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Toward sustainable port development: an empirical analysis of China's port industry using an ESG framework

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In recent years, the issue of sustainable development has become increasingly important in the port industry. As port policies are altered under decentralization and governance models, the application of corporate responsibility (CR) is expanding. It is now expected that ports take on environmental, social, and governance (ESG) responsibilities. This paper focuses on the application of an ESG framework to the port industry in China, with a specific emphasis on social responsibilities. By focusing on ESG-focal issues in the port industry, we establish a model for evaluating the sustainability of ports that takes into account the three dimensions of environment, society, and governance. An empirical analysis of Shanghai Port in China is presented to illustrate the application of the framework. The paper highlights the main contribution of the ESG framework to support sustainable port development and provides recommendations for promoting the implementation of ESG and sustainable development in the industry.

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Introduction

Environmental problems such as pollution, resource depletion, and ecological degradation sparked great concern in society during the twentieth century. In 1983, the United Nations formed the World Commission on Environment and Development (WCED) in response to environmental and economic challenges. And, in 1987, the WCED proposed Our Common Future to the United Nations, which defined sustainable development as "the development that meets the needs of current generations without compromising the ability of future generations to meet their own needs" (Roh et al., 2023).

With the globalization of the world's economy, ports have been taking on increasingly diversified functions, and their impact on economies and societies has been growing. However, the negative externalities associated with ports have also become more prominent (Acciaro, 2015), including noise, water and air pollution, destruction of soil and habitat, and threats to human health (Pavlic et al., 2014; Gupta et al., 2005). The port industry is, also beginning to work on sustainability issues. The United Nations Commission on Trade and Development (UNCTAD) presented a strategy for sustainable port development in 1993 (UNCTAD, 1993), with the goal of lowering the environmental impact of port economic activities. Research on the sustainable development of ports has boomed, with scholars focusing on technological and management tools necessary to achieve green and sustainable development (Aregall et al., 2018; Bjerkan and Seter, 2019; Gupta et al., 2005; Styhre et al., 2017) as well as government policies (Konstantinos et al., 2022; Lam and Li, 2019; Wang et al., 2021). Additionally, more research started focusing on evaluating and balancing the economic, environmental, and social benefits of ports and the surrounding cities (Bottasso et al., 2014; Park and Seo, 2016).

As sustainability theories continue to evolve and enrich, the environmental aspect of port sustainability has increasingly been stated separately as a new phrase, "Green Ports" (Hua et al., 2020; Chen et al., 2019; Lawer et al., 2019). The "Green Port" concept was officially proposed at the 2009 United Nations Climate Change Conference (Hua et al., 2020). It is described as limiting negative environmental consequences while maintaining economic and social performance (Pavlic et al., 2014). Green ports are viewed as a crucial component of sustainable ports (Acciaro, 2015; Lu et al., 2016), making the environmental responsibilities of port development more evident. With the continuous research on green ports, scholars have found that green ports can also achieve sustainable development, social responsibility, and economic benefits in the long run (Lam and Li, 2019).

Port authorities have decentralized or are restructuring their governance models to varying degrees in response to global economic and technological changes, including the landlord port model (Cariou et al., 2014; Munim et al., 2019), the concession model (Noring, 2019), the PPP model (Wang et al., 2018; Yang et al., 2020), and in some cases of full private ownership (such as in the UK) (Asgari et al., 2015). Therefore, port officials have started to act more like entrepreneurs (Caldeirinha et al., 2018). This has resulted in port management becoming more company-centric and market-oriented rather than policy-oriented and port-centric (Woo et al., 2011). To achieve sustainable development, port companies must take responsibility for the impact of their operations on the economy, society, and environment. Previous studies (e.g., Acciaro, 2015; Sun et al., 2017) have highlighted the importance of corporate commitment in achieving sustainable development in port settings.

The concept of ESG (Environmental, Social, and Governance) responsibility, which stems from the concept of sustainable development, emphasizes corporations' responsibility to balance economic, social, and environmental benefits. ESG was first introduced in the developed countries of Europe and America and has since attracted strong interest from scholars.[1] ESG aims to give companies guidance in sustainable development.

However, during our literature review, we found that there are relatively few studies focusing on port ESG, and the application of ESG principles in the port industry seems to receive insufficient attention. This is especially true for developing countries like China, where the awareness of ESG came later compared to Western countries. Considering the enormous annual cargo throughput of Chinese ports, particularly coastal ports with a significant share of trade volume and a consistent growth trend (Fig. 1), there is a pressing need for continuous involvement from port management and adjustments to port operational and management strategies to achieve sustainable port development.

This study aims to examine the current application of ESG in China's port industry, with a focus on ESG disclosure by port firms. The primary contribution is the development of a sustainable development evaluation system for ports, considering the three aspects of environment, social, and governance, given the corporate attributes of modern ports. We creatively adapt the CRITIC evaluation method, which uses the objective properties of the data in the analysis. The CRITIC evaluation method enabled us to compare the intensity of indicators using the entropy weight method and to take into account the conflicting nature of indicators. Finally, we test our model using data from the Port of

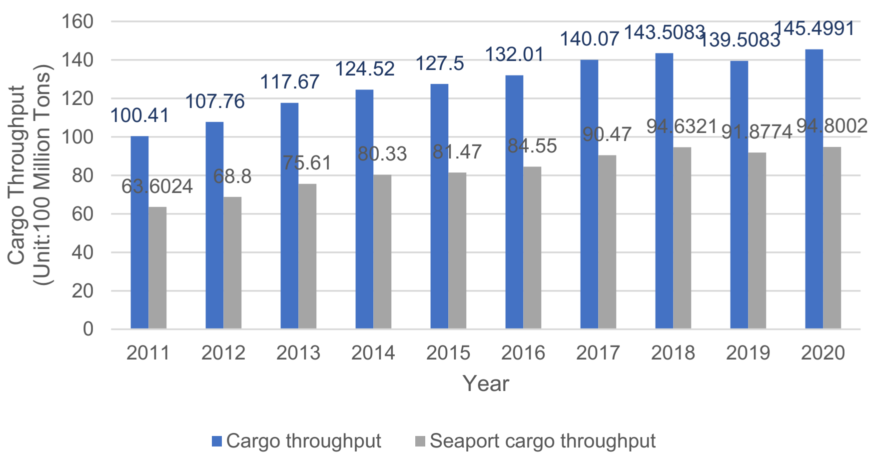

Fig. 1 Cargo throughput of Chinese ports, 2011–2020. In this figure, the blue bars reflect the cargo throughput of Chinese ports from 2011 to 2020, and the gray bars represent the cargo throughput of seaports. The unit of cargo throughput is 100 million tons. Data from *China Port Yearbook*.

Shanghai in China and create guidelines for using an ESG perspective to promote sustainable port development.

The rest of the paper is organized as follows. Section "Literature review" presents an overview of ESG. Section "Model framework" examines the current status of ESG disclosure in Chinese ports and proposes a system for evaluating port sustainability. Section "Methodology" outlines the methodology used in the paper. Section "Case study" presents an analysis using the Port of Shanghai as an example. The conclusions and limitations are presented in the section "Conclusions".

Literature review

ESG is a formalization of the concept of "responsible investment" and "corporate social responsibility (CSR)" (Leins, 2020). These ideas can be traced back to the social movements in the 1960s and 1970s, such as the civil rights movement in the United States, the fight against racial discrimination in South Africa (Tian, 2007), and environmental protection movements worldwide (Wang and Huang, 2021). ESG evolved from these foundations, and in 2004, it was formally introduced in the United Nations report, "Who Cares Wins."

While many scholars have found a positive relationship between ESG performance (ESGP) and financial performance (FP) (Busch and Friede, 2018; Orlitzky et al., 2003; Qureshi et al., 2021; Ferrero-Ferrero et al., 2017), other studies have found opposing conclusions (Duque-Grisales and Aguilera-Caracuel, 2021), arguing that ESG-driven investment imposes additional costs (Derwall et al., 2005; Hassel et al., 2005) and negatively affects FP. Recent studies have suggested that ESGP has a nonlinear relationship with FP (i.e., Adegbite et al., 2019; Bruna et al., 2022) and demonstrated that ESG has a positive effect on innovation (Liu and Lyu, 2022; Tang, 2022) and sustainable performance (Alsayegh et al., 2020).

Despite the growing popularity of responsible investing, there are no agreed-upon standards. ESG standard-setting organizations include the Global Reporting Initiative (GRI), International Standard Organization (ISO), and Sustainability Accounting Standards Board (SASB) et al. Evaluation criteria include the ESG ratings of Bloomberg (Tamimi and Sebastianelli, 2017), Thomson Reuters (Duque-Grisales and Aguilera-Caracuel, 2021), and MSCI (Hughes et al., 2021). The lack of clear criteria may lead to different evaluation results (Scholtens, 2014) and some companies may use ESG simply to improve their corporate image (Huang, 2022). To regulate and improve the quality of ESG disclosure, some countries and regions have introduced mandatory ESG disclosure. For example, the EU Directive 2014/95/EU requires large companies to disclose how they operate and manage in the face of social and environmental challenges, thus moving the disclosure of non-financial information (NFI) from the voluntary to the mandatory domain (Mio et al., 2020). In June 2021, the U.S. House of Representatives passed The ESG Disclosure Simplification Act of 2021, which requires listed companies to disclose additional material ESG information (Wen et al., 2022). According to the *Sustainable Finance and ESG Development Report*, published on the official website of Refinitiv, international regulatory policies related to ESG have doubled since 2015 with the establishment of the United Nations 2030 Agenda for Sustainable Development and the Paris Agreement.

The port industry is widely recognized as a crucial driver of national economic growth, with spillover benefits that extend beyond the industry itself and into the wider society (Deng et al., 2020). However, there are growing concerns regarding environmental accountability, which has led to the port industry assuming environmental, social, and governance responsibilities, aligning with the principles of sustainable port development (Feng et al., 2022). CSR has gained increased application in the port industry, particularly with the proliferation of entrepreneurship in recent years (Acciaro, 2015). Ports are assuming significant responsibility by reducing their environmental impact, promoting humanitarianism, and funding educational initiatives for their employees and neighboring communities.

However, there is a lack of research on the application of ESG in the port industry. Dos Santos and Pereira (2022) have pointed out that while several studies have analyzed the ESGP of shipping companies (Tsatsaronis et al., 2022), no studies have evaluated ESG in port operations. The United Nations Conference on Trade and Development (UNCTAD, 2015) has identified that a port that operates sustainably is more likely to garner support from governments, communities, and the public, as well as potential investors in the maritime industry. Therefore, this study seeks to examine the relationship between ESGP and port sustainability and develop a model for evaluating port sustainability from an ESG perspective.

Model framework

Status of ESG disclosure in the port industry in China. China's port industry is concentrated mainly along its eastern coast, and it is divided into five major clusters based on the National Coastal Port Layout Plan by the Chinese Ministry of Transport. These clusters are the Bohai Rim Port Cluster, Yangtze River Delta Port Cluster, Southeast Coastal Port Cluster, Pearl River Delta Port Cluster, and Southwest Coastal Port Cluster. In the 2021 World's Top 100 Container Ports ranking by Lloyd's List 2021, 24 inland ports in China were featured, which were distributed among the five major port clusters (Fig. 2).

Upon reviewing port yearbooks and other relevant information from the official websites of these 24 ports, we find that as of July 2021, 18 listed companies controlled most of the operations at these ports. Further investigation of these 18 companies reveals that 15 of them publicly disclosed their ESG reports as of 2022. The first four port enterprises to voluntarily disclose an ESG report were Shanghai International Port Group (SIPG), Tianjin Port Co., LTD, Rizhao Port CO., LTD, and Jiangsu Lianyungang Port CO., LTD. They all began to issue ESG reports in 2008. SIPG's ESG report is the most comprehensive, containing the most quantitative data among all the enterprises we have investigated.

There is no standardized label for these ESG reports, as some companies call them CSR reports while others call them sustainable development reports. The most common standards used for ESG disclosure by these port enterprises are as follows: (1) global standards, mainly the GRI Standards issued by the Global Sustainability Standards Board (GSSB); (2) Chinese national standards, such as *Guidance On Social Responsibility Reporting GB/T 36001-2015*; (3) standards issued by China's stock exchanges, including the *Report on Corporate Social Responsibility Compilation Guidelines* issued by Shanghai Stock Exchange, the *Guidelines on the Social Responsibility of Listed Companies* issued by Shenzhen Stock Exchange, and the *Guidelines on ESG Reporting* issued by Hong Kong Stock Exchange; and (4) guidelines compiled by the private sector, such as the *Basic Framework of China's Corporate Social Responsibility Reporting Guidelines* (CASS-CSR4.0). Among these standards, the GRI Standards are relatively complete in content and more widely used since they are recognized as the official standard for countries by the GSSB. However, some indicators in the GRI standards may not be applicable to port enterprises. Table 1 provides a summary of the 15 port enterprises in the sample, including the year they began to disclose ESG reports and their primary reference standard.

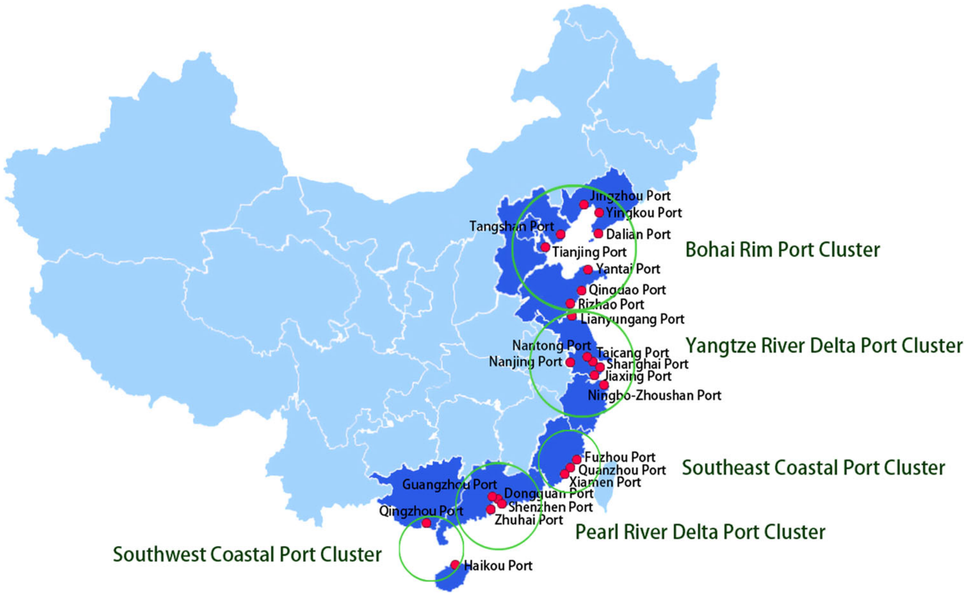

Fig. 2 Distribution of ports in China. This figure shows the concentration of China's ports along the eastern coast, marked in darker colors. Marked by red dots are the 24 Chinese inland ports that are in the 2021 World's Top 100 Container Ports ranking by Lloyd's List. The approximate extent of China's five largest port clusters is also indicated.

The main issues disclosed in the ESG reports in our sample are summarized in Table 2. Under environmental responsibility, the ports disclose their actions related to protecting the environment and conserving resources. Under social responsibility, the ports report their actions in four areas: social development, regional relations, human resource management, and service. These initiatives affect both direct and indirect stakeholders. The sections on governance, as in the disclosures of corporations in other sectors, focus on the management of the organizational structure. For ports, this includes port operation management and services. The operations management has some attributes that are specific to the port industry.

Construction of port sustainability indicators from an ESG perspective

System of Indicators. We focus our attention on the current research topics related to the sustainable performance of the port industry based on ESG reports and find that there is almost no comprehensive research on all three aspects of ESG reporting. Many scholars tend to discuss one aspect separately, such as environmental responsibility and green port performance (Hua et al., 2020; Chen et al., 2019); defining the social role of ports, drivers of social responsibility, and Corporate Social Performance (CSP) of ports (Batalha et al., 2023; Acciaro, 2015; Batalha et al., 2020); and exploring sustainable governance models for ports (Caldeirinha et al., 2018; Schrobback and Meath, 2020; De Langen and Heij, 2014). In addition, we expand our focus to other industries' sustainable performance based on ESG reporting. Many studies often directly use the scores provided by commercial rating agencies as ESG performance indicators (Qureshi et al., 2021; Sandberg et al., 2023; Liu and Lyu, 2022). However, there are differences between ratings from different commercial agencies, and standardization remains a challenge (Sahin et al., 2022). There are still some existing issues, such as insufficient industry classification. In our review in the section "Status of ESG disclosure in the port industry in China", we also find that port companies have some unique characteristics apart from the internationally recognized indicators like GRI. Another issue is the lack of transparency in the evaluation process, especially when dealing with negative information or missing data (Paredes-Gazqueza et al., 2016).

Therefore, we believe it is necessary to combine general standards and take into account the characteristics of the port industry, integrating the existing research results on the E, S, and G aspects. This will help in constructing a comprehensive ESG performance framework tailored to the port industry. Assessing the sustainable performance of port companies based on their ESG reports can also provide more accurate feedback to guide their sustainable development practices. To achieve this, we use 32 representative indicators to construct a comprehensive system for evaluating port sustainability from a complete ESG perspective, as shown in Table 3.

Definitions of indicators

Environment: Ten variables, grouped into three categories, are used to assess the environmental responsibility performance of the port.

The first category is energy-saving capability indicators. Throughput energy consumption (E1) reflects the intensity of energy consumption. Energy-saving rate (E2) reflects the trend in energy savings and is calculated using formula $\xi = \frac{e_1 - e_0}{e_0} \times 100\%$, drawn from the Chinese national standard Port Energy Consumption Statistics and Analysis Methods (GB/T21339-2020), where e_1 and e_0 represent the energy consumption per unit of output, i.e., throughput energy, for the reporting period and the base period, respectively.

The second category is emission-reduction capacity indicators. Carbon emission intensity (E3) measures the CO2 emission-reduction capacity and is calculated using the comprehensive energy consumption multiplied by the carbon emission factor of standard coal, divided by throughput. Air quality index/air pollution index (E4) and noise level (E5) indicators are used to indicate other negative environmental impacts. Environmental capital investment (E6) is the annual investment of enterprises in energy saving and emission reduction, which is used to reflect the efforts of emission reduction.

The third category is resource utilization efficiency indicators. Water consumption per unit of throughput (E7) and sewage

Table 1 Chinese listed port companies participating in ESG disclosure.

Enterprise name (stock symbol)	Main operating ports	Starting year	Report name	Main reference standards
SIPG (600018.SH)	Shanghai Port	2008	Sustainable development report	GRI standards
NZP (601018.SH)	Ningbo-Zhoushan Port, Wenzhou Port, Jiaxing Port etc.	2010	CSR report	*Report on Corporate Social Responsibility Compilation Guidelines* (Shanghai Stock Exchange)
QDPI (601298.SH)	Qingdao Port	2016	Sustainable development report	GRI Standards; *Guidelines on ESG Reporting* (Hong Kong Stock Exchange)
LIAONING PORT (601880.SH)	Dalian Port、Yingkou Port	2012	CSR report	*Report on Corporate Social Responsibility Compilation Guidelines* (Shanghai Stock Exchange)
CMPort (001872.SZ)	Participated in the management of Shenzhen Port, Shantou Port, Zhanjiang Port and many other ports	2017	CSR report	GRI Standards; *Guidelines on ESG Reporting* (Hong Kong Stock Exchange); *Guidance On Social Responsibility Reporting* GB/T 36001-2015
GZP (601228.SH)	Guangzhou Port	2017	CSR report	The Ten Principles of the United Nations Global Compact; *Guidance On Social Responsibility Reporting* GB/T 36001-2015; *Report on Corporate Social Responsibility Compilation Guidelines* (Shanghai Stock Exchange)
TSPGC (601000.SH)	Tangshan Port	2012	CSR report	–
QHD PORT (601326.SH)	Qinghuangdao Port, Caofeidian Port, Huanghua Port	2016	CSR report	*Guidelines on ESG Reporting* (Hong Kong Stock Exchange); *Report on Corporate Social Responsibility Compilation Guidelines* (Shanghai Stock Exchange)
Beibu Gulf Port. (000582.SZ)	Beibuwan Port, Qingzhou Port	2021	CSR report	GRI Standards; Sustainable Development Goals (SDGs); *Guidance On Social Responsibility Reporting* GB/T 36001-2015; *Guidelines on the Social Responsibility of Listed Companies* (Shenzhen Stock Exchange)
YPH (000088.SZ)	Yantian Port	2019	CSR report	GRI Standards; SDGs; *Guidance On Social Responsibility Reporting* GB/T 36001-2015
TJP (600717.SH)	Tianjing Port	2008	CSR report	GRI Standards; *Report on Corporate Social Responsibility Compilation Guidelines* (Shanghai Stock Exchange)
RIZHAO PORT (600017.SH)	Rizhao Port	2008	CSR report	*Report on Corporate Social Responsibility Compilation Guidelines* (Shanghai Stock Exchange)
ZHUHAI PORT(000507.SZ)	Zhuhai Port	2020	ESG report	GRI Standards; *Guidance On Social Responsibility Reporting* GB/T 36001-2015
JZP (600190.SH)	Jingzhou Port	2011	CSR report	GRI Standards; *Guidance On Social Responsibility Reporting* GB/T 36001-2015
Lianyungang Port (601008.SH)	Lianyungang Port	2008	CSR report	–

This table reports 15 port-listed companies in China that publicly disclose ESG reports, including the ports they mainly operate, the beginning year of ESG report disclosure, and the name of the report, as well as the disclosure standards referenced by the report. An "-" in the Main Reference Standards column indicates that the enterprise does not explicitly indicate the standards used in the ESG disclosure report.

Table 2 Focal issues in the ESG reports of Chinese port companies.

Focal issues	Content
Environmental responsibility (E)	
Environmental protection	Greenhouse gas emissions, air pollution prevention, and control, water pollution prevention and control, noise pollution prevention and control, sewage treatment, solid waste utilization, environmental protection financial support, environmental management measures, environmental protection training, emission-reduction technology use, management of supplier environmental awareness
Resource conservation	Energy consumption, water consumption and utilization, electricity consumption, ecological resource protection, biodiversity, shoreline resource utilization, material consumption, clean energy substitution
Social responsibility (S)	
Social development	Public policy, industry cooperation, social donation, science and technology innovation support
Regional relations	Stakeholder relations and engagement, community events, cultural participation
Human resource management	Position structure, gender diversity ratio, anti-discrimination, anti-corruption, salary and benefits, system security, education and training, cultural activities, security measures management, security awareness training, security investment, hardship support
Service	Customer satisfaction, complaints, and handling
Governance responsibility (G)	
Organizational structure	Board of directors, shareholding structure, governance framework, values building, transparent internal and external communication, Scale of organization, anti-corruption, socioeconomic compliance
Operations	FP, tax payment, risk management, economic performance, economic impact, infrastructure development, throughput, port operation efficiency, transportation mode optimization, smart port construction, technology advancement

This table reports the focus issues of environment, society, and governance that port enterprises are concerned about. The content is derived from our statistics and refining of the information disclosed in ESG reports of all port enterprises over the years.

treatment rate (E8) are used to describe water use and sewage discharge. E7 represents water use per unit of throughput, and E8 is the ratio of effluent discharge to water use. Measures are done to increase resource use, such as waste recycling, and hazardous waste disposal, to lessen the detrimental ecological effects of port activities. We choose the indicators are waste recycling rate (E9), and hazardous waste disposal rate (E10).

Society: Twelve variables, grouped into six categories, are used to assess the society responsibility performance of the port.

We have organized social responsibility into six categories: employee management, security, training and education, social contribution capability, vendor, and customer. For the category of employee management, a number of new employees (S1) and employee turnover rate (S2) are used to describe employee mobility, and the percentage of female employees (S3) is used to reflect gender equality and social equity. Security indicator is expressed in terms of security investment (S4) for the reporting period. Training and education indicator is expressed in terms of number of trainings per capita (S5). For the category of social contribution capacity, we chose five indicators.

The amount of social donation (S6) reflects the contribution of a port company to poverty eradication, which is the total amount of social donations such as charitable donations and funding for education in poor areas. Employment opportunities for the neighborhood (S7) are jobs provided to the community. Science and technology innovation projects (S8) are the sum of the number of science and technology projects completed and the number of patents applied during the reporting period. Tax contribution (S9) is the amount of tax paid during the reporting period. Social contribution per share (S10) responds to the combination of social contributions, which is calculated with reference to the Corporate Social Responsibility Compilation Guidelines Report (Shanghai Stock Exchange) by dividing the entire value provided for stakeholders by the enterprise's total share capital, after removing the societal expenses associated with environmental damage and so on. Vendor screening rate (S11) and number of customer complaints (S12) are chosen to represent vendor and customer metrics.

Governance: Ten variables, grouped into five categories, are used to assess the governance responsibility performance of the port.

Governance responsibilities are organized into five categories: organizational management, scale of organization, economic performance, anti-corruption, and socioeconomic compliance. In organizational management, we chose the percentage of independent directors (G1), the percentage of females in management (G2), and the percentage of management remuneration (G3) as indicators to reflect the board's and management's status. Number of employees (G4) and employee compensation (G5) are used as indicators of organization scale. Cargo throughput (G6), container throughput (G7), and profitability (G8) are selected as indicators of economic performance, reflecting the operational capacity and economic situation of the port enterprises. Among them, the profitability indicator directly reflects the cost efficiency of the company, which is calculated as profit divided by cost. The indicator anti-corruption training per capita (G9) represents anti-corruption efforts. The Amounts Penalized (G10) indicator is used to assess socioeconomic compliance during the reporting period.

Methodology

The CRITIC method, first proposed by Diakoulaki et al. (1995), is an objective weighting method that integrates indicators based on their comparative strength and the conflict between them. The CRITIC method is more objective than subjective weighting methods such as the Delphi method and the AHP method. In port-related research, the CRITIC method has been widely applied and is currently being used for various studies, including the evaluation of service capabilities in multimodal transportation hubs centered around ports (Liu & Wang, 2023), the identification of critical flaws affecting vessel detention decisions (Zhu et al., 2023), and the assessment of port resilience (Lin & Liu, 2023).

Data processing. To eliminate the influence of the different magnitudes of the evaluation results, it is necessary to carry out dimensionless processing of each indicator. For positive

Table 3 ESG framework for assessing sustainability.

Category	First-level indicators	Second-level indicators	Variable name	Unit	Predicted direction	Reference
Environment	Energy-saving capability					
		Throughput energy consumption	*E1*	Tons of standard coal/ ten thousand tons	Negative	GRI 302; Asgari et al. (2015); Dos Santos and Pereira (2022); Junior et al. (2022); Chen and Pak (2017); Di Vaio et al. (2018)
		Energy-saving rate	*E2*	%	Positive	
	Emission-reduction capacity					
		Carbon emission intensity	*E3*	Tons/ten thousand tons	Negative	GRI 305; Chen et al. (2022); Chen and Pak (2017); Junior et al. (2022); Di Vaio et al. (2018); Wan et al. (2018)
		Air quality index/Air pollution index	*E4*	μg/m^3	Positive/ Negative	
		Noise level	*E5*	dB	Negative	
		Environmental capital investment	*E6*	Ten thousand yuan	Positive	
	Resource utilization efficiency					
		Water consumption per unit of throughput	*E7*	Cubic meters/ tonne	Negative	GRI 303/304/306; Chen and Pak (2017); Di Vaio et al. (2018); Lim et al. (2019); Wan et al. (2018)
		Sewage treatment rate	*E8*	%	Positive	
		Waste recycling rate	*E9*	%	Positive	
		Hazardous waste disposal rate	*E10*	%	Positive	
Society	Employee management					
		Number of new employees	*S1*	Person	Positive	GRI401/405; Junior et al. (2022); Paredes-Gazqueza et al. (2016)
		Employee Turnover Rate	*S2*	%	Negative	
		Percentage of female employees	*S3*	%	Positive	
	Security					
		Security investment	*S4*	Ten thousand yuan	Positive	GRI403; Junior et al. (2022); Ha et al. (2017); Lim et al. (2019)
	Training and education					
		Number of trainings per capita	*S5*	Times	Positive	GRI404; Di Vaio et al. (2018); Ha et al. (2017); Paredes-Gazqueza et al. (2016)
	Social contribution capability					
		Amount of social donation	*S6*	Ten thousand yuan	Positive	GRI413; *Report on Corporate Social Responsibility Compilation Guidelines* (Shanghai Stock Exchange); Junior et al. (2022); Ha et al. (2017); Paredes-Gazqueza et al. (2016)
		Employment opportunities for the neighborhood	*S7*	Unit	Positive	
		Science and Technology Innovation Projects	*S8*	Unit	Positive	
		Tax Contribution	*S9*	Hundred million yuan	Positive	
		Social contribution per share	*S10*	Yuan	Positive	

Table 3 (continued)

Category	First-level indicators	Second-level indicators	Variable name	Unit	Predicted direction	Reference
	Vendor					
		Vendor screening rate	*S11*	%	Positive	G414; Ha et al. (2017); Paredes-Gazqueza et al. (2016)
	Customer					
		Number of customer complaints	*S12*	unit	Negative	Junior et al. (2022); Ha et al. (2017)
Governance	Organizational management					
		Percentage of independent directors	*G1*	%	Positive	Kocmanova and Simberova (2012) ; Schrobback and Meath (2020); Paredes-Gazqueza et al. (2016)
		Percentage of females in management	*G2*	%	Positive	
		Percentage of management remuneration	*G3*	‰	Positive	
	Scale of organization					
		Number of employees	*G4*	person	Positive	GRI 102; Junior et al. (2022); Paredes-Gazqueza et al. (2016)
		Employee compensation	*G5*	Hundred million yuan	Positive	
	Economic performance					
		Cargo throughput	*G6*	Hundred million tons	Positive	GRI 201; Kocmanova and Simberova (2012); Chen et al. (2022); Asgari et al. (2015); Junior et al. (2022); Ha et al. (2017); Lim et al. (2019)
		Container throughput	*G7*	Ten thousand TEU	Positive	
		Profitability	*G8*	%	Positive	
	Anti-corruption					
		Anti-corruption training per capita	*G9*	Unit	Positive	GRI 205、Kocmanova and Simberova (2012)
	Socioeconomic compliance					
		Amounts penalized	*G10*	Ten thousand yuan	Negative	GRI 419; Kocmanova and Simberova (2012)

This table reports the established port ESG performance indicators, which have been constructed based on a combination of environmental, social, and governance responsibilities. The indicators include 14 first-level indexes and 32 second-level indexes.

Table 4 Standardized data matrix.

Variable	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
E1	0.00	0.25	0.63	0.85	0.81	0.76	0.76	1.00	0.78	0.79	0.66	0.81
E2	1.00	0.70	0.88	0.68	0.42	0.42	0.35	0.71	0.00	0.37	0.15	0.57
E3	0.00	0.56	0.71	1.00	0.77	0.59	0.61	0.82	0.71	0.29	0.16	0.12
E4	0.00	0.08	0.15	0.23	0.56	0.37	0.51	0.50	0.68	0.79	0.86	1.00
E5	0.11	0.00	0.39	0.22	0.11	0.11	0.28	0.11	0.39	0.94	1.00	0.89
E6	0.07	1.00	0.62	0.00	0.06	0.77	0.64	0.19	0.08	0.07	0.06	0.05
E7	0.00	0.34	0.49	0.73	0.82	0.82	0.79	0.95	0.93	1.00	0.95	0.97
E8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S1	0.00	0.87	1.00	0.94	0.79	0.75	0.39	0.69	0.63	0.31	0.21	0.29
S2	1.00	0.38	0.72	0.00	0.46	0.46	0.38	0.23	0.08	0.46	0.68	0.15
S3	0.33	0.33	0.15	0.03	0.01	0.00	0.25	0.47	0.64	0.85	0.99	1.00
S4	0.07	0.00	0.09	0.21	0.02	0.40	0.88	0.18	0.49	1.00	0.14	0.46
S5	0.00	0.06	0.06	0.13	0.16	0.27	0.30	0.47	0.40	0.63	0.85	1.00
S6	0.31	0.00	0.06	0.66	0.74	0.74	1.00	0.78	0.91	0.70	0.75	0.76
S7	0.00	0.88	1.00	0.79	0.62	0.60	0.31	0.51	0.47	0.23	0.16	0.21
S8	0.08	0.03	0.00	0.01	0.01	0.03	0.23	1.00	0.79	0.51	0.31	0.61
S9	0.00	0.14	0.31	0.49	0.27	0.55	0.40	0.70	0.63	1.00	0.52	0.70
S10	0.04	0.00	0.06	0.13	0.26	0.33	0.34	0.72	0.70	0.65	0.52	1.00
S11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S12	0.36	0.21	0.97	0.95	0.85	1.00	0.76	0.79	0.00	0.68	0.73	0.69
G1	0.42	0.56	0.42	0.30	0.56	0.56	0.30	0.09	0.00	0.25	0.42	1.00
G2	0.01	0.01	0.08	0.00	0.13	0.42	0.47	0.55	0.46	0.62	0.75	1.00
G3	1.00	0.68	0.79	0.00	0.48	0.12	0.89	0.59	0.61	0.28	0.16	0.79
G4	1.00	0.91	0.82	0.72	0.63	0.55	0.53	0.42	0.32	0.13	0.06	0.00
G5	0.00	0.04	0.09	0.12	0.37	0.54	0.63	0.72	0.88	0.75	0.83	1.00
G6	0.00	0.42	0.56	0.86	0.83	0.64	0.65	1.00	1.00	0.83	0.62	0.83
G7	0.00	0.15	0.19	0.26	0.35	0.42	0.45	0.62	0.72	0.79	0.80	1.00
G8	1.00	0.82	0.15	0.25	0.42	0.21	0.04	0.15	0.08	0.05	0.00	0.26
G9	0.00	0.00	0.07	0.23	0.16	0.13	0.10	0.34	0.41	0.89	0.87	1.00
G10	0.99	1.00	1.00	0.00	1.00	0.95	0.96	0.87	0.98	0.50	0.91	1.00

This table reports the data of the 32 indicators established by SIPG from 2010 to 2021 after data standardization. The values are reserved as two decimal places. All the original data are from SIPG's ESG reports, annual reports, China Port Yearbook, and Shanghai City Yearbook.
Source: Based on author's calculation.

indicators, the forwarding process is carried out. For negative indicators, the inverse process is carried out. The calculation formula is given in (1) and (2).

$$X'_{ij} = \frac{X_j - X_{\min}}{X_{\max} - X_{\min}} \quad (1)$$

$$X'_{ij} = \frac{X_{\max} - X_j}{X_{\max} - X_{\min}} \quad (2)$$

Calculation steps. The CRITIC assignment method used in this paper compares the intensity of indicators using the entropy weighting method (Krishnan et al., 2021), taking into account the contradictory nature of the indicators. It exclusively uses the objective properties of the data. Contrast intensity refers to the size of the difference between values obtained for the same indicator from various evaluation schemes, expressed in the form of a standard deviation. The larger the standard deviation, the greater the fluctuation; that is, the larger the variation, the greater the weight given to the indicator. The conflict between the indicators is expressed by the correlation coefficient. Strong correlations with other indicators indicate small conflicts between the focal indicator and the other indicators, suggesting that the indicators reflect the same information. If the analysis suggests that the information content is duplicated across indicators, the contrast strength of the indicator is weakened. The calculation steps are as follows.

Step 1. From the original index data matrix, as shown in Eq. (3). The matrix has n samples and p evaluation indicators, where X_{ij} denotes the i-th sample and the value of the j-th evaluation indicator.

$$X = \begin{Bmatrix} X_{11} & \cdots & X_{1p} \\ \vdots & \ddots & \vdots \\ X_{n1} & \cdots & X_{np} \end{Bmatrix} \quad (3)$$

Step 2. The variability of the indicator is expressed as a standard deviation, which is calculated for the j-th indicator.

$$\begin{cases} \overline{X_j} = \frac{1}{n}\sum_{i=1}^{n} X_{ij} \\ S_j = \sqrt{\frac{\sum_{i=1}^{n}\left(X_{ij}-\overline{X_j}\right)^2}{n-1}} \end{cases} \quad (4)$$

Step 3. The indicator conflict value is expressed as a correlation coefficient.

$$R_j = \sum_{i=1}^{p}(1 - r_{ij}) \quad (5)$$

Step 4. Calculate the information quantity, as shown in Eq. (6). C_j indicates the information quantity of the j-th evaluation index within the whole evaluation index system; the larger the information quantity, the greater the weight assigned.

$$C_j = S_j \times R_j = \sqrt{\frac{\sum_{i=1}^{n}\left(X_{ij} - \overline{X}_j\right)^2}{n-1}} \times \sum_{i=1}^{p}\left(1 - r_{ij}\right) \tag{6}$$

Step 5. Weight is calculated as follows:

$$W_j = \frac{C_j}{\sum_{j=1}^{p} C_j} \tag{7}$$

Table 5 Data calculation process.

Variable	Variability	Conflict	Information content	Weight
E1	0.277	25.043	6.941	2.71%
E2	0.292	36.657	10.718	4.18%
E3	0.314	32.882	10.313	4.02%
E4	0.322	23.622	7.597	2.96%
E5	0.361	25.932	9.353	3.65%
E6	0.352	34.258	12.068	4.70%
E7	0.305	23.817	7.271	2.83%
E8	0	31	0	0.00%
E9	0	31	0	0.00%
E10	0	31	0	0.00%
S1	0.322	33.413	10.753	4.19%
S2	0.287	36.317	10.427	4.06%
S3	0.371	26.105	9.679	3.77%
S4	0.331	27.158	8.979	3.50%
S5	0.323	23.845	7.711	3.01%
S6	0.32	26.479	8.477	3.30%
S7	0.31	34.254	10.624	4.14%
S8	0.347	25.506	8.854	3.45%
S9	0.273	24.217	6.612	2.58%
S10	0.321	23.386	7.515	2.93%
S11	0	31	0	0.00%
S12	0.315	30.149	9.501	3.70%
G1	0.258	30.694	7.912	3.08%
G2	0.328	23.437	7.695	3.00%
G3	0.326	33.136	10.812	4.21%
G4	0.332	40.476	13.42	5.23%
G5	0.359	23.495	8.438	3.29%
G6	0.28	25.277	7.065	2.75%
G7	0.308	23.232	7.157	2.79%
G8	0.316	38.787	12.262	4.78%
G9	0.366	24.653	9.015	3.51%
G10	0.301	31.125	9.383	3.66%

The table reports the value of each process calculated against the study case data by the CRITIC method. The final weighting results are listed in the last column of the table.
Source: Based on author's calculation.

Step 6. The weights are multiplied by the values to get the evaluation score.

Case study

Data collection and calculation. ESG disclosure reports are a recent development among Chinese port enterprises, but there is a lack of uniform standards. Many of these reports do not contain sufficient information. Shanghai Port has one of the earliest ESG report disclosures and the best disclosure performance among Chinese port enterprises. As the research object for an empirical analysis, we concentrate on Shanghai Port considering the accessibility and comparability of data.

This paper focuses on Shanghai Port and analyzes data from its ESG reports, annual reports, China Port Yearbook and Shanghai City Yearbook between 2010 and 2021. During the data collection process, most of the indicators' data can be directly obtained from publicly disclosed information. Some data require simple calculations based on the meaning of the indicators, such as E2 and S10, and the calculation methods are explained in the section "Definitions of indicators". Additionally, for indicators with missing data for individual years, we use interpolation to estimate and supplement them, as in the case of the E6 indicator. However, for indicators that are completely missing for all years in the study period and have no publicly disclosed information, we follow the approach described by Paredes-Gazqueza et al. (2016) and assign a value of 0 to them. Examples of such indicators include E8, E9, E10, and S11. The selected data has been forwarded and inverted to obtain the data matrix in Table 4.

The variability and conflict of the indicators have been calculated separately using the CRITIC assignment method. Then, the weights for each variable have been derived. The relevant data are summarized in Table 5.

Results and discussion

Indicator weights. The weights of each indicator have been calculated using the procedure shown in Fig. 3. The total weights of the indicators for environment, society, and governance are 25.05%, 38.63%, and 36.30% respectively, shown in Fig. 4. This aligns with the issue we encounter during data collection, where empirical cases tend to have more detailed and abundant disclosure information in the social and governance aspects compared to the environmental aspect. There is a deficiency in environmental disclosure, particularly in terms of quantitative data.

Sustainable performance in the three aspects of ESG. The development of Shanghai Port's sustainability capacity and its cumulative performance in environment, society, and governance sustainability from 2010 to 2021 are shown in Fig. 5. Through the

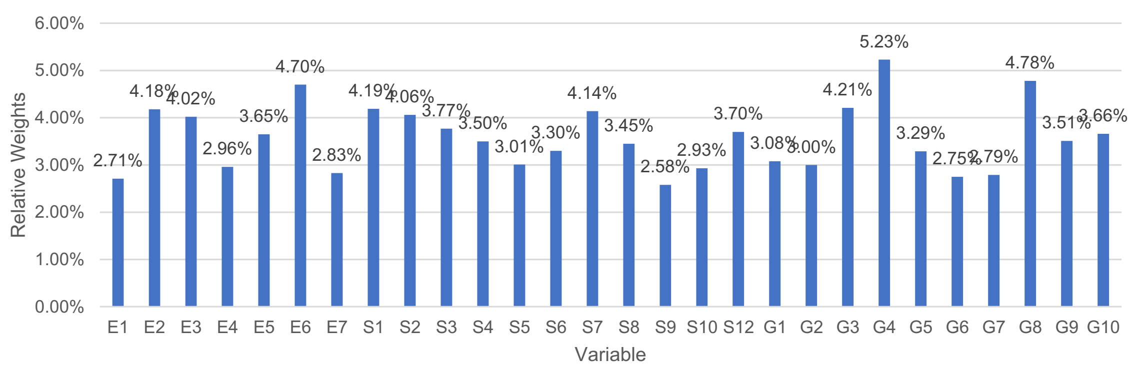

Fig. 3 Relative weights of the indicators. This figure shows the relative weights of 32 indicators in the study case. In this case, indicators with a value of 0 attached to them because they were not disclosed are not shown in the figure because they have a weight of 0.

Total curve in Fig. 5, it can be seen that the Shanghai Port's sustainability has improved over the last twelve years despite volatility. The most significant improvement has been in social performance through the bar charts of the three ESG categories. Environmental performance has increased slightly, but only a little. Governance performance has also improved slightly, but to a lesser extent because it was already relatively good.

We examine the performance of Shanghai Port in the three ESG aspects for the most recent year, 2021, and further discuss it. The cross-sectional data is represented in Fig. 6. From Fig. 6, we observe that Shanghai Port's sustainable performance in the three ESG aspects needs improvement and balance. Currently, governance responsibility performance is the best, followed by social responsibility performance, while there is room for improvement in the environmental aspect.

Discussion of individual indicators. Further efforts are made to focus on the empirical instances' environmental responsibility performance characteristics. Since the ratification of the Copenhagen Accord in 2010, Shanghai Port has been vigorously transforming all aspects of its operations from port construction to operation management, focusing on promoting environmental protection, energy conservation, and emission reduction.

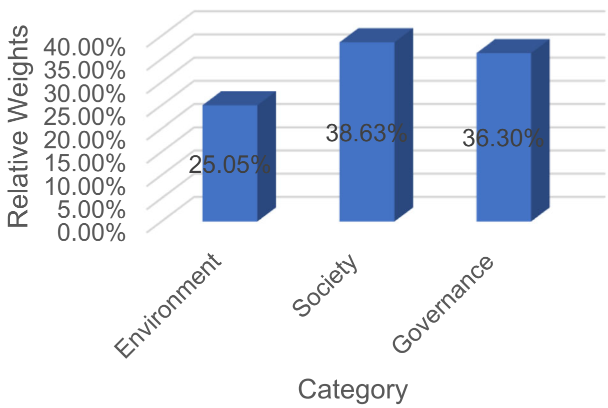

Fig. 4 Relative weights of environmental, social, and governance. The figure shows the relative weights of the environmental, social, and governance categories in this case.

Shanghai Port plans to establish a "green port" that is a low-carbon operation. In addition to improving the environmental management system, a large amount of money has been invested in energy-saving and emission-reduction technologies, including shore power, oil-to-electricity conversion, LNG technology, green lighting, and clean energy substitution (https://www.portshanghai.com.cn/). However, some trends in individual indicators are particularly relevant to the indicators identified in this study. For example, the trends in carbon emission intensity and throughput energy consumption (Fig. 7a) are not encouraging. Possible reasons for these trends are as follows.

(1) The implementation of energy-saving and emission-reduction measures faces significant obstacles. For instance, incorporating shore power technology in ports requires not only infrastructural transformation but also the transformation of ships to connect to the new power equipment. This technology poses several technical challenges, such as power distribution, which must be addressed before successful implementation. Consequently, implementing shore power requires a substantial amount of capital investment and multi-sectoral cooperation, which cannot be achieved overnight. Currently, research is focused on shore power policies and optimal subsidies (Yin et al., 2020).

(2) China primarily relies on thermal power for electricity generation, making it difficult for technologies like shore power and oil-to-power to significantly reduce the country's carbon emissions. However, these technologies can still have a positive impact by reducing the emissions of various pollutant gases and improving overall air quality. Instead of solely focusing on individual technologies, China should prioritize developing a diverse range of clean energy sources to replace thermal power generation. This approach would provide a more comprehensive solution to reducing carbon emissions while also promoting sustainable development.

The social sustainability aspect of the study is illustrated by the jobs indicator (Fig. 7b), which indicates a steady decline in employment opportunities over the last decade, posing serious concerns. This decline can be attributed to the adoption of automation technology and the development of smart ports. Although the trend towards automation and intelligent machines is not unique to the port industry, it improves production

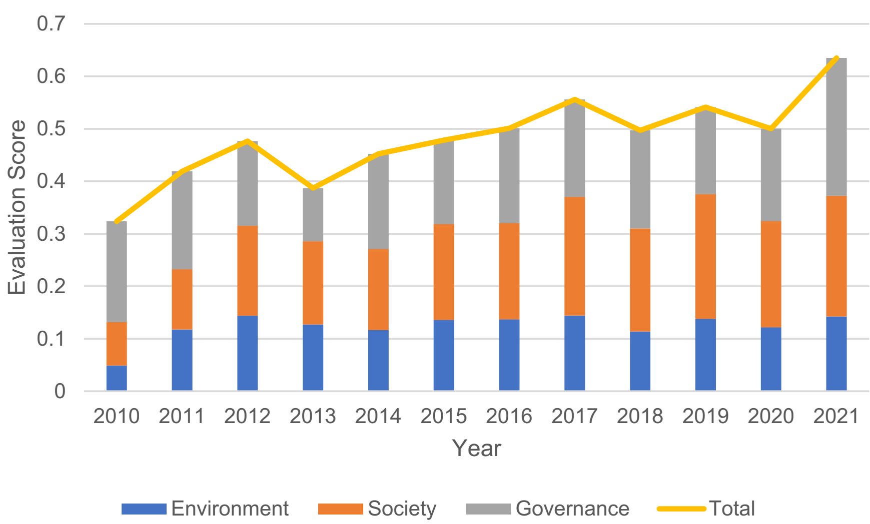

Fig. 5 Sustainability evaluation results. This figure shows the sustainability evaluation scores of the example. The environment, society, and governance scores are marked with different colors, and the cumulative sustainability scores are marked with curves.

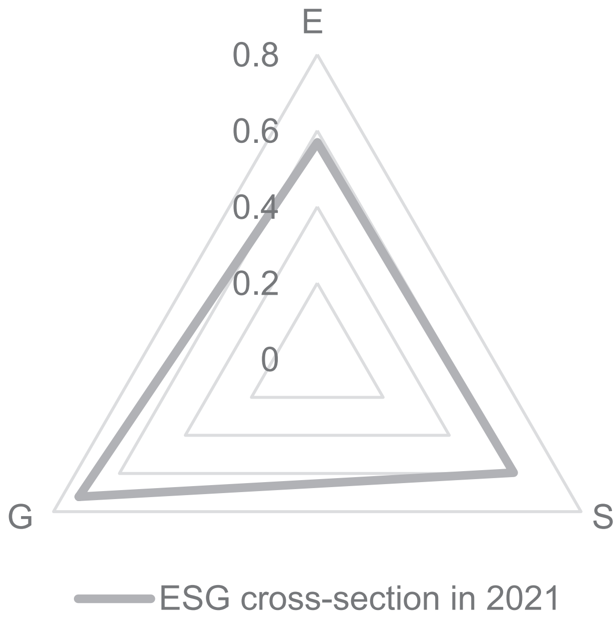

Fig. 6 Radar chart of ESG performance cross-section in 2021. This figure shows the cross-section data for the three ESG dimensions taken for the year 2021 to show the attainment in a radar chart. The values for each of the three dimensions E, S, and G are obtained by dividing their evaluation scores for the year 2021 by the weights of each category.

efficiency and increases production capacity, ultimately benefiting the firms economically. However, the societal impact of job restructuring requires more attention from governments and researchers. Possible strategies to mitigate this trend include improving the quality of education for all and promoting careers in science and technology innovation.

Conclusions

This paper analyzes the ESG reports of Chinese port enterprises to evaluate their social responsibility. Using an ESG framework, the study establishes indicators that represent the three dimensions of environment, society, and governance for assessing the port's sustainable responsible governance performance. The study shows that ESG reports are useful sources of information for monitoring environmental, social, and economic impacts and identifying good practices for whole-port development. This evaluation system could be a foundation for more research on the application and development of an ESG framework for the port industry.

Ports play a crucial role in modern sustainability frameworks by contributing to sustainable development in various areas such as the economy, environment, human health, social well-being, and employment equity. ESG reports of port companies offer valuable insights into their environmental, social, and governance responsibility practices. Using quantitative indicators, the environmental, social, and economic impacts of ports can be effectively monitored, thus enabling the identification of sustainable practices that can be applied to promote whole-port development.

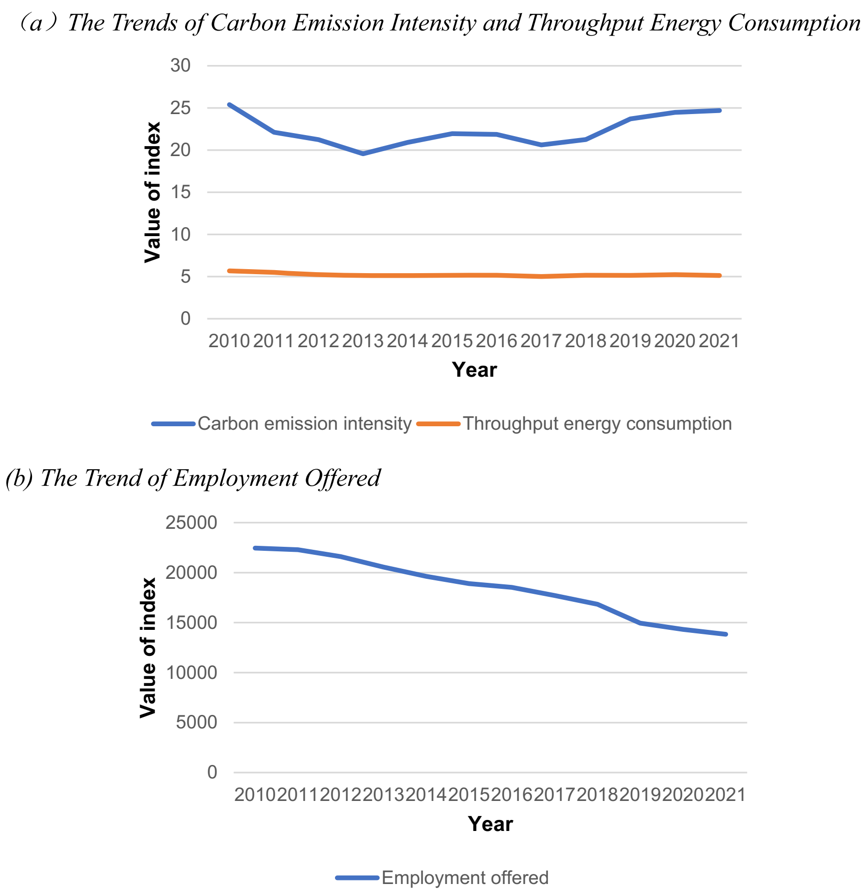

Fig. 7 Individual indicator trends. a The trends of carbon emission intensity and throughput energy consumption. **b** The trend of employment offered. These Figures show some trends in individual indicators from 2010 to 2021. Figure **a** shows the trends of carbon emission intensity and throughput energy consumption. Figure **b** shows the trend of employment offered.

This study has revealed a few issues in the ESG disclosure practices of Chinese port companies, such as inadequate participation, inconsistent disclosure standards, and low-quality disclosures. To address these problems, it is essential for regulators to establish ESG disclosure policies and standards that are tailored to the port industry. This will help to clarify the development objectives of port companies and enhance the quality of ESG disclosure, ultimately promoting sustainable ESG practices within the industry.

Although this study provides valuable insights into the ESG disclosure practices of Chinese port enterprises and establishes a set of indicators for evaluating port sustainability, the lack of data limits the scope of analysis. Therefore, future research should aim to include a cross-sectional comparison of ports, which will enable a more comprehensive understanding of the ESG practices in the industry. It is also crucial for the whole-port industry to strengthen its commitment to ESG and to develop more consistent disclosure standards and policies. Moreover, the evaluation system for port sustainability developed in this study should be refined to better clarify the sustainable development objectives of the industry and promote the sustainable development of the port and the region as a whole. By doing so, the port industry can contribute more effectively to the sustainable development of the economy, environment, and society.

Data availability

All data generated or analyzed during this study are included in this article and its supplementary information files.

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Note

1 In 2004, Kofi Anan, the former Secretary General of the United Nations, invited 20 financial institutions to prepare a report, Who Cares Wins, that introduced the concept of ESG (Li et al., 2021).

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The authors declare no competing interests.

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