the coupled social-environment; (ii) a transformational agenda, that addresses the needs of the research community to complement its historic role in offering a participatory and practical approach to problem solving; (iii) a scientific option to move past the reductionist approach of the traditional sciences through a holistic systems approach to problem-solving; and (iv) a solution-oriented approach studying the complex, coupled social-environment system across multi temporal and spatial scales. These definitions affirm the multidimensionality of sustainability science and the far-reaching nature of the scientific challenge of characterizing sustainability.

In 2015, the United Nations adopted the 2030 Agenda for Sustainable Development with 17 Sustainable Development Goals (SDGs) (United Nations, 2015). The system of SDGs comprises a complex set of sub-targets and about 230 indicators that need to be embedded in sustainability science systems to realise effective sustainable outcomes. To address the complexity, Barbier and Burgess (2017) showed that each of the SDGs can be identified as primarily an economic, environmental, or a social system goal, representing a systems approach to sustainable development. In 2018, the World Ports Sustainability Program (WPSP) led by the International Association of Ports and Harbours (IAPH) partnering with major port organisations, set out to support sustainable development in ports that aligned with the UN's Sustainability Agenda and the SDGs. They provided a comprehensive list of potential actions in the port sector that will contribute to achieving the SDGs (WPSP, 2020). Thus, the concept of sustainability is increasingly finding its way into port systems (Alamoush et al., 2021), as is explored in greater detail in this study.

2.2. Indicator-based assessment

The first evidence of using indicators to track change originated in the field of economics in the 1920s with the Harvard Economic Society's ABC barometers for business activities (Samuelson, 1987), the forerunners of the popular leading cyclical economic indicators of Mitchell and Burns (1938). For use in the environmental context, Heink and Kowarik (2010) adopted the definition applied by the Organisation for Economic Cooperation and Development (OECD) to an indicator in ecology and environmental planning as 'a component, or a measure of environmentally relevant phenomena used to depict or evaluate environmental conditions or changes or to set environmental goals'. Indicators have two key functions, namely: (i) to reduce the number of parameters and measurements typically required to represent a situation; and (ii) to simplify communication processes of results to end-users (OECD, 1993). Therefore, from an environmental management and planning perspective, indicator assessment provides a useful approach to present available and necessary information in a simplified and digestible format for decision-making. It is important to balance the number of indicators, as well as the details on these. Too many indicators may clutter the overview, while too few indicators may be insufficient to provide all the required and relevant information. Simplifying and adapting indicator assemblages for end-users may not always adhere to strict scientific rigour, and as a result indicators should be considered as an expression of the best available knowledge (OECD, 1993). In selecting indicators, it is important to set *suitable targets* against which the 'measured' results can be compared to provide information on current states or trends (Moldan et al., 2017).

The use of indicators is central in sustainability assessment, where numerous indices have been developed using different amalgams of individual indicators. Given the complex and often place-based interpretation of sustainability, a wide diversity of approaches and indicators have emerged (Bell and Morse, 2018). Spangenberg (2018) emphasized the importance of being fully aware of possible biases in the selection of indicators and the interpretation of measures, for example linked to assumptions deriving from world views within which they were selected, and the consequential influence on messages. To facilitate improved commensurability across community reporting ontology, using critical issues and indicators developed by the community, and standard global sustainability conceptualisations, James (2015) argued that sustainability reporting frameworks should cater for bottom-up sustainability processes and associated indicators, but also allow for alignment with global reporting requirements. Furthermore, frameworks need to provide guidance for selecting indicators as well as approaches for assessing outcomes (James, 2015).

With sustainability performance increasingly finding its way into port systems (Geerts et al., 2021), Puig et al. (2014) argued that suitable indicators for performance assessment in ports should meet the following criteria: (i) responsiveness – able to timeously determine environmental, social, or economic change; (ii) specificity – using cause-effect relationships that are responsive to human activity with low responsiveness to other sources of change; (iii) accuracy – results should be consistent for the set purpose; and (iv) availability of data – the presence of relevant measurements or estimates.

2.3. Port governance systems and sustainability

Port governance comprises both internal and external systems (Verhoeven and Vanoutrive, 2012). Internal governance systems are conceptualized in different ways. For example, Ibrahimi (2017) distinguishes two decision-making levels, namely strategic decision-making (termed 'institutional') and administration and management (termed 'operational'), respectively and commonly associated with port authorities and port operators. Different tasks and responsibilities are associated with these decision-making levels, depending on the nature of the port governance model. Port governance models have typically ranged from the service port with a predominantly public character, the landlord port comprising mixed public-private organisations, to the private service port where the state has no marked involvement or interest (Notteboom and Haralambides, 2020). Although this typology of port models is an over-simplification (see Ibrahimi, 2017), it provides some insight into how different port governance systems might influence and implement sustainable port development. For example, planning, infrastructure and operations can be more easily aligned in a public port which is governed by a single public authority, but innovation and efficient use of resources might be lacking. On the other hand, private ports, where terminals are handled by private companies, are most flexible with respect to investments and operations, but risk paying less attention to local societal and environmental issues (World Bank, 2007). Notteboom and Haralambides (2020) examined port governance models using a policy science lens and distinguished different combinations of national/international, public/private, and industrial/post-industrial factors leading to eight flavours of port governance. They also recognise the increasing need for port governance to adapt to changing external conditions, including increasing sustainability requirements. External governance concerns the related or affected economic, societal, and public aspects as port operations do not take place in isolation. This is especially relevant at the port-city interface where interaction occurs across diverse economic, social, environmental and cultural dimensions (see Tijan et al., 2021; de Oliveira et al., 2021). Port governance also must consider and address national legislation and policies. Furthermore, ports increasingly need to address governance at the port cluster level, taking cognisance of regional and international orientations (Lam et al., 2013; Notteboom and Haralambides, 2020).

Glass and Newig (2019) view effective governance as a critical fourth pillar to facilitate balance across the traditional sustainability pillars of economic viability, environmental responsibility, and social equity. Indeed, good governance has been acknowledged as an effective tool towards advancing sustainable development and is therefore crucial in sustainable development strategies (Kardos, 2012). While different port models display different strengths and weaknesses for sustainable development, a common challenge lies in the strengthening of processes and mechanisms in institutions to enable both internal and external stakeholders to participate in setting sustainability agendas (Kardos, 2012). These multi-player governance regimes should strive for a reasonably coherent vision and be committed to sustainability-oriented coordination (Kemp et al., 2005), for example, through the coordination of policies both horizontally (i.e., among port related actors) and vertically (international, regional national and local tiers) (Lafferty, 2002). In essence, within each port model, good governance translates into long-term commitment and policy alignment via vertical and horizontal coordination characterised by accountability, coherence, effectiveness, openness, and participation. (European Commission, 2001; Notteboom and Haralambides, 2020).

To bridge the disconnect between the natural environmental and traditional engineering aspects of port governance, Taljaard et al. (2021) developed a framework for integrated port management (IPM) which aligns key environmental management processes with traditional port planning and development phases. Effective implementation of the IPM framework requires integration within organisational procedures, as well as appropriate science-based technologies and tools to assist port officials in this regard. Indeed, the process of improving sustainability rests on an organization itself but requires an objectifiable and generalised framework in connecting place-based and general contexts (James, 2015). The Port Sustainability Performance (PSP) Index proposed here, supports the IPMframework by offering a tool to quantify performance within the sustainability assessment component of the framework.

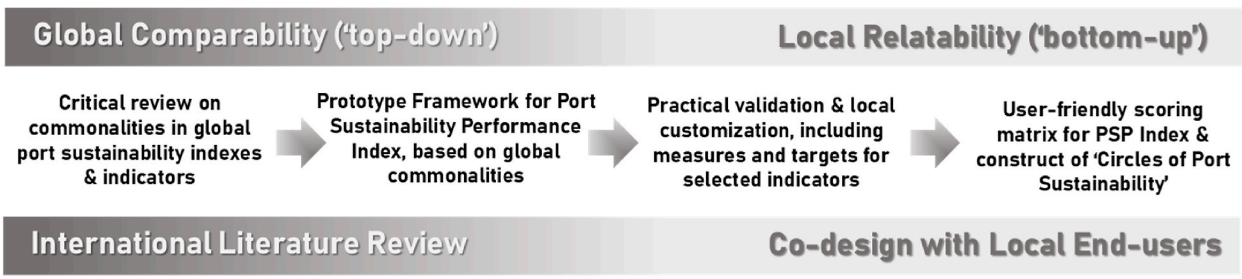

Fig. 1. Key components of the research approach to combine global ('top-down') comparability with local ('bottom-up') relatability in port sustainability performance assessment.

3. Research method

In this study we adopted a design science approach (Bots, 2007). A design-science approach is characterised as a sequential transformation process whereby a problem or 'need' is identified, for which an initial 'prototype design' is developed based on available information, and which is then tested and verified in practice to produce an 'artefact' (i.e. solution to the problem or need) (Taljaard et al., 2012). The decision to adopt an incremental, adaptive approach where knowledge derived from empirical validation is used to refine a prototype design (Bots, 2007; de Boer et al., 2019), highlights the contextual nature of design and the importance of contextual knowledge in the management of coastal landscapes (Cicin-Sain and Knecht, 1998; Taljaard et al., 2012, 2013) within which seaports are located.

Key components of the design science approach to combining global ('top-down') techno-scientifically oriented sustainability indicators with place-based locally relatable ('bottom-up') contexts, as well as addressing limitations encountered in empirical verification (the 'need') are illustrated in Fig. 1. First, a critical evaluation of the international literature on port sustainability assessments was performed to distil commonalities in global performance indicators, and identify typical frames used to structure sustainability performance indices. After James (2015), this learning, together with our place-based experiential knowledge, was used to develop a science-based framework for a Port Sustainability Performance (PSP) Index, explicit aligning with the SDGs (the 'prototype design'). This place-based experiential knowledge entails the situational knowledge of the authors gathered over more than two decades as environmental scientists and service providers in port environmental management (see Appendix A: Supplementary Data in Taljaard et al., 2021).

To demonstrate localisation of the PSP index we used a South African case study. In accordance with global trends, South Africa's National Ports Authority (TNPA) is engaging in sustainability performance reporting across the country's eight commercial ports (Transnet South Africa, 2022). These commercial ports all largely follow a service port governance model with some inefficiencies, for instance in maritime services, as a consequence (Mthembu and Chasomeris, 2023). A standardised approach to measure and report port sustainability performance has not yet been established in South Africa. This offered an opportunity to demonstrate localisation of the PSP Index through a co-design process (see Slinger et al., 2023). First, the authors engaged with key staff from the TNPA's environment and sustainability department at an in-house workshop to introduce the science-based framework for the PSP Index. There was agreement in principle on the overall concept, but confirmation on the suitability of the suite of globally representative indicators within a local context was still required. This confirmation was sourced through in-person and/or e-mail communications with TNPA officials responsible for governance, environment, social and economic matters related to the indicator list (see Appendix A: Supplementary Datafor list of departments and designation of TNPA officials that participated). Such avenues of communication were also used to identify locally relatable measures and targets for selected indicators with which to assess performance, as suggested by Moldan et al. (2017). Acknowledging the resource constraints often encountered in developing countries of the global south, participating officials were explicitly requested to first consider for suitability the existing measures and targets already being monitored in ports for legal and/or auditing purposes, prior to introducing 'new' parameters.

To address the challenge pertaining to empirical verification in port sustainability performance assessments (Laxe et al., 2017; Schipper et al., 2017), the participating TNPA officials were also consulted in the identification of rating systems for measures and associated targets suitable for quantifying indicator performance. A simple spreadsheet model was used to develop a flexible, easy-to-use weighted scoring matrix whereby allocated ratings could be aggregated into informative outputs. Finally, the concept of *Circles of Sustainability* (James, 2015; de Alencar et al., 2020; Bryant and Elliot, 2021) was adapted for application in ports to visually display performance outputs of the PSP Index, in alignment with related SDGs (the 'artefact').

4. Results and discussion

4.1. Global comparability: Commonalities in sustainability performance indicators

To claim global comparability, it was important to critically evaluate international port sustainability performance case studies from which to select a suite of representative performance indicators. Eighteen case studies were found suitable for inclusion (Peris Mora et al., 2005; Saengsupavanich et al., 2009; Lirn et al., 2013; Chiu et al., 2014; Shiau and Chuang, 2015; Asgari et al., 2015; Laxe et al., 2017; Lu et al., 2016; Roh et al., 2016; Chen and Pak, 2017; Puig et al., 2017; Roos and Neto, 2017; Schipper et al., 2017; Xiao and Lam, 2017; Oh et al., 2018; Stein and Acciaro, 2020; Brunila et al., 2023). These case studies were based in practice involving domain (port) experts. For the purposes of the critical evaluation, studies had to explicitly identify performance indicators which could be organised within recognisable sustainability dimensions (e.g. environment, social and economic). While the range of selected case studies is not exhaustive it is considered sufficiently wide ranging to cover a spectrum of (previously proposed) port sustainability indicators, specifically to highlight commonalities as a means of selecting representative globally comparable indicators.

The sustainability performance indicators extracted from the selected case studies, organised in the traditional dimensions of sustainability, that is environment, social and economic (e.g., Purvis et al., 2019) are presented in Table 1. Sub-categories, largely based on issues or activities, listed under each dimension were standardised to enable comparison. As a result, some indicators in may not be categorised as per the original literature publication, but rather in the most common category used for that indicator.

Evidence of sustainability performance requirements for ports emerged in 2005 (Peris Mora et al., 2005), when the need for a standardised reporting system was identified following progress in the implementation of environmental management systems (EMSs) in European ports. Given their primary purpose the indicators focused on environmental matters, pertaining primarily to impacts associated with pollution (air, water, soil noise), waste creation and resource, but including an additional category ('other') to cover

Table 1
International review of port sustainability indicators (solid dots represent indicators selected by three or more studies; open dots indicate less than three studies).

DIMENSION/CATEGORY/INDICATOR		REFERENCE																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
ENVIRONMENT																			
Air quality	Air quality (status)	●		●	●	●	●	●		●		●	●	●				●	●
	Air pollution management (including dust and cold ironing)	●		●		●	●	●	●	●		●	●	●	●	●	●	●	●
Water/Sediment quality	Environmental water quality (status)	●	●		●		●	●			●	●	●	●			●		●
	Environmental sediment/soil quality (status)	●			●		●					●	●	●			●		●
	Solid waste amount (status)	●					●										●		●
	Wastewater amount (status)	○					○												
	Wastewater/water treatment	●	●	●				●	●	●	●	●	●	●	●	●	●	●	
	Solid waste management	●		●	●				●	●			●	●			●	●	
	Hazardous waste management	●			●				●					●	●		●	●	
	Ballast water management			●					●			●			●		●		
	Dredge management	●						●	●			●		●	●	●	●		●
Noise, odour and light	Noise pollution (status)	●		●	●	●	●							●			●	●	
	Noise pollution management	●		●		●		●	●					●	●	●	●	●	
	Odour emission (status)													○				○	
	Odour emission management													○				○	
	Mitigation of light influence (e.g., smart lighting)							●								●	●		
Habitat and biodiversity	*Erosion/sedimentation (status)*	○															○		
	Habitat and biodiversity integrity (status)			●	●		●	●				●		●	●	●	●		
	Ecosystem integrity management (avoid destruction)			●								●		●	●		●		
	Erosion/sedimentation control			●								●			●		●		
Eco-efficiency	Greenhouse gas emissions (status)	●				●		●				●			●	●	●		
	Incidents with environmental repercussions (e.g., spills) (status)	○	○																
	Water use/consumption efficiency	●			●						●						●		
	Fuel consumption efficiency (e.g., low sulphur fuel and cold ironing)	●		●			●		●						●		●	●	
	Energy use/consumption efficiency	●		●	●	●	●		●	●		●			●		●	●	●
	Usage of environmentally efficient (e.g., recyclable and recycled) materials			●	●			●								●	●		
	Recycling of materials/waste recovery & minimization			●		●		●		●	●			●		●			
	Improvement of landscaping and port greenery (e.g., tree planting)				●			●									●		
	Efficient/responsible usage of space (e.g., spatial planning)	●						●	●		●					●			
	Speed/combustion control			○													○		
	Environmentally efficient transport systems (vehicles and vessels)							●							●		●		
Environmental management practice	Environmental legislative framework & policies		●				●		●			●	●				●	●	●
	Corporate commitment towards sustainability		●				●								●		●	●	
	Managerial organisation (e.g., institutional structures for environment)		●				●								●		●	●	
	Environmental assessment and management systems (e.g. EMS)		●						●		●	●		●				●	
	Emergency preparedness and response (risk & contingency planning)		●	●			●		●		●				●		●	●	
	Incentive systems to promote sustainable practice								○										
SOCIAL																			
Climate robustness	Climate change risk assessment and response planning							●		●		●							●
	Investment in flood and coastal protection											○							
Community	*Social image of port (status)*	○																	
	Creation of job opportunities (e.g., including community)							●				●	●			●	●		

DIMENSION/CATEGORY/INDICATOR		REFERENCE																	
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Protection of heritage and cultural areas (e.g., historic relics)							●	●				●				●		
	Public awareness and education on sustainable port development				●				●						●				
	Recognition of community wellbeing, also along supply chain (space/health/safety/security)			●				●				●	●			●	●	●	
	Community consultation and investment (e.g., port-city collaboration)							●	●		●	●				●			●
	Port-city population																		○
	Investment in social and cultural activities								●		●					●		●	
	Promotion of public accessibility											○							
	RD&I investment (studentship/intern opportunities and collaboration)								○		○								
	External (public) reporting and communication on sustainability effort								●								●	●	
Employment	Training and education of port employees		●		●		●		●	●	●	●			●	●	●	●	
	Employee communication and involvement in decision making																○	○	
	Employee job security (e.g., full time employed)							●			●					●		●	●
	Recognition of employee wellbeing (health, safety, security)					●		●	●		●	●	●			●	●	●	●
	Social equality in employment							●			●					●		●	
ECONOMIC																			
Income and profitability	Cost efficiency & productivity (e.g., operating costs versus revenue)					●	●		●		●		●				●		●
	Expenditure/investment in sustainable development		●					●	●	●	●	●		●	●	●	●	●	
	Occupancy rate (ship visits)					○					○								
	Economic contribution																		○
	Port cargo growth											○					○		
Service quality	Service quality & efficiency (e.g., traffic/cargo handling, turn-around time, safety)			●		●	●	●	●	●	●	●	●			●	●	●	●
	Improvement of port infrastructure construction							●				●				●		●	
	Hinterland connectivity											○					○		
	Level of digitalization																	○	
Macro-value	Accessibility to other economic markets (e.g., fisheries, tourism)							●				●				●	●		
	Tax generation		●													●	●		

1: Peris Mora et al., 2005: 2: Saengsupavanich et al., 2009; 3: Lirn et al., 2013; 4: Chiu et al., 2014; 5: Shiau and Chuang, 2015; 6: Asgari et al., 2015; 7: Lu et al., 2016; 8: Roh et al., 2016; 9: Roos and Neto, 2017; 10: Laxe et al., 2017; 11: Schipper et al., 2017; 12: Xiao and Lam, 2017;13: Puig et al., 2017; 14: Chen and Pak, 2017; 15: Oh et al., 2018; 16: Stein and Acciaro, 2020; 17: Brunila et al., 2023; 18: Ogara et al., 2023 impacts associated with port infrastructure (alteration of currents and the seafloor, soil occupation).

Saengsupavanich et al. (2009) applied ISO14001 and port state control measures in Thailand to derive 12 performance indicators for ports. These primarily focussed on assessing environmental management performance in relation to success, awareness, determination, preparedness, and environmental policy coverage. To inform prioritisation in green port performance in Asia, Lirn et al. (2013)focused on indicators within the environmental dimension, addressing, for example, air pollution, noise, solid and liquid waste, and marine biology preservation.

Chiu et al. (2014) reviewed academic studies and the practical experience of several port authorities to identify a set of key factors (as indictors) underpinning sustainability (green port operations). Focusing on in-port operations and development planning, specifically energy conservation, environmental protection, and ecology care, they categorised the key factors into air pollution, water pollution, noise pollution, land and sediments pollution, materials selection, water consumption, energy usage, general waste handling, hazardous waste handling, habitat quality and greenery, community promotion, and education, as well as port staff training. They then used a fuzzy AHP analysis to aggregate the results to assist port authorities in identifying priority actions, as well as in measuring port performance.

In Taiwan, Shiau and Chuang (2015) developed port sustainability indicators through stakeholder participation processes. Considering aspects such as cost efficiency, cost effectiveness, service effectiveness, service impact and service reduction, they selected 34 indicators spanning environmental, social and economic dimensions. To investigate sustainability performance in UK ports, Asgari et al. (2015) focused largely on indicators within the environmental and economic dimensions, but also included indicators covering social and management aspects, such as staff training and implementation of green policies.

Laxe et al. (2017) developed a sustainability performance tool for Spanish ports, by re-orientating indicators from synthetic indices and including an institutional dimension to the traditional three-dimensional (environment, social, economic) analysis. However, indicators within the institutional dimensions have generally been accounted for in the social and economic dimensions by others. Of note is that the measures by which indicators were quantified, largely drew on available information contained in the mandatory sustainability reports of case study ports, demonstrating the combination of place-based organisational information into general sustainability contexts (James, 2015).

Roh et al. (2016) also distilled sustainability criteria (or indicators) from the existing literature, which they assessed for applicability in Vietnamese ports. The list of indicators spanned environmental, social, and economic dimensions, but interestingly the authors chose internal management and external management as the main category for organising the indicators. Internal management comprised four sub-groupings: internal environmental management (13 indicators), optimised operation plan (7), cost saving (3), and internal social process (4). The external management category included another four sub-groupings: external environmental management (6), environmental collaboration with shipping companies (4), external social programme (6), and external evaluation collaboration (2). In line with our purpose of reviewing port sustainability indicators applied globally, we regrouped these indicators into the dimensions of environment, social and economic more commonly used for sustainability indicators. However, we view their overarching environmental management category as insightful, and therefore include it as category within the environmental dimension.

A study by Lu et al. (2016) distilled and grouped a set of sustainability indicators into four sustainability assessment factors, environmental material (11 indicators), economic issues (6), environmental practices (6), and social concerns (6). The indicators were applied to a selection of ports, in consultation with stakeholders, to prioritise their importance in terms of the three sustainability assessment factors (implicitly across the environment, social and economic dimensions). In Brazil, Roos and Neto (2017) proposed a set of indicators to assess environmental sustainability from an economic and financial viewpoint. The indicators were largely based on the literature but also considered applicability to the country's ports, acknowledging the importance of considering both top-down and bottom-up contexts (James, 2015). To overcome challenges with data deficiencies, the system can be applied in a simplified (using 5 indicators) or advanced (using 12 indicators) manner.

Schipper et al. (2017) distilled a set of social, economic, and environmental key performance indicators to evaluate and interpret future port sustainability specifically focusing on planning initiatives. Using evidence-based knowledge scoring, the indicators were organised and aggregated into social-, environmental- and economic sustainable scores, and then combined into an overall Sustainable Integrated Condition Index. Using this approach, they were able to compare future sustainability based on development planning in a selection of ports across the world.

Xiao and Lam (2017) adopted a systems approach to investigate sustainability within a port-city context in Singapore. Selected generic criteria were organised within the three key dimensions of environment, social and economics, but in most cases specific indicators were identified as relevant to the port and the city system. To encourage a more science-based and systematic approach in the selection of environmental indicators in European ports, Puig et al. (2017) developed a computer and science-based tool whereby port authorities could identify the most appropriate indicators based on their specific situation. Focusing on green performance, Chen and Pak (2017) identified a set of evaluation indicators for Chinese ports, mostly covering environmental aspects, using the Delphi technique. Twenty-one green performance indicators were prioritised and categorised into six dimensions, namely liquid pollution management, air pollution management, noise control, low carbon regulations and energy savings, marine biology preservation, and organization and management.

To assess sustainability in South Korea ports, Oh et al. (2018), used the importance-performance analysis technique to identify indicators from previous research and interviews. A total of 27 sustainability indicators (or criteria) was identified across the three traditional pillars of sustainability, environmental (11), economic (7), and social (9). Following a comprehensive, systematic review of international literature covering sustainability assessments and monitoring in the port sector, Stein and Acciaro (2020) proposed a set of measures to assist ports in assessing corporate sustainability. As in most other examples, their primary dimensions were environmental, social, and economic. Focusing on indicators from the literature that were actually measured, they grouped indicators within each of these dimensions into a number of categories, that is for environment: water pollution management (4), eco-efficiency (8) and air pollution management (8); for social: community impact (5), employment quality (3), legal and political benefits (5); and for economic: income and profitability (6), service quality (5) and macro-value (5). Their listing of measurement modes, such as answering a simple existing/non-existing question, is also useful. Stein and Acciaro (2020) embed these into a corporate sustainability measurement framework for ports to empirically assess the effectiveness of corporate sustainability actions towards environmental, social, or economic value creation.

In Finland, Brunila et al. (2023) developed a conceptual performance assessment tool for environmental performance in small seaports that may not have sufficient resources to implement expensive performance processes. A checklist type self-diagnosis approach was adopted with specific indicators organised into four categories, that is environmental management (5), sustainability (5), environmental impact (5), and self-monitoring (4). While the categorisation in this tool was different, the indicators within categories were recognisable and could be organised within the traditional pillars of sustainability for comparability. They also introduced the level of digitalisation as an indicator, which may be significant in future ports. Focusing on the port-city and marine system, Ogara et al. (2023) used the Drivers, Pressures, States, Impacts and Responses (DPSIR) approach and Causal Networks to test the validity of a selection of key indicators and associated measures (78) within a sustainability framework aimed at the Global South. The suite of key indicators was categorised within the three traditional dimensions of sustainability (environment, social and economic) but, after Karnauskaitė et al. (2018), governance was also added as a fourth dimension, focusing largely on written policies and legislation as indicator.

Significant *commonalities* emerged on review of the array of indicators previously applied in port sustainability performance assessments, as represented by those indicators included in three or more studies (Table 1). Most studies organised indicators into three traditional *environmental*, *social*, and *economic* pillars of sustainability. However successfully achieving sustainability strongly depends on effective governance arrangements (Glass and Newig, 2019). In the 'circles of sustainability' approach for urban centres James (2015) included politics as a fourth dimension of sustainability, while de Alencar et al. (2020) adopted a similar approach for application in coastal systems. *Governance* was added as a fourth dimension by Ogara et al. (2023) in their port-city sustainability framework after Karnauskaitė et al. (2018), who viewed it as a critical element to secure sustainability in coastal systems. Some of the case studies we reviewed did include indicators pertaining to environmental management practice but grouped these within the environmental dimension (e.g., Asgari et al., 2015; Stein and Acciaro, 2020; Brunila et al., 2023). Furthermore, Laxe et al. (2017) included an *institutional* dimension, but the type of indicators listed within this dimension were largely included within the *social or economic* dimensions by others.

Within the *environment* dimension, indicators can best be categorised into six main groupings; (1) Air quality, (2) Water/Sediment quality, (3) Noise, odour, and light, (4) Habitat and biodiversity, (5) Eco-efficiency, and (6) Environmental management practice. In

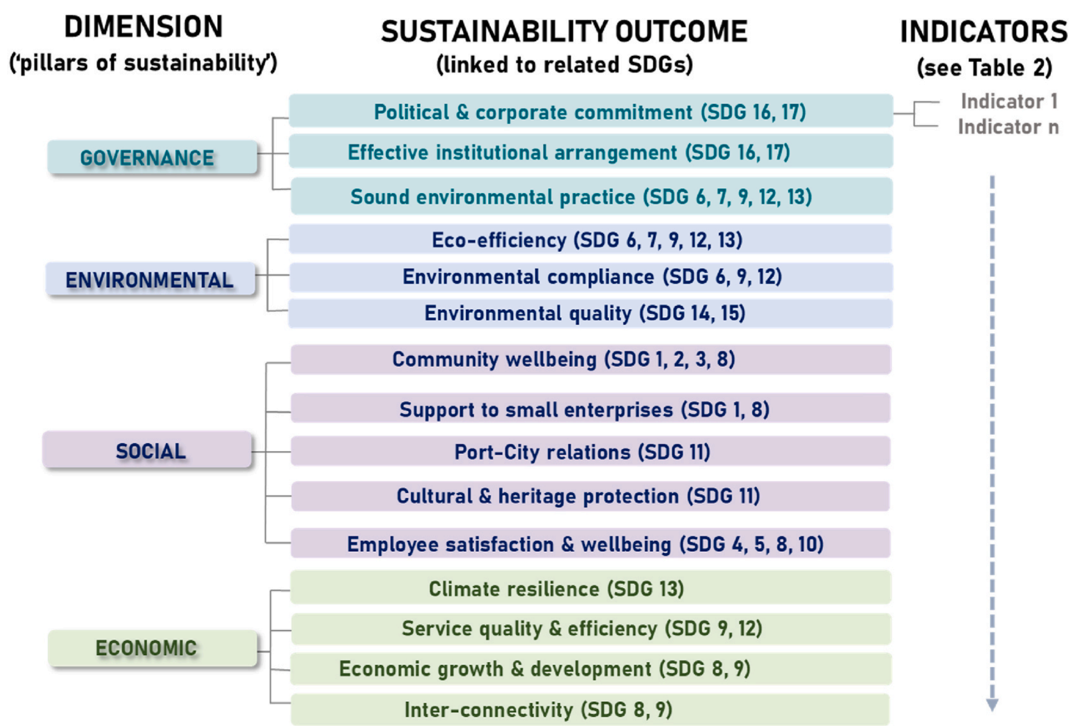

Fig. 2. Framework for PSP Index derived from global (top-down) contexts, showing key dimensions, associated sustainability outcomes (with linked SDGs) and pointing the corresponding global indicators as presented in Table 2.

the reviewed literature many commonalities were apparent within this dimension. This is not surprising given that this dimension is probably the best studied, having already receiving research attention under the original 'Green Port' concept that preceded the broader concept of 'Sustainable Port Development' (Hiranandani, 2014). Three key groupings emerged within the *social* dimension: (1) Climate robustness, (2) Community, and (3) Employment. Increased recognition of social aspects in port sustainability performance becomes evident in case studies published post-2015 (Table 1) following the emergence of the 'Sustainable Port Development' concept. Within the *economic* dimension, indicators could be grouped into (1) Income and profitability, (2) Service quality, and (3) Macro value. Even though the economic performance was recognised as a key aspect within the earlier 'Green Ports' concept, together with environmental performance, indicators within this dimension also only gained momentum post-2015.

Reflecting on suite of common indicators, representative of the global context, these were found to span both *planning initiatives* (Schipper et al., 2017) and *operational effectiveness* (Stein and Acciaro, 2020) able to demonstrate *value creation* (Stein and Acciaro, 2020).

4.2. Science-based framework for PSP index

Acknowledging the necessity for a sustainable reporting framework that enables linkages between local place-based requirements with global reporting formats (James, 2015), the four key pillars of sustainability emerging from the literature were chosen as the main dimensions to frame the proposed PSP index. These included the three traditional pillars of sustainability (*environment, social* and *economic*), as well as *governance* as a critical fourth pillar (Fig. 2).

James (2015) argued that logical sub-domains should be identified within each of the key dimensions to be useful from a management perspective. As illustrated in Table 1, specific activities or issues have typically been applied as sub-domains within which to structure sustainability performance assessments. However, guided by the primary purpose of these performance assessments being to demonstrate extent of *value creation*, as reflected in good governance, environmental responsibility, socially equitability, and economic viability (e.g., Stein and Acciaro, 2020), it was considered more appropriate to focus on logical *sustainability outcomes* as sub-domains for the PSP index that would be locally relatable, while still globally recognisable (James, 2015). Therefore, a selection of sustainability outcomes, considered most identifiable and relevant to port systems, based both on the experiential knowledge of the authors and the reviewed scientific literature, was identified (Fig. 2).

Selected sustainability outcomes within the *governance* dimension (political and corporate commitment, effective institutional arrangement, and sound environmental practice) largely reflect important cross-cutting governance and planning systems critical to achieve success across other sustainability outcomes within the environmental, social, and economic dimensions. Sustainability outcomes within the *environmental* dimension (eco-efficiency, environmental compliance, and environmental quality) focus on operational effectiveness, but also on the status of the environment, ultimately demonstrating environmental responsibility. Outcomes within the *social* dimension (community well-being, support to small enterprises, port-city relations, cultural and heritage protection, employee satisfaction) primarily reflect relations, well-being and satisfaction of social entities most relevant within a port context. Finally, selected sustainability outcomes within the *economic* dimension (climate resilience, service quality and efficiency, port growth and development, and inter-connectivity) reflect the infrastructural and operational risks associated with climate change, as well as port operational efficiencies, and their influence on the state of financial sustainability.

To measure port performance in terms of the selected sustainability outcomes, a set of suitable indicators was required as a means for empirical validation. The suite of common, globally representative indicators extracted from the international literature (i.e., indicators included in three or more studies – see Table 1) was therefore aligned with each of the sustainability outcomes across the four sustainability dimensions (Table 2).

Worldwide, the 17 SDGs are currently used as the primary benchmark against which to evaluate progress and achievements towards sustainable development United Nations (2015). These can be viewed as the agreed global *sustainability outcomes*. However, the 17 SDGs are not organised within the recognised pillars of sustainability typically used in framing sustainability performance assessments, including those in ports as demonstrated in the reviewed case studies. Therefore, it is often difficult for port operators to link performance measures to SDGs. This creates a challenge; measures of port sustainability performance should obviously be able to gauge progress towards achieving these agreed outcomes, certainly in the case of countries that are signatories to Agenda 2030. To assist in the regard, Barbier and Burgess (2017) showed the relationship among SDGs and the sustainability dimensions of environmental, or social system goals, while WPSP (2020) provided a comprehensive list of potential actions in the port sector that would contribute to achieving each of these goals. It was, therefore, considered necessary to logically match the *sustainability outcomes* in the PSP Index with globally agreed *sustainability outcomes* (or SDGs) as is illustrated in Fig. 2.

4.3. Local relatability: Practical validation and localisation of PSP index

Consistent with a design science approach, the Framework for a PSP index was then subjected to practical validation, recognising the ′importance of organisations (or end-users) themselves needing to relate to, understand and populate such indexes. The position of TNPA as a national port authority employing the service port governance model across South Africa's eight commercial ports meant that the TNPA's need for a standardised approach to port sustainability performance reporting offered a co-design opportunity to demonstrate localisation of the PSP Index using the South African situation.

Following in principle agreement of the scienced-based Framework for a PSP Index by key staff from TNPA's environment and sustainability department, the suitability of the suite of globally representative indicators was interrogated by a selection of TNPA officials responsible for governance, environment, social and economic matters related to the indicator list using in-person and/or e-

Table 2
PSP Index Framework: Dimensions, associated sustainability outcomes with globally representative indicator list (derived from international literature) as well as locally customised indicator list.

DIMENSION & SUSTAINABILITY OUTCOME		GLOBALLY REPRESENTATIVE INDICATOR LIST	LOCALLY CUTOMISED INDICATOR LIST
Governance	Political & corporate commitment	Environmental legislative framework & policies	Legislative framework in place to enable sustainable planning, development, and operations in ports
		Corporate commitment towards sustainability	Organizational culture towards sustainable development
		Expenditure/investment in sustainable development	Dedicated budgets allocated and implemented for sustainable development
		Public reporting and communication on sustainability effort	Public Communication
	Effective institutional arrangement	Managerial (institutional) organisation	Formal in-house institutions overseeing for environmental/social matters in port
			Dedicated institution to engage with port customers (tenants/terminal operators)
			Dedicated institution to engage with stakeholders outside port boundaries
			Dedicated collaborative arrangement between port & adjacent city (local authority)
	Sound environmental practice	Environmental assessment and management systems	Strategic Environment Assessment (SEA)
			Environmental & Social Impact Assessment (ESIAs)
			Environmental Management Systems (EMS)
		Air pollution management	Management Plans/Programmes (EMPs), Frameworks or Standard Operating Procedures (SOPs) pertaining to sustainability (reflecting specific aspects within measures)
		Wastewater/water treatment	
		Solid waste management	
		Hazardous waste management	
		Ballast water management	
		Dredge management	
		Ecosystem integrity management	
		Noise pollution management	
		Mitigation of light influence	
		Erosion/sedimentation control	
		Emergency preparedness and response	Contingency planning
Environment	Eco-efficiency	Water use/consumption efficiency	Water use efficiency
		Greenhouse gas emissions	Climate mitigation (with emissions as measure)
		Energy use/consumption efficiency	Energy efficiency (with fuel efficiency as measure)
		Fuel consumption efficiency	
		Usage of environmentally efficient materials	Selection and procuring of eco-friendly materials
		Recycling of materials/waste recovery & minimization	Recycling/minimize from construction and building waste (circular economy concept)
			Other waste recycling (water; sediment) e.g., grey water and beach replenishment
		Improvement of landscaping and port greenery	Port greenery (tree planting)
		Efficient/responsible usage of space	Efficient and responsible land/sea use (space planning)
		Environmentally efficient transport systems within port	*Not included, no data*
	Environmental compliance	Atmospheric emissions	Atmospheric emissions
		Wastewater amount (included but <3 case studies)	Wastewater discharges
		Solid waste amount	Solid waste/Hazardous waste
		Incidents with environmental repercussions (included <3 case studies)	Environmental Incidents
			Environmental Assurance audits (additional)
			Compliance to EMS (additional)
	Environmental quality	Air quality	Status of air quality
		Environmental water quality	Status of marine water quality
		Environmental sediment/soil quality	Marine sediment quality status
			Status of soil and groundwater quality
		Noise pollution	*Not included, no data*
		Habitat and biodiversity integrity	Status of Habitat/biodiversity status (land and sea)
			Invasive species
Social	Community wellbeing	Investment in social and cultural activities	Corporate social initiatives (e.g., school support, support of cultural activities, port open days)
		Recognition of community wellbeing (space/health/safety/security)	
		Public awareness and education on sustainable port development	Community-based environmental education and awareness programmes/events
		Promotion of public accessibility (included but <3 case studies)	Access rights for communities (e.g., fishing, harvesting of material, cultural activities)

(*continued on next page*)

Table 2 (*continued*)

DIMENSION & SUSTAINABILITY OUTCOME		GLOBALLY REPRESENTATIVE INDICATOR LIST	LOCALLY CUTOMISED INDICATOR LIST
	Support to small enterprises	Creation of job opportunities (e.g., including community)	Support to environmentally related community enterprises (e.g., alien vegetation removal, mangrove planting) Contracts awarded to local/small businesses
	Port-City relations	Community consultation and investment (port-city collaboration)	Port-City collaboration Port-city relationship
	Cultural & heritage protection	Protection of heritage and cultural areas (e.g., historic relics)	Protection of cultural heritage assets
	Employee satisfaction & wellbeing	Employee training and education	Training (incl. education on sustainability matters)
		Employee communication and involvement in decision making	Employee engagement forums
		Recognition of employee wellbeing (health, safety, security)	Employee grievances/satisfaction Employee recognition Wellness assistance Occupational safety awareness Employee safety
		Social equality in employment	Employment equity
		Employee job security (e.g., full time employed)	Employee job security
Economic	Climate resilience	Climate change risk assessment and response planning	Climate change (CC) preparedness Climate change early warning systems Climate change incident assessment
	Service quality & efficiency	Port service quality & efficiency (e.g., traffic/cargo handling, turn-around time, safety)	Technical capacity and efficiency Quality of potable water supplied Customer satisfaction Port Security Cyber security
		Improvement of port infrastructure	Improvement port infrastructure
	Economic growth & development	Cost efficiency & productivity (e.g., operating costs vs revenue)	Port revenue generation through formal port activities Port revenue generation through complementary sectors Business growth opportunities for others in port
		Accessibility to other economic markets (e.g., fisheries, tourism)	Business growth opportunities for others in port
		Tax generation	Tax generation
	Inter-connectivity	*Hinterland connectivity*	Hinterland connectivity

mail communication. For the most part, the TNPA officials considered the globally representative indicator list as appropriate but suggested some refinements (see Table 2 – locally customised indicator list). For example, within the *Governance* dimension, they opted to group environmental management plans and programmes under *Sound environmental practice* as a single indicator, later using the status of different plans and programmes as measures. In the Environment dimension, *Wastewater amount* and *Incidents with environmental repercussions* within *Environmental compliance* were not popular within previous case studies (i.e., they were identified in less than 3 case studies), but they were considered important by the TNPA with pollution flagged as a key challenge in South African ports. *Environmentally efficient transport systems* within *Eco-efficiency,* however, was omitted based a lack of data availability, as was *Noise pollution* under *Environment quality*. Within the Social dimension, *promotion of public accessibility* – also listed in less than three reviewed case studies – was considered a priority for the TNPA under *Community wellbeing.* Coastal access is a legal requirement within South Africa's coastal legislation (Republic of South Africa, 2008) and is therefore also considered a priority to the country's ports. Within the *Economic dimension, Hinterland connectivity* was only considered in two previous studies (Schipper et al., 2017; Stein and Acciaro, 2020). However, inefficient hinterland road and rail connectivity has become a critical concern for long-term economic sustainability in South African ports (Bichou, 2021). *Inter-connectivity* was therefore included as another explicit sustainability outcome, even though its indicator did not emerge as a *common* global indicator.

The next step involved the selection of place-based *measures and associated targets* (after Moldan et al., 2017) for the locally selected indicators to enable performance assessment. Acknowledging resource constraints, participating TNPA officials first consider existing measures and targets, already being monitoring in ports for legal and/or auditing purposes. Where suitable measures and performance targets were already in place, those were applied and where not, those were agreed upon with the relevant responsible departments. In some instances, more than one measure was considered necessary to reflect performance, based on the complexity of the issue represented by some of the indicators (see Appendix A: Supplementary Data Appendix B for details on selected measures and associated targets). Through this co-design process, it became clear that within its current planning and operational procedures, the TNPA was already monitoring an array of measures, with associated targets, pertaining to sustainability performance, albeit organised in a departmental, sectoral manner rather than being organised within the globally comparable dimensions and associated outcomes of sustainability as posed in the PSP Index. This demonstrates that method/approach adopted in the development of the PSP Index, combining global comparability ('top-down') with local relatability ('bottom-up'), may not be onerous to implement as in many instances data and information were already monitored in the South African case. In essence, the existing (local) measures and associated targets just required re-orientation into the four-pillar and sustainability outcome structure, generally adopted globally in science-based port sustainability performance assessments.

4.4. Empirical verification: Weighted scoring matrix for PSP index

To address the empirical verification challenge it was necessary to develop a flexible, easy-to-use scoring matrix for the PSP Index. First, rating systems had to be selected to quantify performance of selected measures against associated targets. An incremental rating system was considered most appropriate, given the resolution of available data and information used in TNPA's existing performance monitoring. This incremental rating system ranged from full compliance (4) to the associated targets to non-compliance (0) (see Appendix A: Supplementary Data Appendix B for rating systems on selected measures and associated targets). The intermediate ratings (1, 2 and 3) within the rating system were negotiated and agreed upon with participating TNPA officials. For ease of interpretation, the scores allocated to a measure (i.e. potentially ranging from 0 to 4) were then normalised to 100 (4 = 100; 0 = 0). Where a single measure was allocated to an indicator, its score equalled the measure's score, but in instances where more than one measure was selected, these were aggregated into a final indicator score. In turn, sustainability outcome scores were derived from aggregation of associated indicators. Similarly dimensions scores were derived by aggregating associated sustainability outcome scores before final aggregation of dimension scores into an overall sustainability score as illustrated in Fig. 3.

The scoring matrix for the PSP Index can easily be executed using a simple spreadsheet approach (e.g. Excel). The spreadsheet design follows the structure as proposed in Fig. 3, calculating aggregated scores based on selected weightings (see Appendix A: Supplementary Data for example of spreadsheet design). While an overall score for sustainability performance is valuable for comparing across ports or within a port over time, the outputs from this index also need to provide port authorities with practical information to inform management. By incrementally building up to an overall sustainability score, port authorities can identify specific sustainability outcomes, even individual indicators contributing most (or least) to achieving sustainability. This type of information allows port authorities to prioritise interventions to achieve overall sustainability or to focus on outcomes more critical to their situation.

4.5. Circles of port sustainability: Visualisation

To provide a user-friendly means of visualising sustainability performance, the concept of *Circles of Sustainability,* previously applied in urban planning (James, 2015) and coastal management (de Alencar et al., 2020; Bryant and Elliot, 2021), was adapted for ports using output from the PSP Index (Fig. 4).

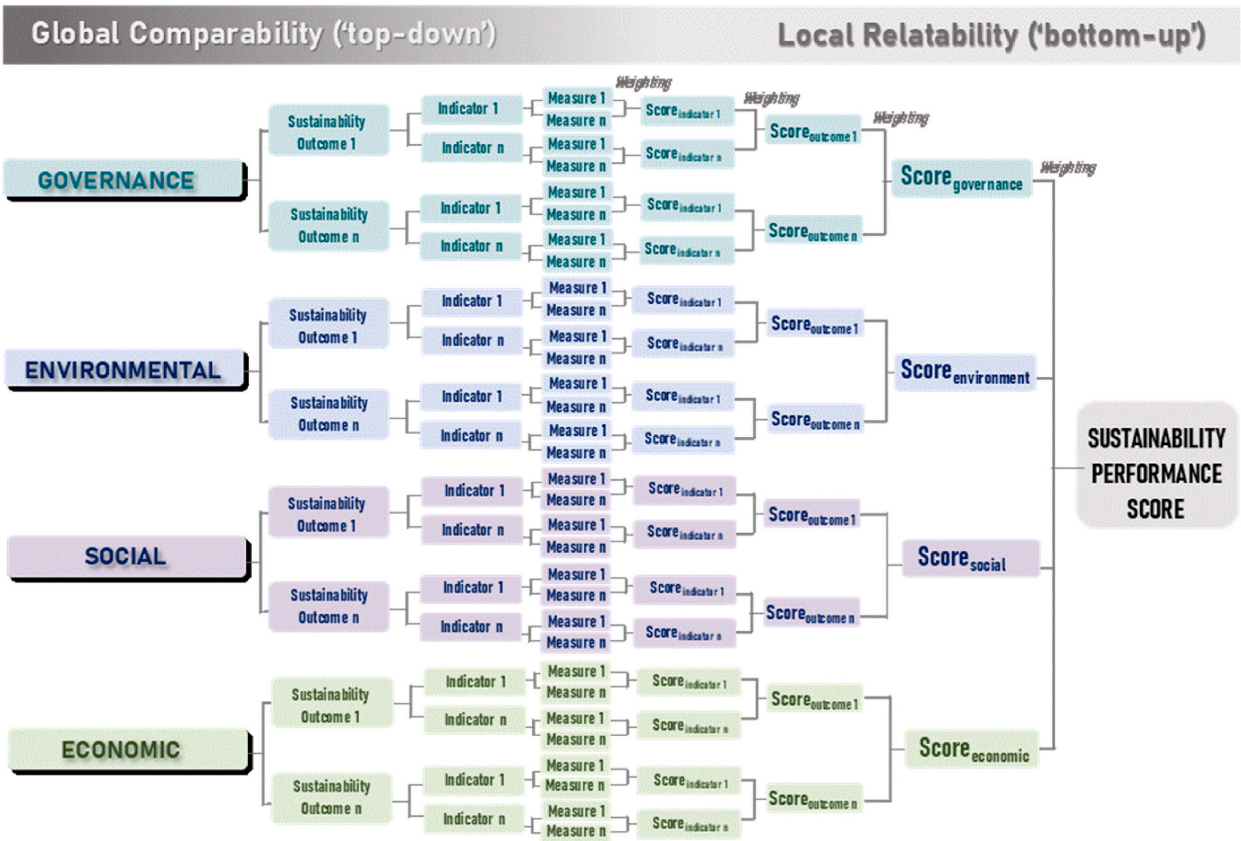

Fig. 3. Conceptualisation of weighted scoring matrix for the PSP Index.

Circles of Port Sustainability depicts the performance of each of the 15 sustainability outcomes (out of 100) on the axes of the radar diagram, organised into the four sustainability dimensions (environment, social, economic and governance), also showing alignment with related SDGs.

For example, the illustration in Fig. 4 shows good performance in most sustainability outcomes, except *Eco-efficiency* and *Climate resilience*, point to the key priorities for improvement. By using the concept of *Circles of Port Sustainability*, a complex array of elements comprising port sustainability can be simplified reliably to allow port authorities to visualise where they are strong and where effort is required to improve sustainability. This also offers a user-friendly means of visualising change in sustainability reporting by comparing *Circles of Port Sustainability* over time (within a port) or space (across multiple ports) provided that the same indicator list, measures and associated targets, and rating systems are applied.

5. Conclusion

A novel method for port sustainability performance assessment that combines global ('top-down') techno-scientifically oriented indicators with place-based locally relatable ('bottom-up') contexts (James, 2015; Bell and Morse, 2018) is developed in this research. First, we drew on the published literature to distil commonalities in global sustainability performance indicators and incorporated these in a science-based Framework for the PSP Index, explicitly aligning the related SDGs. A co-design process with TNPA demonstrated the inclusion of local relatability in the South African situation where a service port governance model prevails. This involved the customisation of performance indicators, and the identification of place-based measures and targets relevant to the South African ports. Further, an easy-to-use weighted scoring matrix, applying an agreed rating system and using a simple spreadsheet approach, was developed to provide empirical verification. An adapted version of the *Circles of Sustainability* concept yielded a visualisation of outputs from the PSP Index as *Circles of Port Sustainability*.

The resulting PSP Index and easy-to-use empirical verification mean that individual port authorities could potentially use this method to measure their own performance, for example to inform sustainability decision-making. The method also allows for monitoring of sustainability performance trajectories over time, as well as for comparing performance across a selection of ports in sustainability reporting, provided that the same indicators, measures, targets and rating systems are applied. The method's flexibility in local customisation means that it can potentially be applied across different port governance systems, regionally and globally. This may necessitate some adjustment of performance measures, targets and rating systems, proposed here, to better address their local relatabilities. Also, in time, it may be necessary to re-assess the globally representative indicator list to incorporate future scientific learning on port sustainability performance assessment. This research therefore represents a contribution to bridging the science-practice divide in reporting on port sustainability performance.

A limitation of the study may stem from the simple spreadsheet used for empirical validation, rather than applying more sophisticated methods, such as AHP analyses (e.g., Lirn et al., 2013; Chiu et al., 2014; Asgari et al., 2015) or Delphi techniques (e.g., Chen and Pak, 2017). However, these approaches require technical expertise that may not be readily available to port management authorities, specifically those in the developing countries of the global south. The easy-to-use spreadsheet enables port authorities to

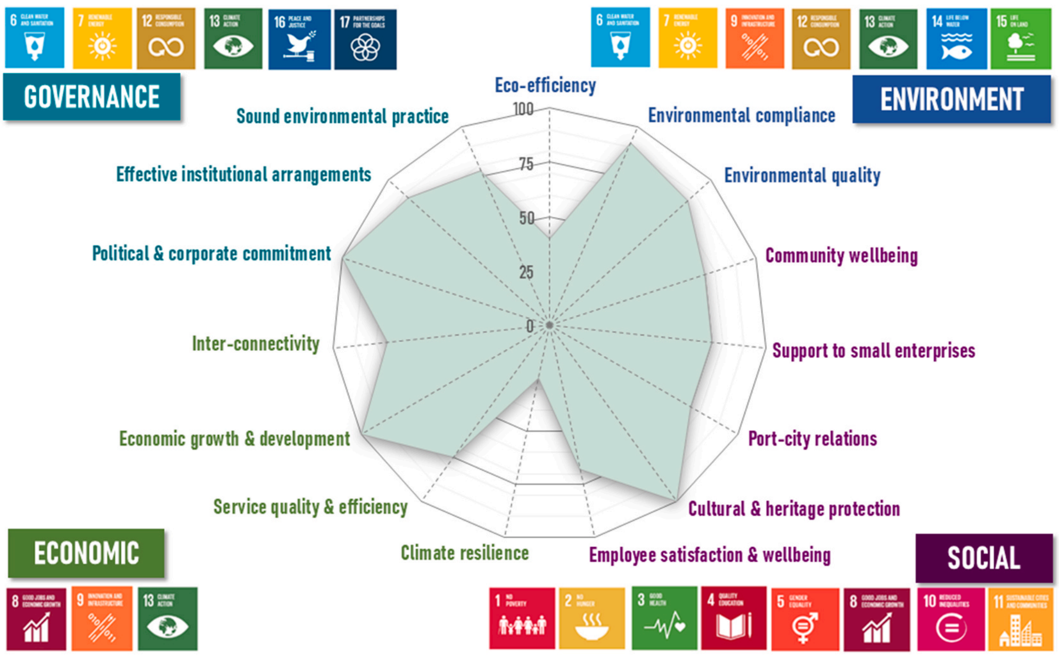

Fig. 4. Circle of Port Sustainability - visualisation of PSP index output.

initiate and undertake their own performance assessments using readily available software (e.g. Excel). As port authorities gain confidence in using these types of indices, and discover their value in informing sustainable development investment, more sophisticated analytical techniques could be considered.

Aligned with the design science approach, the next phase in this research involves pilot testing of the PSP Index in a variety of ports to validate and refine its construct, particularly regarding its usability in comparing sustainability performance across a selection of ports. A further aspect of validation involves the ease of application by individual port authorities.

CRediT authorship contribution statement

Susan Taljaard: Writing – review & editing, Writing – original draft, Visualization, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Jill H. Slinger:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Steven P. Weerts:** Writing – review & editing, Funding acquisition, Formal analysis, Conceptualization. **Heleen S.I. Vreugdenhil:** Writing – review & editing, Methodology. **Cebile Nzuza:** Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envdev.2024.101068.

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