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The role of port smartness in achieving sustainable development goals

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ABSTRACT

This research aims to investigate the simultaneous effect of smartness and sustainability in port cities. For this purpose, this study introduces the Smart Port Sustainability Index (SPSI) as a key metric for measuring the impact of port smartness on sustainable development goals. The results of SPSI values for different ports show that higher levels of intelligence do not necessarily correspond to greater sustainability. Ports that solely focus on adopting smart technologies may disregard environmental and social components of sustainable development. Alternatively, the efforts made by ports to achieve sustainable development goals can be regarded as a favorable factor in enhancing the intelligence and sustainability of ports. Furthermore, the regional analysis indicates that European ports outperform ports in North America and Asia across all three: sustainability indicators, Smartness operation, and the Smart Port Sustainability Index.

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Smart port; industry 4.0;
SDG; port intelligence;
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1. Introduction

The strategic positioning of ports and their pivotal role in facilitating the transport chain has transformed them into key economic drivers and trade gateways (Hossain, Adams, and Walker 2019). Today more than 80% of international trade volumes are carried by sea (Lane and Pretes 2020). Thus, the port industry's critical role in the economic development of surrounding communities is evident through its diverse range of investments and businesses (Cong et al. 2020). However, sustainable development in this sector is hindered by environmental concerns, social challenges such as community displacement (Al-Emran and Griffy-Brown 2023), and the need for job creation and economic diversification (Yang et al. 2022). The United Nations has established a series of Sustainable Development Goals to confront these challenges and secure a sustainable future for all nations. Recently, port managers have increasingly turned to advanced technologies and data analysis to enhance port operations and optimize resource utilization (Yen Barbara et al. 2023). This approach, known as 'port smartness', has significant potential to support the Sustainable Development Goals to promote sustainability and increase the industry's contribution to the global economy.

In recent years, studies have explored the efforts to achieve the Sustainable Development Goals (SDGs) in port cities (see Caliskan 2022; Liu et al. 2021; Xiao and Siu Lee Lam 2017). Also, many studies investigated the development of smart ports and their various aspects (see D'Amico et al. 2021; Molavi, Lim, and Race 2020). In addition, there exist studies about smart shipping (e.g. Xiao, Chen, and McNeil 2022). However, a clear research gap exists in understanding the role of 'port

smartness' in realizing the SDGs. This paper aims to address this gap by examining the contribution of port smartness to sustainable development and the achievement of the SDGs. For this purpose, this paper firstly introduces the concept of port smartness and its potential relationship with sustainability. Next, the engagement of smart ports with SDGs is discussed, supported by specific examples from the industry. In the main part of the study, we aim to achieve an objective evaluation of the effect of port smartness on sustainability by developing and testing a smart port sustainability index. The last part of the research presents the results, blended with insightful information.

2. Literature review

2.1. Port smartness and sustainability

Smart growth in urban areas first emerged during the 1990s in response to alarming trends in air pollution, loss of historic sites, increased traffic, and rising costs of public amenities. To be more precise, the concept of 'smart growth' pertains to a method of development management that facilitates economic progress while minimizing problems such as traffic congestion and environmental deterioration (Boullauazan, Sys, and Vanelslander 2023). The concept of smart port was first introduced in 2010 by (Molavi, Lim, and Race 2020). They argued that providing a unique and comprehensive definition is not possible; however, in general, port intelligence involves the use of advanced technologies, such as artificial intelligence and the Internet of Things, to improve port operations and optimize the use of resources by providing real-time data and analytics. Compared to traditional ports, smart ports benefit from a workforce with higher education and specialized skills. Additionally, they incorporate smart infrastructure and automation to optimize port operations, leading to increased port flexibility (Wu et al. 2013). Moreover, smart ports actively engage in knowledge sharing to facilitate development, promote sustainable practices, and ensure safe activities. Shuo et al. (2016) described the smart port as a logistics information centre enabling intelligent management of transport and traffic systems (Cimino et al. 2017) as well as real-time information sharing. Hsu et al. (2023) mentioned six factors as success factors of smart port (1) accurate and secure delivery of cargo; (2) accurate electronic document transfer; (3) rapid provision of port berths to shorten the turnover time of ships; (4) convenient and comprehensive logistics and customs procedures; (5) transparent information integration on a single platform; and (6) use of big data to arrange container transport.

According to the American Association of Port Authorities (AAPA), port sustainability is defined as strategies and activities that meet current and future needs of port stakeholders while protecting and sustaining human and natural resources. Port intelligence can help port operators make informed decisions about resource allocation, energy efficiency, and environmental impact reduction (Al-Sharafi et al. 2023). By having smart infrastructure, a smart port can optimize its operations, increase flexibility and safety, and contribute to sustainable development (Rajabi et al. 2018). In the new era, the sustainable development of ports faces many pressures, including blind expansion of the port scale, environmental pollution and inefficient use of resources (Wiegmann and Louw 2011). The role of smart port practices on sustainable port development are impressive, and also extensive. For instance, fuel consumption and carbon footprint are diminished by reducing congestion and increasing efficiency with smart logistics systems (e.g. intelligent routing algorithms) and port automation (e.g. automated cargo handling systems) (Caliskan 2022). Process and quality improvement, as well as monitoring and upgrading can be achieved through data driven decision making and predictive maintenance systems offered by smart ports. The required environmental technology can be met by the smart waste management systems and smart eco-friendly infrastructure. Smart port leads sustainable development and guarantees safe, resilient and secure activities through the capabilities of its (extended) port community and enabling technologies (Boullauazan, Sys, and Vanelslander 2023). Communication and cooperation factor of sustainable port development can be related with integrated systems and data sharing among various

stakeholders of ports such as terminal operators, shippers, shipping lines, customs, port authorities, and freight forwarders (Caliskan 2022). In the next part it is discussed more comprehensively the potential impacts of specific practices of smart ports on 17 sustainable development goals developed by United Nations.

2.2. Smart port sustainability engagement with SDGs

Sustainable development goals (SDGs) are globally accepted to stimulate actions toward economic, environmental and social sustainability. Different researchers have proposed different definitions for sustainable development, United Nations Brundtland argued that 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland 1987). Barbier and Burgess (2001) express, sustainable development is a concept that implies that economic development today must ensure that future generations are left no worse off than present generations. The mounting social pressures faced by port managers have necessitated adopting of suitable measures to ensure environmental sustainability and promote sustainable development. Consequently, port managers have been compelled to explore applying advanced technologies to enhance productivity. In recent years, the pursuit of sustainable development has become a priority for many ports worldwide. To this end, the International Association for Ports and Harbors (IAPH) launched the Global Sustainability Program in 2018. This program aimed to encourage ports to commit to achieving the Sustainable Development Goals outlined by the United Nations. Currently, 71 ports worldwide have pledged to work towards achieving the SDGs through the Global Sustainability Program. This program outlines the goals of sustainable development through a comprehensive framework consisting of five general categories. Resilient infrastructure (SDGs 8, 9, 13, 14), climate and energy (SDGs 7, 9, 12, 13), community outreach & port city dialogue (SDGs 3, 6, 11, 14, 15), governance (SDGs 1, 2, 4, 5, 10, 16) and safety and security (SDGs 3, 4, 8, 16). Several ports have actively participated in the pursuit of the Global Sustainability Program's goals. For instance, the port city of Valencia has implemented the Internet of Things system (IoT) in some of its trucks, which enables port authorities to monitor vehicle routes in real-time (SDGs 8, 9, 11). This initiative allows them to manage and anticipate potential truck congestion at the gates, leading to enhanced efficiency and better transportation fleet management (SDGs 13, 17) (Caballini et al. 2020). In a similar vein, the Hamburg municipality has collaborated with the management centre of port roads to install over 300 sensors on various bridges and roads. This initiative aims to monitor and regulate traffic flow in the port area (SDGs 7, 9, 11, 13). Furthermore, Hamburg has implemented several sustainable projects in its port area to promote environmental preservation. One notable initiative involves the installation of smart street lighting that uses motion detection sensors to illuminate only the necessary areas, thus reducing energy costs (SDGs 7, 8, 9, 11, 12). In addition to the aforementioned initiatives, Hamburg has equipped its goods warehouse with smart sensors capable of detecting and analysing temperature, humidity, and air conditioning. This implementation enhances product quality and minimizes damage to goods (SDGs 2, 3). The port of Rotterdam authority has collaborated with IBM and leveraged digital tools and facilities to enhance the port's environmental indicators. Through the implementation of IBM's equipment, the port can collect and process information related to weather conditions, berth availability, tidal forecasts, wind speed and direction, among others. Such data allows port operators to accurately evaluate the positive economic (SDG 8), and environmental impact of fuel consumption (SDGs 7) while enabling safer entry of ships into the port (SDGs 9, 11) ("IBM" 2018). In the realm of education, Rotterdam has established a laboratory dedicated to research and development in the field of smart logistics. This laboratory employs 3D printers, which offer a cost-effective and timely solution to produce approved assembly parts on a large scale (SDGs 4) (Ramlab 2017). Furthermore, the Port of Montreal has partnered with Concordia University and engaged startups specializing in robotics, automation, and artificial intelligence to develop and implement smart logistics solutions within the port. This initiative exemplifies the port's commitment to advancing

sustainable development goals through innovation and collaboration with academia and the private sector. (SDGs 9) (Witte et al. 2018). Port of Antwerp is another notable example of a port implementing SDGs. In pursuit of economic growth (SDGs 8, 9) and environmental protection (SDGs 11, 13), the port has undertaken an extensive program to achieve the goals of sustainable development. Despite efforts to promote sustainable development while enhancing port operations through intelligence, a gap remains in the literature regarding measuring the impact of port smartness on sustainable development goals. This research seeks to fill this gap by introducing the Smart Port Sustainability Index which is handled comprehensively in the methodology section.

3. Methodology

This study introduces the Smart Port Sustainability Index (SPSI) as a key metric for measuring the impact of port smartness on sustainable development goals through (Equation 1) which comprises two main components; smart port index (SPI) and Port Sustainability Index (SI). For this study, 21 ports from various regions of the world were selected for analysis (Table 1). These included ten ports from Europe (EU), five ports from North America (NP), and six ports from Asia (AP). The selection of these ports was based on two criteria. Firstly, the availability of annual reports and other relevant information by the port administration, and secondly, diversity of port locations. Additionally, efforts were made to ensure that the selected ports were from developed and developing countries to provide a more comprehensive measure of the impact of intelligence.

The SPI index measurement is based on the development of the method presented by (Molavi, Lim, and Race 2020), in which a set of key performance indicators (KPIs) was developed to quantify port performance within each domain of smart port activities. Based on this, four primary domains were considered: industrial operation (SOI), energy efficiency (SEGI), environmental protection (SENI) and safety and security (SSSI). After reviewing the reports, a scoring system was implemented. This system involved assigning a value of 1 to the subdomain index if the port explicitly stated and provided explanations for activities related to each smart port activity domain on their reports or website. Conversely, no value was assigned to areas that were not addressed or mentioned. Also, α , β , γ , δ , λ represent weight parameters. Generally, there are two common methods for calculating these weight parameters: the Analytic Hierarchy Process (AHP) (Van der Horst 2002) and the Analytic Network Process (ANP) (Saaty and Vargas 2013). As the calculation of weight parameters

Table 1. Sampled ports.

	No	Ports	Country	TEU (m.t)
EU	1	Hamburg	Germany	8.5
	2	Antwerp	Belgium	11.1
	3	Genova	Italy	2.3
	4	Amsterdam	Netherlands	8.2
	5	Barcelona	Spain	3.2
	6	Liverpool	United Kingdom	0.9
	7	London	United Kingdom	2.2
	8	Rotterdam	Netherlands	14.8
	9	Valencia	Spain	5.1
	10	Bremerhaven	Germany	5.8
NP	11	Vancouver	Canada	3.1
	12	Montreal	Canada	1.7
	13	Los Angeles	United States	10.8
	14	New York	United States	7.9
	15	Georgia Port	United States	4.6
AP	16	Port of Singapore	Singapore	36.9
	17	Port of Hong Kong	China	19.8
	18	Port of Shanghai	China	43.5
	19	Busan port	South Korea	21.6
	20	Port of Tokyo	Japan	4.8
	21	Mumbai	India	5.1

Table 2. Smart port index (SPI) measurement.

Ports	Indicators				SPI
	SOI	SEgl	SEnI	SSSI	
Hamburg	0.741	0.597	0.758	0.541	.659
Antwerp	0.759	0.711	0.632	0.601	.657
Vancouver	0.358	0.391	0.732	0.590	.517
Los Angeles	0.538	0.407	0.753	0.519	.544
Singapore	0.679	0.721	0.745	0.511	.664
Genova	0.520	0.518	0.611	0.541	.501
Amsterdam	0.687	0.790	0.810	0.645	.690
Barcelona	0.555	0.565	0.742	0.741	.538
Liverpool	0.457	0.504	0.652	0.611	.499
London	0.697	0.630	0.701	0.593	.602
Rotterdam	0.753	0.708	0.761	0.658	.671
Valencia	0.345	0.422	0.603	0.551	.511
Bremerhaven	0.423	0.583	0.741	0.635	.601
Montreal	0.521	0.657	0.701	0.598	.529
New York	0.584	0.621	0.544	0.642	.513
Georgia Port	0.520	0.614	0.574	0.685	.521
Hong Kong	0.311	0.404	0.362	0.318	.341
Shanghai	.418	0.455	0.574	0.611	.498
Busan port	0.512	0.498	0.671	0.599	.630
Tokyo	0.523	0.513	0.638	0.701	.645
Mumbai	0.325	0.398	0.411	0.345	.348

is beyond the scope of this article, these parameters were determined based on (Molavi, Lim, and Race 2020) as follows: $\alpha = 1/4$, $\beta = 1/3$, $\gamma = 1/4$ and $\delta = 1/4$. After calculating the coefficients, the SPI index values for the selected ports were computed using equations 2 through 7, and the resulting values for each port are presented in Table 2.

The SPI index values suggested between $[1, -1]$, and compared the smartness level of the different ports. This index can be effective for the initial understanding intelligence level of ports (Antão et al. 2016).

$$SPSI = 3.6(s_{ij}(SPI)_{ij} + i_{j}(SI)_{ij}) \tag{1}$$

$$SPI = \lambda_1 SOI + \lambda_2 SEgI + \lambda_3 SEnI + \lambda_4 SSSI \tag{2}$$

$$SOI = \sum_{i=1}^{n1} \alpha_{ik} l_i, \quad \sum_{i=1}^{n1} \alpha_i = 1, \alpha_i \geq 0, \quad \mu = 1, \dots, n1 \tag{3}$$

$$SEgI = \sum_{i=1}^{n2} \beta_{ik} 2_i, \quad \sum_{i=1}^{n2} \beta_i = 1, \beta_i \geq 0, \quad \mu = 1, \dots, n2 \tag{4}$$

$$SEnI = \sum_{i=1}^{n3} \gamma_{ik} 3_i, \quad \sum_{i=1}^{n3} \gamma_i = 1, \gamma_i \geq 0, \quad \mu = 1, \dots, n3 \tag{5}$$

$$SSSI = \sum_{i=1}^{n4} \delta_{ik} 4_i, \quad \sum_{i=1}^{n4} \delta_i = 1, \delta_i \geq 0, \quad \mu = 1, \dots, n4 \tag{6}$$

$$\sum_{i=1}^4 \lambda_i = 1, \quad \lambda_i \geq 0, \quad \mu = 1, 2, 3, 4 \tag{7}$$

Also, to gain a preliminary understanding of the extent to which ports contribute to achieving SDGs, we followed the methodological approach employed by (Hossain, Adams, and Walker 2021) and selected 25 indicators to assess the sustainability initiatives implemented by ports the indicators are presented in Table 3. The utilized indicators were selected through a comprehensive review of relevant literature, with the aim of assessing and contrasting the level of sustainability within ports.

Table 3. Sustainability indicators.

Ports	Sustainability Indicators	Source of Sustainability Discloser ^a	Sum of Indicators Adopted by Port
Hamburg	1- Environmental Policy (EP)	SR 2017–2020	20
Antwerp	2- Publicly availability of EP	SR 2019	21
Vancouver	3- Environmental Management System	FLCP 1998–2019- (sustainableworldports.org)	17
Los Angeles	4- EMS Certification (ISO 14,001)	Website (www.portoflosangeles.org)	18
Singapore	5- Air Quality Monitoring	AR 2017 and 2019	21
Genova	6- Water Quality Monitoring	Website (www.portsofgenoa.com/it/)	16
Amsterdam	7- Noise Level Monitoring	SR 2021	22
Barcelona	8- Sediment Quality Monitoring	SR 2018–2020	17
Liverpool	9- Wildlife Protection	SR 2019	18
London	10- Energy Efficiency and Conservation	ER 2020	20
Rotterdam	11- Renewable Energy (RE) Use	AR 2021	21
Valencia	12- Emissions Inventory	SR 2017	16
Bremerhaven	13- Shore Power	SR 2016 + ER 2018	19
Montreal	14- LNG Facility	FLCP 1998–2020	18
New York	15- Green Incentives	AR 2019 +Website (sustainableworldports.org)	19
Georgia Port	16- Green Infrastructure Development	AR 2019 +Website (sustainableworldports.org)	18
Hong Kong	17- Environmental Monitoring Report	AR 2019	11
Shanghai	18- Sustainability Reporting	AR 2019	18
Busan port	19- Sustainability with GRI Guidelines	AR2019 and SR 2018	19
Tokyo	20- Community Engagement	AR 2019 + ER 2021	21
Mumbai	21- Environment Menu Bar on port website	ER2019	11
	22- Environmental Professional		
	23- Research and Development (R&D)		
	24- Climate Change Adaptation		
	25- Port Environmental Review System		

SR: Sustainability report; FLCP: Federal legislation for Canadian ports; ER: Environmental report; CSR: Corporate social responsibility report; AR: Annual report.

Each indicator employed represents a distinct initiative implemented by the ports in their pursuit of environmentally friendly and sustainable practices.

The port's website and annual reports were the primary sources of data for calculating the Port Sustainability Index (SI), and a total of 69 reports from the period spanning 2016 to 2021 were obtained (Ashrafi et al. 2020; Hossain, Adams, and Walker 2019; Hua et al. 2020; Notteboom et al. 2020; Wang et al. 2020). These sources were selected based on their credibility and reliability in providing accurate information on the sustainability initiatives adopted by ports. For this purpose, we employed a content analysis method that provides knowledge and understanding of the phenomenon under study by collecting and analyzing the documentation content (Lawrence 2007). In general, this method of analysis involves both quantitative and qualitative approaches. In the qualitative analysis method, useful data is extrapolated from the mass volume of data with an inside-out analysis (Weber 1990). The quantitative method is usually used to test existing hypotheses and theories, and its mode of operation is deductive content analysis (Scheufele 2008). After conducting a comprehensive evaluation of the available reports, a scoring system was implemented to derive a sustainability index. This scoring system assigned a score of one to the port that exhibited the highest performance for a given index, indicating optimal performance. In instances where there was negligible activity in a particular area, a score of zero was assigned. Scores between zero and one were allocated for cases falling within the spectrum of notable activity. Moreover, if specific information was lacking for a desired field, no score was recorded for that criterion, and it was excluded from the calculations. The details of these calculations for the 25 indicators are presented separately in Table 4.

s_{ij} and \hat{s}_{ij} represent the standard deviation of SPI and SI respectively, calculated using Bessel's correction method (Equation 8). The standard deviation of SPI and SI was calculated as 0.098 and 0.140, respectively.

$$s = \sqrt{\frac{\sum (x-x')^2}{n-1}} \quad (8)$$

4. Results

The SPSI values for ports were calculated using Equation 1, as presented in Figure 1. After obtaining SPSI values for ports, a correlation analysis was conducted to assess the impact of Port Sustainability Index (SI) and the Smart Port Index (SPI) separately. While the evaluation results generally indicated a positive interaction, some anomalies were observed. Specifically, in the correlation analysis between SPI and SPSI, it was noticed that in 9 of the sampled ports, higher SPI did not necessarily correspond to higher SPSI in one or more cases, compared to other ports. The values are presented graphically in the Figure 2 below. Although in many cases there was also the opposite of this issue. But it seems that it is not possible to put forward a general rule that more intelligence in ports will necessarily lead to more sustainability.

A similar analysis was conducted to assess the impact of the SI index on the SPSI index, revealing a generally positive antecedent effect. In many instances, an increase in sustainability corresponded to an increase in SPSI, supporting a positive relationship. However, it is important to note that this relationship is not universally applicable as some cases demonstrated the opposite outcome, suggesting that the relationship between smartness and sustainability is complex and context-dependent. The values are presented graphically in the Figure 3 below.

In order to clarify this very interesting result, the variation of the SPSI index against the SPI and SI was checked through linear regression. Figure 4 depicts the graph that illustrates the variation of the SPSI index against the SPI index. In certain circumstances, ports that prioritize smart technology adoption may disregard environmental and social components of sustainable development (D'Amico et al. 2021). While the utilization of intelligent

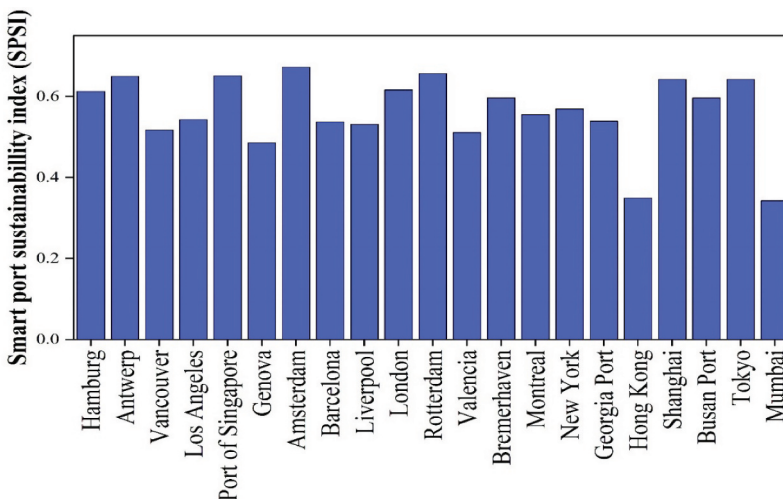


Figure 1. Smart port sustainability index (SPSI).

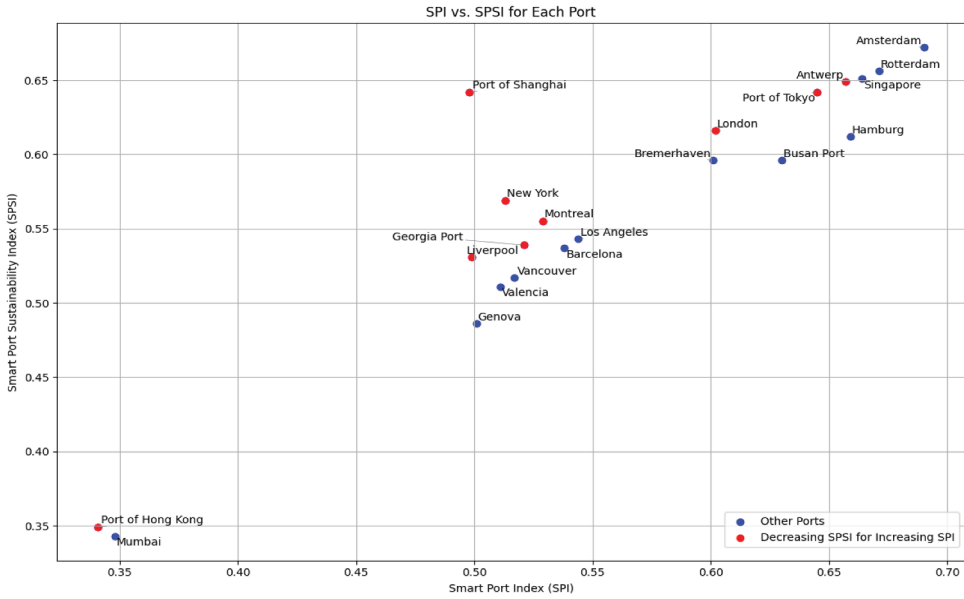


Figure 2. SPI vs. SPSI for each port.

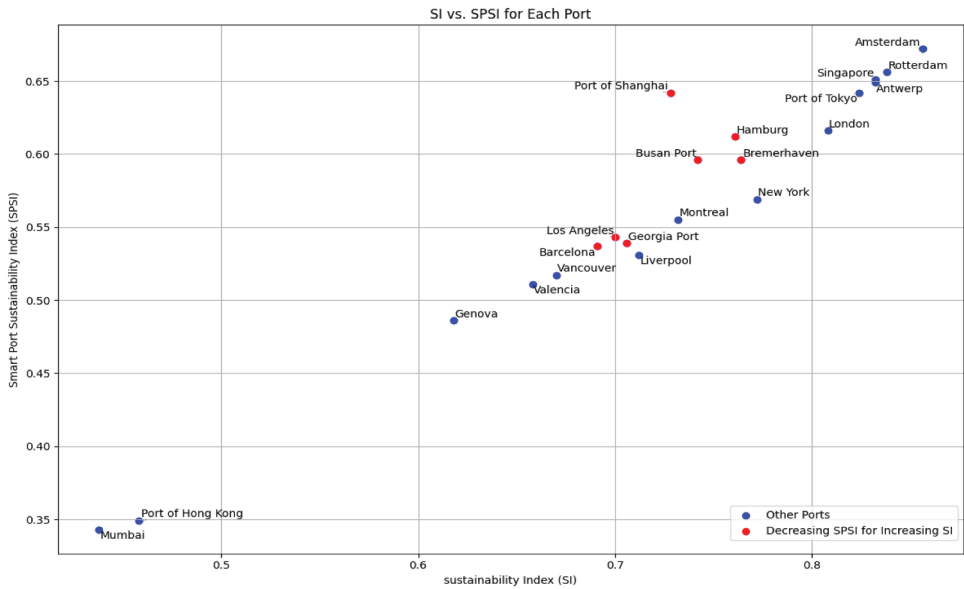


Figure 3. SI vs. SPSI for each port.

technologies is necessary, it is not adequate due to the escalating trend of data production and globalization (Balliauw et al. 2020).

On the other hand, in over 75% of the analysed ports, an increase in the sustainability index corresponded to a simultaneous increase in the SPSI index (Figure 5). This observation suggests

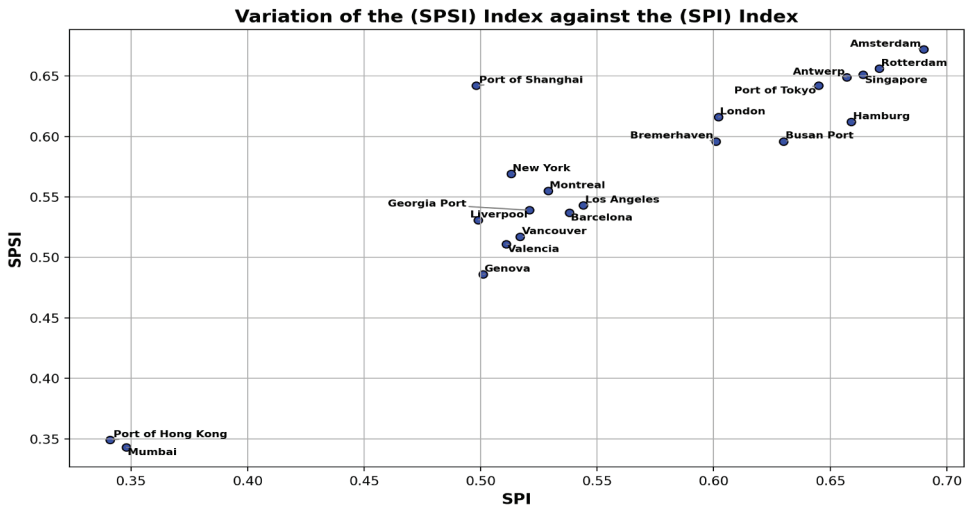


Figure 4. Variation of (SPSI) index against (SPl)index.

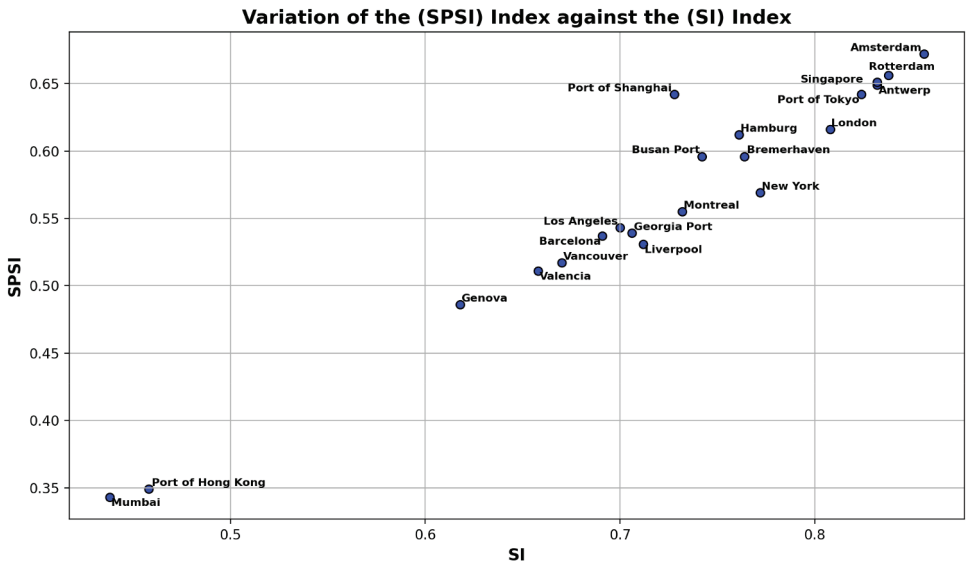


Figure 5. Variation of (SPSI) index against (SI)index.

that the enhancement of sustainable development indicators can be considered a beneficial factor in enhancing the intelligence and sustainability of ports.

In addition, Table 5 displays the SPSI values and their corresponding averages for the three regions of Europe, North America, and Asia, respectively.

Furthermore, the results of the regional analysis indicate that European ports outperform ports in other regions across all three sustainability indicators, Smartness operation and the Smart Port Sustainability Index (Figure 6).



Table 5. SPSI values for EU, NP, and AP ports.

Ports	Hamburg	Antwerp	Amsterdam	Barcelona	Liverpool	London	Genova	Rotterdam	Valencia	Bremerhaven	AVE SPSI
SPSI values for EU ports											
SPSI	0.612	0.649	0.672	0.537	0.531	0.616	0.486	0.656	0.511	0.596	0.586
Ports	Vancouver			Los Angeles		Montreal		New York		Georgia Port	
SPSI values for NP ports											
SPSI	0.517		0.543		0.555		0.569		0.539		0.544
Ports	Singapore	Hongkong	Port of Shanghai		Busan Port		Port of Tokyo		Mumbai		AVE SPSI
SPSI values for AP ports											
SPSI	0.651	0.349	0.642		0.596		0.642		0.343		0.537

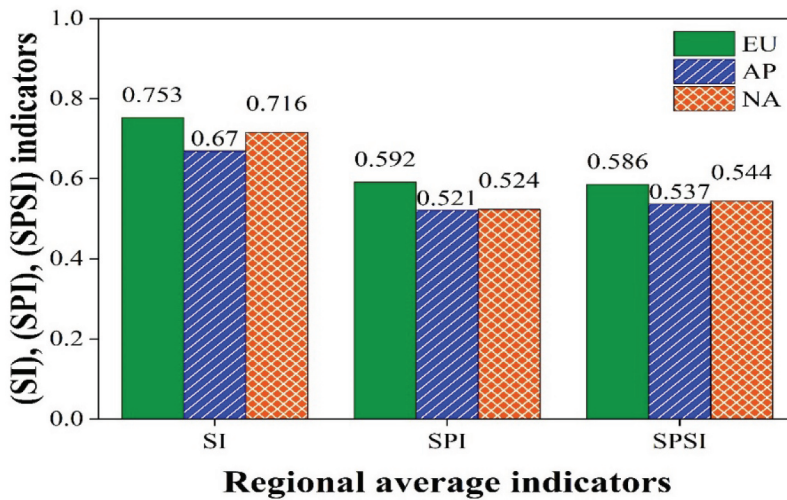


Figure 6. Regional SPI, SI and SPSI indexes.

5. Conclusion and implications

The simultaneous consideration of intelligentization and sustainable development in ports is an aspect that has been relatively overlooked by researchers. This study introduces the Smart Port Sustainability Index (SPSI) as a key metric for measuring the impact of port smartness on sustainable development goals. For this study, 21 ports from various regions of the world were selected for analysis. The selection of ports was based on the data availability and diversity of port locations. The results of the study showed, higher levels of intelligence do not necessarily correspond to greater sustainability. In certain circumstances, ports that prioritize adoption of smart technologies may inadvertently overlook the environmental and social aspects of sustainable development. For example, large amounts of data processing and storage capacity are required for smart port systems. The management of this capacity has the potential to increase energy consumption. At the same time, smart port investment may cause an increase in electronic waste. Improper management and recycling of these wastes may cause negative environmental impacts. Finally, the application of smart technologies may require a more complex system for port operators. This can lead to system failures and interruptions, which can negatively impact business continuity and environmental impact. The potential social externalities of smart port investment are greater than environmental externalities. With intelligent systems, it is possible to see social externalities such as unemployment, skill and talent needs and education, data privacy and security, community participation and accessibility. Smart technology investments can lead to automating some business processes and increasing efficiency. This may mean the disappearance or reduction of some jobs. It is possible that some workers in the port are at risk of becoming unemployed. This can lead to problems such as rising unemployment rates and increasing social inequalities. Using smart technologies may require dockers to need new skills and abilities. This means that the education and skill level of the current workforce needs to be improved. If adequate training opportunities are not provided, some employees may lose their jobs or have to move to lower-skilled jobs. Smart port systems collect and process large amounts of data. This raises data privacy and security concerns. This may lead to social security and privacy problems, especially if strict measures are not taken to protect personal and commercial data. Smart technology investments can transform community participation and impact on business decisions. This may result in the community being less involved or excluded in the activities and decision processes of port operators. This can lead to local dissatisfaction and

social unrest. The proliferation of smart technologies can deepen the digital divide. Segments of society that do not have access to technological infrastructure or have low levels of digital literacy may not be able to fully benefit from these technological developments. This can increase social inequalities and trigger social justice issues.

On the other hand, in over 75% of the analysed ports, an increase in the sustainability index was accompanied by a simultaneous increase in the Smart Port Sustainability Index (SPSI). This finding suggests that the improvement of sustainable development indicators can be viewed as a favourable factor in enhancing the intelligence and sustainability of ports. For example, the goal of reducing environmental externalities in ports brings with it the necessity of monitoring and evaluating environmental impacts. For this, big data collection and analysis can be achieved with the ability of digitalization such as smart sensors and the internet of things. The goal of reducing energy consumption and emissions is possible with software that optimizes energy use, energy-saving lighting systems, renewable energy sources, and smart transportation systems. Activities carried out for social sustainability in ports can also contribute to the process of digitalization and becoming a smart port. Occupational health and safety in ports is an important social sustainability factor. Digital technologies, smart sensors and monitoring systems can help improve occupational health and safety processes. In addition, digital platforms can be used to deliver training and awareness programs to workers. Collaboration and communication among port workers can also be enhanced through digitalized tools. This increases the efficiency of business processes and supports teamwork. Social sustainability also includes the training and skills development of port workers. Digitization provides employees with accessible and interactive training opportunities through e-learning platforms and virtual training tools. In this way, employees can gain more knowledge and skills, develop their careers, and become more proficient in their jobs. The goal of better interaction of ports with society also brings smart technologies. Social media, web-based platforms and other communication tools enable ports to more effectively communicate with the community, share their projects and gather feedback. This increases community participation in port activities and promotes transparency.

In conclusion, this research aimed to investigate the simultaneous effect of smartness and sustainability in ports. For this propose, this study introduced the Smart Port Sustainability Index (SPSI) as a key metric for measuring the impact of port smartness on sustainable development goals. The results of this study brought to mind the chicken and egg situation. Sustainability and digitalization are complementary and mutually contributing concepts when the goal is to ensure sustainability. While sustainability promotes digitalization, digitalization can also be used to achieve sustainability goals. Therefore, both sustainability and digitalization are important issues that need to be addressed together for a more sustainable future. However, the results also show that if the sole aim is to getting smarter then there is generally no guarantee that sustainability will definitely be realized.

5.1. Limitations

Due to the reliance on ports' websites and their annual reports as the primary data source, some results presented in this study may be subject to limitations arising from incomplete or unavailable information. Accordingly, we excluded specific ports from the analysis, such as those located in Africa and South America. Furthermore, larger ports often demonstrate greater adherence to reporting standards, which may contribute to greater availability of sustainability-related data (Santos, Lima Rodrigues, and Castelo Branco Branco 2016).

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