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The carbon reduction effect of ESG performance: empirical evidence from Chinese shipping enterprises

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Environmental, social and governance (ESG) practices have become a crucial pathway for the sustainable development of enterprises, and so have shipping enterprises. Based on the unbalanced panel data of China's A-share listed shipping enterprises from 2009 to 2022, this study uses a multiple regression model to empirically test the impact of ESG performance on carbon emission reduction and its regional heterogeneity. The findings indicate that ESG performance significantly reduces the carbon emission intensity of shipping enterprises, a conclusion that remains robust across various robustness tests and endogenetic analyses. Further heterogeneity analysis reveals that the carbon emission reduction effect of ESG performance is more pronounced in the southern region. These results underscore the importance of strengthening ESG capabilities as a key strategy for promoting the low-carbon transition of shipping enterprises and achieving sustainable development.

KEYWORDS

ESG performance, carbon emission intensity, shipping enterprises, low-carbon transition, sustainable development

1 Introduction

The shipping industry plays a pivotal role in global trade, and the Coronavirus Disease 2019 (COVID-19) outbreak in particular has pushed the shipping industry to a critical point of major challenges and transformation (Xiao and Xu, 2024). In the post-pandemic era, with the rapid growth of the international economy and global trade, the volume of maritime cargo has increased significantly, and carbon dioxide emissions have continued to rise. In 2023, the International Maritime Organization (IMO) introduced its latest strategy for reducing carbon emissions from ships, targeting net-zero emissions for the global shipping industry by around 2050. To tackle the significant challenges of carbon reduction in the sector, regions such as the European Union have implemented policies like the EU Emissions Trading System and the FuelEU Maritime initiative, aiming to accelerate industry-wide decarbonization through stricter emission standards. At the same time, leading shipping companies are actively supporting the industry's low-carbon transition.

Firms like Maersk, Compagnie Maritime d'Affrètement Compagnie Générale Maritime (CMA CGM), and Mediterranean Shipping Company (MSC) have begun investing in or ordering new green-fuel vessels to drive this transformation forward.

China has been a major driving force behind the sustained growth of global maritime trade volumes. According to the Ministry of Transport, China's foreign trade shipping volume accounted for 30.1% of global maritime trade in 2023, up 2.2 percentage points from the previous year. To support the implementation of international carbon reduction strategies for ships and accelerate the green transformation of the shipbuilding industry, China released the Action Plan for Green Development of the Shipbuilding Industry (2024–2030) in 2023. The plan outlines clear objectives, including the establishment of a preliminary green development system for the shipbuilding industry by 2025 and a comprehensive green system by 2030, providing clearer direction and guidelines for the industry's low-carbon transition. In this context of low-carbon transformation, shipping companies are increasingly prioritizing ESG practices. ESG refers to environmental, social, and governance, aiming to assess the sustainability of a company's operations across these three dimensions. Investors are increasing integrating ESG principles into their portfolios, seeking to support ethical companies that actively promote responsible corporate behavior (Pedersen et al., 2021). More customers, especially multinational corporations such as Amazon and Walmart, are demanding low-carbon solutions across the supply chain to align with sustainability goals. Although the importance of corporate ESG practices in advancing carbon reduction within the industry is widely acknowledged by governments and the business community, the shipping sector still lacks a unified, dedicated, and comprehensive ESG measurement framework. Consequently, empirical research on the impact of ESG performance on carbon reduction remains limited, and whether regional variations exist in its effects is still unclear.

The impact of ESG performance on carbon emissions of shipping enterprises can be systematically analyzed from multiple dimensions. From an environmental perspective, shipping enterprises can reduce energy consumption and environmental pollution by enhancing their ESG performance. This includes encouraging the adoption of stronger environmental management practices, fostering green technology innovation in shipping, and mitigating environmental risks through technological advancements. With the implementation of green innovative solutions, shipping enterprises can pursue a more scientific and feasible approach to reducing carbon emissions. From the perspective of social responsibility, strong social responsibility performance ensures that enterprises prioritize the formulation and implementation of environmental protection strategies alongside the pursuit of economic benefits. This includes actively monitoring and disclosing carbon emission information. From the corporate governance perspective, enterprises with robust ESG performance are better positioned to curb managerial misconduct, mitigate the tendency to neglect long-term sustainable development goals in favor of short-term interests, and, consequently, place greater emphasis on carbon emission management, thereby reducing carbon emission intensity. Moreover, the multi-dimensional disclosure of ESG information can reduce information asymmetry between shipping enterprises and external stakeholders, thereby enabling stakeholders to gain a more comprehensive understanding of the enterprises' efforts in low-carbon transformation and make more informed decisions. Strong ESG performance can also convey pro-social signals, enhancing the public and stakeholder reputation of enterprises, which can then be translated into a competitive advantage. This, in turn, boosts investor confidence, reduces uncertainty and risk in investment decisions, and attracts high-quality investors and consumers. As a result, enterprises are more likely to select green, low-carbon, and energy-efficient partners, thereby contributing to carbon reduction.

This study examines China's A-share listed shipping companies from 2009 to 2022 as the research sample. Based on the measurement of corporate carbon emission intensity, a fixed effects model is constructed to empirically examine the impact of ESG performance on carbon emissions in shipping enterprises. Furthermore, the research sample is divided into southern and northern regions to perform a comparative analysis of regional differences in the impact. The results indicate that the ESG performance of shipping enterprises has a significant impact on reducing carbon emissions, with the effect being more pronounced in enterprises located in the southern region.

This study makes two key contributions. First, from a research perspective, it expands the scope of literature on corporate ESG by adding new evidence regarding the relationship between ESG performance and carbon emission reduction. Previous studies have extensively explored the role of ESG performance in enterprises, including its impact on firm performance or value (van Beurden and Gössling, 2008; Brooks and Oikonomou, 2018; Albuquerque et al., 2020; Bissoondoyal-Bheenick et al., 2023; Chen et al., 2024b), corporate risk (Albuquerque et al., 2019; Boubaker et al., 2020; Cerqueti et al., 2021; Reber et al., 2022; He et al., 2023), and innovation (Tan and Zhu, 2022; Li et al., 2023; Mohy-ud-Din, 2024). Stakeholders often evaluate a company's environmental performance through its ESG practices (Orazalin and Mahmood, 2020). However, relatively little attention has been devoted to the environmental benefits of ESG performance, particularly within the shipping industry. Addressing on this gap, the study situates itself within the context of the ongoing low-carbon transformation of enterprises, which is critical for global trade and economic development. It innovatively focuses on the ESG issues within the shipping industry, using China's A-share listed shipping companies as research samples to empirically investigate the carbon emission reduction effects of ESG performance. By empirically analyzing the impact of ESG performance on carbon emissions, this study contributes to advancing carbon reduction goals in the shipping sector.

Second, in terms of research content, the study deepens the research by examining the heterogeneity of shipping enterprises' location choices, thereby offering more targeted countermeasures and recommendations. China's vast territory is marked by significant regional differences, a long-standing topic of discussion, and the shipping industry is no exception. The shipping industry operates within a complex system, encompassing employment, taxation, technological innovation, economic development, and more. The location choices of shipping enterprises significantly shape the focus of their business operations, driving industrial clustering, and, over time, influence the regional development patterns. This study not only investigates the impact of ESG performance on carbon emissions but also divides the research samples based on the geographical distribution of shipping enterprises into southern and northern regions. The findings highlight regional differences in the carbon emission reduction effects of ESG performance, thereby enriching the research conclusions and offering corresponding policy recommendations. These suggestions aim to encourage enterprises to strengthen and promote the low-carbon transformation of the shipping industry through improved ESG performance.

This paper is structured as follows. Section 2 reviews the relevant literature. Section 3 outlines the research design, including the model, variables, sample selection and data. Section 4 presents our main empirical results and discussion. Finally, Section 5 presents the conclusions and recommendations.

2 Literature review

Under the pressing challenges of global climate change, reducing carbon emissions has become the central focus of academic research in the transportation field, generating numerous discoveries, including those of Churchill et al. (2021), Ashik et al. (2022), and Li et al. (2025). With the growing importance of international trade, research on shipping carbon emissions has increasingly captured scholars' attention. Existing studies in this field can be broadly categorized into three areas: investigating carbon emissions at the enterprise level, analyzing carbon emissions at the industry level, and exploring carbon emissions in shipping-related sectors, including a broader range of transport modes.

At the enterprise level, existing literature has explored the driving factors behind carbon emissions and strategies for their reduction. Shimotsuura et al. (2023) investigated the carbon emissions of international container shipping using company-level microscopic data and identified the transportation structure as a key driving factor for decarbonization in this sector. Additionally, speed reduction, technological advancements, and shorter travel distances have been shown to significantly contribute to reducing container shipping emissions (Cariou et al., 2019). However, the underlying sources of changes in carbon emissions at the enterprise level remain insufficiently understood (Shimotsuura et al., 2023).

With the inclusion of the shipping industry in the EU Emissions Trading System, an increasing number of scholars have begun to examine carbon emission reduction in shipping enterprises from the perspective of carbon taxes and other fiscal policies. Regarding the implementation of current carbon emission surcharges and cap-and-trade schemes for shipping enterprises, greater attention has been given to the complex interplay between government regulations and the operational decisions of shipping companies (Zhu et al., 2020; Tian et al., 2024; Sun et al., 2024). For the sustainable development of the shipping industry, the construction of green ports is also one of the important strategies (Xiao et al., 2024). In addition to government regulation, some scholars analyze carbon emissions by integrating ports and shipping enterprises into a unified analytical framework. Liu et al. (2023) constructed a shipping supply chain model comprising ports and liner companies to explore the impact of carbon tax policies on carbon emission reduction technologies. They found that ports and liner companies can achieve mutual benefits and win-win outcomes when considering consumers' green preferences and knowledge sharing. Similarly, Jin et al. (2024) developed a maritime supply chain game model involving one port and two shipping companies under the backdrop of carbon tax policies in the maritime sector. Their findings indicate that, under specific conditions, a cooperative emission reduction mechanism between shipping companies and ports can yield both economic and environmental benefits. Moreover, factors such as the market environment, carbon tax policies, and the level of information sharing and cooperation significantly influence the decision-making of shipping companies (Jin et al., 2024). From the perspective of carbon emission reduction strategy selection, Meng et al. (2022) incorporated governments, ports, and shipping enterprises into a unified evolutionary game model. Their study revealed that the stable strategy of active government regulation, proactive emission reduction by port enterprises, and proactive emission reduction by shipping enterprises effectively promotes carbon emission reduction. Additionally, increasing government subsidies for shipping enterprises enhances the likelihood of their active participation in carbon emission reduction.

At the industry level, a substantial number of studies have focused on carbon emissions in the shipping industry, producing a wide range of findings. As one of the primary modes of transportation in international trade, the shipping industry demonstrates a strong correlation and agglomeration effect of carbon emissions associated with shipping trade (Xu et al., 2024). From the perspective of the spatial spillover effects of carbon emissions, factors such as container throughput, total import and export trade, economic growth, ship numbers and tonnage, liner accessibility, and energy intensity all play significant roles (Xu et al., 2024). Furthermore, global emergencies, such as COVID-19, have significantly influenced the volatility of carbon emissions in the shipping sector (Ju and Hargreaves, 2021; Shi and Weng, 2021; Mujal-Colilles et al., 2022; Xu et al., 2023; Li et al., 2024). Similarly, climate-related disasters have a direct impact on shipping activities, leading to increased carbon emissions, as detailed in Huang et al. (2025).

Policy intervention is widely regarded as a crucial means of effectively reducing carbon emissions in the shipping industry. Hu and He (2024) analyzed shipping industry data from 22 provinces in China spanning 2007 to 2022 and found that fiscal policies significantly influence carbon emissions in the sector. However, the effects of tax-based policies and transfer payment policies differ, and digital technology plays a strong regulatory role (Hu and He, 2024). From the perspective of economic regulation, Ye et al. (2024) found that cooperative systems, which combine mechanisms such as cap-and-trade and tax subsidy systems, are more effective for decarbonizing the shipping industry than single economic regulations. Considering the impact of marine emission trading system on ship speed and fleet deployment, switching fuel or installing scrubber is the best carbon reduction strategy (Wang et al., 2025). From the energy consumption perspective, technological advancements in marine fuels, the optimization of fuel usage schemes, and the adoption of alternative fuels are critical for achieving carbon reduction targets in the shipping industry (Hong et al., 2023; Hellström et al., 2024). Additionally, technologies like carbon capture, utilization, and storage (CCUS) are considered effective solutions for reducing carbon emissions (Hua et al., 2023). The use of ships to transport CO_2 has the potential to be more cost-effective than offshore pipelines and could improve CCUS outcomes, though government incentives and economic strategies may be required to realize this potential (Baroudi et al., 2021).

Shipping is a critical mode of transportation, and some scholars have conducted research on its carbon emissions from broader perspectives, particularly focusing on the port industry, a key infrastructure sector closely linked to the shipping industry. López-Aparicio et al. (2017), using the Nordic Port as a case study and leveraging a comprehensive emissions inventory, identified oceangoing vessels as the primary source of carbon emissions, with domestic ferries being the main contributors among harbor vessels. Notably, increasing the use of liquefied natural gas in domestic ferries could reduce a 17% reduction in carbon emissions. In the context of digitalization, port smartization policies have been shown to significantly enhance the carbon emission efficiency of ports through factors such as the number of port berths, wharves length, and container throughput (Zhang et al., 2024). The full utilization of shore power is also identified as a key strategy for reducing port-related shipping emissions (Wang et al., 2024). Given that green shipping corridors are considered a major solution for decarbonizing the shipping industry, Ismail et al. (2024) developed a practical framework to address the challenges ports face in participating in these corridors, concluding that such participation is instrumental in advancing industry-wide decarbonization. Zhang et al. (2023) further argued that decarbonization innovations, such as green shipping corridors, should consider China's multi-scale governance, including its role in fostering domestic innovation diffusion and its global influence on policy diffusion.

Further, some scholars have focused on coastal areas to explore the issue of ocean carbon emissions. For instance, Wang et al. (2023) conducted an empirical analysis of ocean carbon emission efficiency and its influencing factors in 11 coastal provinces in China. Their findings revealed significant regional disparities in ocean carbon emission efficiency, identified technological progress as the key driver for improvement, and highlighted trade openness and financial development as important factors influencing emission efficiency. Chen et al. (2024a), focusing on China's three major marine economic zones, found that the carbon emission potential of the marine fishery sector varies across coastal provinces and cities. Additionally, they noted that higher levels of openness to international trade negatively impact the overall marine economic benefits. Zhang et al. (2023) examined the Greater Bay Area of China, highlighting its pivotal role as a bridge in governance practices across different administrative levels by analyzing cross-level policy diffusion and policy dynamics in controlling marine carbon emissions.

The analysis above demonstrates that the field of low-carbon development in shipping has been the subject of extensive and in-depth discussions. In recent years, with the ongoing promotion of low-carbon transformation, ESG has emerged as a novel approach to addressing carbon emission challenges, and ESG concept has become a critical framework for guiding sustainable development efforts. Scholars have explored various aspects of ESG, such as performance, rating and report disclosures, to analyze its relationship with carbon emissions from diverse perspectives. At the macro level, improvements in national ESG performance effectively inhibit carbon emissions, with stricter environmental policies amplifying this effect (Long and Feng, 2024). At the medium level, ESG practices have a substantial impact on carbon emissions within industries, where high levels of industrial carbon emissions pose significant challenges to sustainable development (Biswas et al., 2024). At the micro level, ESG ratings of enterprises effectively curb the carbon emission intensity of companies, with this effect being more pronounced among heavily polluting enterprises (Li and Xu, 2024). Conversely, some scholars have observed that ESG ratings have a greater inhibitory effect on carbon emission efficiency in non-heavy polluting enterprises (Qian and Liu, 2024). Regarding regional differences, the carbon emission reduction effect of corporate ESG investment is more significant in eastern China (Cong et al., 2022).

With the widespread development of the ESG concept, the ESG practices of shipping enterprises have become a focal point of attention. For instance, Fujian Guohang Ocean Shipping (Group) Co., Ltd. has, in recent years, consistently invested in and innovated within the ESG field. By implementing an ESG development strategy, the company has promoted sustainable development and earned a place on the 2024 Klynveld Peat Marwick Goerdeler (KPMG) China ESG 50 Green and Low-Carbon Pioneer list. Research indicates that ESG has a significant positive impact on the sustainable development, financial performance, and long-term viability of the shipping industry, and it is necessary to integrate ESG into the decision-making processes of global shipping companies (Moschaki, 2023). However, current academic research on how ESG practices of shipping enterprises affect their carbon emissions remains underdeveloped. To address this, this study focuses on shipping enterprises, aiming to empirically test the impact of ESG performance on carbon emissions.

Building on the systematic review of the literature related to ESG performance and carbon emission intensity, this study summarizes the findings and identifies gaps in previous research. To investigate the relationship between ESG performance and carbon emission intensity in Chinese shipping enterprises, this paper employs an empirical analysis approach. A regression model is established, and multiple regression analysis, an econometric method, is used to test the carbon emission reduction effect of ESG performance in shipping enterprises. The robustness of the main research findings is verified through robustness tests and an examination of endogeneity. This approach not only provides direct insights into the relationship between ESG performance and carbon emission intensity in shipping enterprises but also offers new empirical evidence on the impact of regional differences on the environmental performance of these enterprises, enhancing the scientific rigor and reliability of the results. Additionally, the literature review reveals that previous studies on carbon emissions in the shipping industry have primarily focused on the impact of economic or technical factors, with relatively little attention given to ESG. By empirically analyzing the relationship between ESG performance and carbon emission intensity, this paper expands the research scope in this field and presents new directions and methodologies for future research.

3 Methodology

3.1 Empirical model

This paper develops the following multiple regression model to examine the relationship between ESG performance and the carbon emissions of shipping enterprises.

$$LnCEI_{it} = \alpha + \beta LnESG_{it} + \gamma Controls_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

where *LnCEI* denotes the carbon emissions of shipping enterprises, *LnESG* refers to the enterprise ESG performance, and *Controls* represents a series of control variables accounting for other factors that may influence carbon emissions. α represents the intercept term of the model. The subscript *i* denotes the enterprise, while *t* represents the year. μ and λ indicate the firm fixed effect and year fixed effect, respectively, and ε represents the random error term.

3.2 Variable selection

3.2.1 Dependent variable

The dependent variable in this study is the carbon emissions of shipping enterprises. Following the methodologies of Chen et al. (2024c); Yu et al. (2022), and Chapple et al. (2013), we adopt carbon emission intensity as the measurement metric. This metric is calculated by dividing the enterprise's carbon dioxide emissions by its operating income. The calculation formula is as follows:

$$CEI = (Enterprise\ Carbon\ Emissions)/(Enterprise\ Operating\ Revenue) \quad (2)$$

Furthermore, based on the approach of Zhou and Liu (2024), the calculation of *Enterprise Carbon Emissions*, as outlined in Equation 2, is as follows:

$$Enterprise\ Carbon\ Emissions = ((Enterprise\ Operating\ Costs * Total\ Industry\ Energy\ Consumption * Carbon\ Dioxide\ Conversion\ Coefficient))/(Industry\ Operating\ Costs) \quad (3)$$

In Formula 3, the *Carbon Dioxide Conversion Coefficient* is 2.493, based on the carbon dioxide calculation standard established by the Xiamen Energy Conservation Center in China. It should be noted that in this study, carbon emission intensity is measured by dividing a company's carbon emissions by its operating income and then taking the natural logarithm of the result.

3.2.2 Core independent variable

The core independent variable in this study is enterprise ESG performance. Based on the study by Lin et al. (2021), the ESG index provided by Sino-Securities Index Information Service (Shanghai) Co. Ltd. is selected as the measurement standard. In addition to Sino-Securities, there are several other ESG rating agencies in China, such as SynTao Green Finance, Harvest Fund, and Rankins ESG Ratings. This study specifically chooses the ESG index data from Sino-Securities because it covers all Chinese A-share listed companies. Regarding the data update mechanism, Sino-Securities adopts a combination of quarterly evaluations and dynamic tracking, ensuring high timeliness and strong traceability. The index is measured on a scale from one to nine, with higher values indicating better ESG performance. In this paper, the quarterly average ESG index is used as the basis for deriving the annual rating result. Further, by referring to the practice of Zhao et al. (2024) and Qian and Liu (2024), natural logarithm is taken for processing.

3.2.3 Control variables

To address the impact of missing variables, this paper draws on the studies of Li and Xu (2024); Qian and Liu (2024), and Zhou and Liu (2024), and incorporates controls for additional factors that may influence enterprise carbon emissions. These factors include listing age (Age), enterprise size (Size), enterprise leverage (Lev), profitability (Roa), asset turnover rate (Tat), Tobin's Q (Tobinq), board size (Board), and the proportion of independent directors (Indep). Table 1 provides the definitions of the variables used in this study.

3.3 Sample selection and data sources

The ESG rating data from Sino-Securities Index Information Service (Shanghai) Co. Ltd. has been available since 2009. To ensure data consistency and availability, this study focuses on the period from 2009 to 2022. Listed shipping enterprises in China's A-share market during this period are selected as research samples from the ESG rating database of Sino-Securities. To ensure the validity and accuracy of the data, enterprises flagged as abnormal (ST and *ST) by the ESG rating database are excluded, along with those missing ESG indicator data. After these exclusions, a final sample of 29 listed shipping enterprises is obtained. The study ultimately constructs an

TABLE 1 Variable definitions.

Variable	Definition
LnCEI	Carbon emission intensity, calculated by dividing the enterprise's carbon dioxide emissions by its operating income and taking its natural logarithm
LnESG	Enterprise ESG performance, is expressed as the natural logarithm of the ESG index provided by Sino-Securities Index Information Service (Shanghai) Co. Ltd
Age	Listing age, defined as the number of years a company has been publicly listed
Size	Enterprise size, defined as the total assets of enterprise
Lev	Enterprise leverage, defined as the ratio of total liabilities to total assets
Roa	Profitability, defined as the ratio of net profit to total assets
Tat	Asset turnover rate, defined as the ratio of operating income to total assets
Tobinq	Tobin's Q, defined as the ratio of market capitalization to total assets
Board	Board size, defined as the number of board members
Indep	The proportion of independent directors, defined as the number of independent directors to total number of board members at the end of the period

unbalanced panel dataset comprising 312 enterprise-year observations.

Other data are sourced from the social responsibility reports of listed shipping companies, the China Energy Statistical Yearbook, company annual reports, and the China Stock Market and Accounting Research (CSMAR) Database. To ensure data accuracy and minimize the influence of outliers, the main continuous variables are winsorized at the 1% level at both ends.

3.4 Descriptive statistics

Table 2 presents the descriptive statistics for the variables in this study. The results indicate that the mean and median values of all variables differ slightly, suggesting no significant bias in the data structure. This observation supports the reasonableness of the data processing methods used in this study. The average value of *LnESG* is 1.2796. Compared to the overall average ESG level of China's A-share listed companies, there remains significant room for improvement. For instance, Qian and Liu (2024) found that the natural logarithm of the average ESG rating of Chinese A-share listed companies from 2011 to 2020 was 1.4041. Similarly, Lin et al. (2023) reported that the average ESG index of China's A-share listed companies during 2010–2020 was 6.507, whereas the average ESG index of the research sample in this study is only 3.7372.

4 Results and discussion

4.1 Correlation analysis and multicollinearity test

Tables 3, 4 present the results of the Pearson correlation matrix among the variables in Equation 1 and the variance inflation factor (VIF) analysis, respectively. The correlation coefficient between carbon emission intensity (*LnCEI*) and ESG performance (*LnESG*) is -0.2690, which is significant at the 1% level. This finding preliminarily indicates a negative correlation between ESG performance and carbon emission intensity—specifically, better ESG performance by an enterprise is associated with lower

TABLE 2 Descriptive statistics of the variables.

Variables	Observations	Mean	Std. Dev.	Max	Median	Min
LnCEI	312	0.7021	0.3144	1.4950	0.7582	-0.2397
LnESG	312	1.2796	0.2940	1.7918	1.3863	0.0000
Age	312	11.8333	6.9461	29.0000	11.0000	1.0000
Size	312	3.8295	5.8195	51.1780	1.7917	0.0513
Lev	312	0.4470	0.1616	0.9738	0.4301	0.0103
Roa	312	0.0359	0.0418	0.2566	0.0322	-0.1460
Tat	312	0.3570	0.2664	1.8185	0.2847	0.0475
Tobinq	312	1.4473	1.7517	24.4953	1.0969	0.6245
Board	312	10.0192	1.9708	18.0000	9.0000	5.0000
Indep	312	36.4770	4.7248	60.0000	36.0350	25.0000

TABLE 3 Correlation analysis.

	LnCEI	LnESG	Age	Size	Lev	Roa	Tat	Tobinq	Board	Indep
LnCEI	1.0000									
LnESG	-0.2690***	1.0000								
Age	-0.0850	-0.1060	1.0000							
Size	-0.1910***	0.2980***	-0.1190**	1.0000						
Lev	0.342***	0.0610	0.1730***	0.2790***	1.0000					
Roa	-0.4860***	-0.0240	-0.0540	0.2210***	-0.4170***	1.0000				
Tat	0.0130	-0.1840***	0.2220***	0.0030	0.1010*	0.2110***	1.0000			
Tobinq	0.1420***	-0.2780***	0.1520***	-0.1290**	-0.0750	0.2670***	0.4590***	1.0000		
Board	0.0330	0.0630	-0.3190***	0.0700	-0.0670	-0.0950*	-0.1960***	-0.2000***	1.0000	
Indep	-0.0800	0.1590***	0.2340***	0.3040***	0.1610***	0.0500	0.1380**	0.1840***	-0.2880***	1.0000

***, **, and * denote statistical significance at 1%, 5%, and 10%, respectively.

carbon emission intensity. Additionally, the absolute value of the correlation coefficients between the variables does not exceed 0.5. The mean VIF for the variables is 1.44, with a maximum value of 1.70, both well below the threshold of 10, indicating that there is no serious multicollinearity problem in the model.

4.2 Benchmark regression results

Table 5 presents the carbon reduction effects of ESG performance in shipping enterprises. In the benchmark regression analysis, a progressive regression strategy is adopted. Column (1) only for annual time and firm-specific fixed effects. The results indicate that the coefficient of *LnESG* is -0.3989, which is statistically significant at the 1% level. Column (2) introduces a series of control variables based on the model in Column (1). The results show that the coefficient of *LnESG* is -0.0746, which is also statistically significant at the 1% level. These findings reveal a significant negative correlation between the ESG performance of shipping enterprises and their carbon emission intensity. In other words, better ESG performance is associated with lower carbon emission intensity. This conclusion aligns with the findings of Li and Xu (2024) and Long and Feng (2024). The possible reason is that higher ESG ratings convey positive and clear signals of environmental and social responsibility to the market. This enhances corporate value (Ghoul et al., 2017), improves investment efficiency (Lin et al., 2023), promotes green innovation, and increases information transparency (Qian and Liu, 2024), ultimately driving enterprises to pursue low-carbon transformation and sustainable development.

4.3 Robustness testing and endogeneity analysis

To ensure the reliability of the main research conclusions, robustness tests were conducted by replacing the core independent variable and excluding specific samples. First, to mitigate potential measurement errors caused by the reliance on a single indicator measurement method, the core independent variable was replaced. Specifically, the comprehensive ESG score (*LnCESG*) from the ESG ratings provided by Sino-Securities Index Information Service (Shanghai) Co., Ltd. was employed as the indicator to evaluate enterprises' the ESG performance. To address potential heteroscedasticity issues, the natural logarithm of the score is applied. Subsequently, the baseline regression model (Equation 1) was re-estimated, with the results presented in Column (1) of Table 6. The findings indicate that the regression coefficient of *CESG* is -0.2702, which is significantly negative at the 1% level. This result aligns closely with the baseline regression result (-0.0746, P< 0.01), confirming the robustness of the findings.

Next, to account for the potential impact of the global COVID-19 pandemic on the shipping industry, the analysis was restricted to samples from 2019 and earlier. The regression results, shown in Column (2) of Table 6, reveal that the regression coefficient of *LnESG* is -0.0722, which remains significantly negative at the 1% level. This finding is also consistent with the baseline regression result (-0.0746, P< 0.01), further substantiating the robustness of the conclusions.

To further address potential endogeneity bias, this study explores the issue of endogeneity in greater depth. Specifically, the lagged one-period enterprise ESG performance (*L.LnESG*) is

TABLE 4 Multicollinearity test.

Variable	LnESG	Age	Size	Lev	Roa	Tat	Tobinq	Board	Indep	Mean VIF
VIF	1.2200	1.2500	1.6800	1.6400	1.7000	1.3900	1.5000	1.2400	1.3800	1.4400
1/VIF	0.8228	0.8002	0.5963	0.6087	0.5885	0.7200	0.6657	0.8069	0.7273	

TABLE 5 Benchmark regression results.

Variables	(1)	(2)
LnESG	-0.3989***	-0.0746***
	(0.0713)	(0.0193)
Age		-0.0616***
		(0.0017)
Size		0.0034*
		(0.0020)
Lev		0.1213***
		(0.0435)
Roa		-2.3052***
		(0.1632)
Tat		0.0458*
		(0.0239)
Tobinq		0.0114***
		(0.0034)
Board		0.0044
		(0.0043)
Indep		0.0004
		(0.0012)
Constant	1.2126***	1.3011***
	(0.0925)	(0.0831)
Obs	312	312
R^2	0.1000	0.9520
Adj. R^2	0.0074	0.9433

*** and * denote statistical significance at 1% and 10%, respectively. Standard errors are in parentheses.

adopted as the core independent variable. The lagged ESG performance variable is expected to exhibit stronger exogeneity compared to its contemporaneous counterpart. The results of the re-estimation, using the lagged core independent variable, are presented in Column (3) of Table 6. The findings indicate that the regression coefficient of *L.LnESG* is -0.0426, which is statistically significant at the 5% level. This result reaffirms the robustness of the study's main conclusions.

4.4 Heterogeneity analysis

China has a vast territory, and due to variations in geographical location, natural conditions, culture, and economic development, it is traditionally divided into northern and southern regions, with the Qinling Mountains-Huaihe River Line serving as the boundary. Benefiting from its advantageous maritime transportation and inland navigation along the Yangtze River, the southern region possesses superior seaport infrastructure and greater shipping capacity. Furthermore, compared to the northern region, ports in the southern region exhibit a higher density and a greater proportion of international routes. Consequently, in the context of globalization, the development gap between the northern and southern regions has progressively widened. The shipping industry comprises a highly complex industrial system, where each business segment has the potential to evolve into an independent industry, thereby influencing the overall regional development. In recent years, the southward relocation of major state-owned shipping enterprises has further shifted the overall focus of China's shipping sector toward the southern region. Given the significant carbon emissions associated with the shipping industry, sustainability concerns have become increasingly critical. In the implementation of China's dual carbon strategy, the northern and southern regions exhibit notable differences in policy implementation and strategic priorities due to variations in natural resources, economic structures, energy compositions, and industrial layouts. These differences may lead to regional disparities in the impact of ESG performance on the carbon emission effects of shipping enterprises.

To further examine this issue, this study categorizes shipping enterprises into two sub-samples based on their geographical location–the southern and northern regions–and conducts a grouped regression analysis using Equation 1. Here, Region = 0 represents the southern region, while Region = 1 represents the northern region. The results in Column (4) of Table 6 indicate that the coefficient of *LnESG* is significantly negative at the 1% level, suggesting that ESG performance has a strong inhibitory effect on carbon emissions among shipping enterprises in the southern region. This finding implies that shipping enterprises in the southern region are more likely to achieve low-carbon transformation through improvements in ESG performance.

Overall, the empirical analysis indicates that strong ESG performance among shipping enterprises significantly reduces their carbon emission intensity. This effect may be attributed to the integration of environmental management measures, social responsibility practices, and corporate governance mechanisms within the ESG framework, which collectively drive the adoption of green technological innovations and facilitate the transition to low-carbon strategies. This is particularly relevant in the current context, as China emphasizes the development of New Quality Productive Forces and actively fosters technological innovation. For instance, shipping enterprises with strong ESG performance are more likely to proactively upgrade shipping technologies, advance the energy transition within the shipping industry, and continuously enhance vessel energy efficiency. They also tend to adopt a more proactive stance in aligning with national energy conservation and emission reduction policies, actively implement sustainable development principles, and improve information transparency by promoting green innovation in shipping. As a result, such enterprises are more likely to gain recognition from environmentally conscious suppliers and attract high-quality

TABLE 6 Results of robustness testing and endogeneity analysis.

Variables	Robustness test		Endogeneity analysis	Heterogeneity analysis	
				Region = 0	Region = 1
	(1)	(2)	(3)	(4)	(5)
LnESG		-0.0722***		-0.0807***	0.0437
		(0.0240)		(0.0214)	(0.0443)
LnCESG	-0.2702***				
	(0.0881)				
L.LnESG			-0.0426**		
			(0.0209)		
Age	-0.0615***	-0.0383***	-0.0600***	-0.0647***	-0.0639***
	(0.0018)	(0.0025)	(0.0019)	(0.0023)	(0.0041)
Size	0.0034*	0.0080*	0.0048**	0.0106**	-0.0038
	(0.0020)	(0.0044)	(0.0021)	(0.0043)	(0.0033)
Lev	0.1134**	0.1164*	0.0358	0.0434	0.1807*
	(0.0439)	(0.0606)	(0.0482)	(0.0547)	(0.0955)
Roa	-2.3168***	-2.3315***	-2.5402***	-2.2435***	-2.1456***
	(0.1648)	(0.2016)	(0.1840)	(0.1782)	(0.3552)
Tat	0.0415*	0.0342	0.0651**	0.0343	0.3317***
	(0.0241)	(0.0281)	(0.0265)	(0.0254)	(0.0868)
Tobinq	0.0124***	0.0129***	-0.0056	0.0121***	-0.1401**
	(0.0034)	(0.0038)	(0.0058)	(0.0034)	(0.0542)
Board	0.0043	0.0082	0.0037	0.0076	-0.0087
	(0.0043)	(0.0063)	(0.0046)	(0.0050)	(0.0084)
Indep	0.0004	0.0012	0.0006	-0.0009	0.0002
	(0.0012)	(0.0016)	(0.0013)	(0.0015)	(0.0020)
Constant	2.3589***	1.1441***	1.2899***	1.4312***	1.2715***
	(0.3727)	(0.1149)	(0.0939)	(0.0953)	(0.1757)
Year dummies	Yes	Yes	Yes	Yes	Yes
Obs	312	228	277	215	97
Adj. R^2	0.9421	0.8083	0.9445	0.9457	0.9611

***, **, and * denote statistical significance at 1%, 5%, and 10%, respectively. Standard errors are in parentheses.

investors, further amplifying the effect of carbon emission reduction.

The results of the heterogeneity analysis indicate that the negative correlation between ESG performance and carbon emission intensity is more pronounced among shipping enterprises in southern China. The southern region has a higher concentration of shipping enterprises, experiences faster technological advancements, and has a more developed overall economy. As a result, these enterprises place greater emphasis on the adoption of green energy and low-carbon technologies, leading to a stronger mitigating effect of ESG performance on carbon emission intensity. In contrast, northern shipping enterprises primarily operate bulk carriers and oil tankers, whose energy efficiency improvements are constrained by vessel age and long technology renewal cycles, making the adoption of low-carbon technologies more challenging in the short term. Additionally, northern ports serve as key nodes in China's west-to-east and north-to-south coal transportation corridors, playing a crucial role in energy logistics. Consequently, their carbon emission intensity is inherently high, which weakens the carbon reduction effect of ESG practices due to the structural characteristics of the industry. Furthermore, the implementation priority of environmental regulation policies in the northern region is more inclined to give way to economic growth, resulting in significantly weaker enforcement than that in the southern region. As a result, ESG practices tend to focus more on compliance rather than value creation, thereby diminishing the regulatory incentive effect of ESG. Moreover, economic constraints contribute to lower investment in green technology research and development among northern shipping enterprises compared to their southern counterparts, further slowing the progress of low-carbon transformation. This lack of systematic advancement in ESG adoption makes it difficult for ESG performance to generate a substantial carbon emission reduction effect in northern China.

5 Conclusions and policy recommendations

In recent years, China's dual carbon strategy has driven a national shift toward low-carbon transformation across various industries. Given the shipping industry's dominant role in global trade, accelerating its low-carbon transformation is particularly urgent. Enhancing ESG practices is essential for achieving carbon reduction targets and serves as a key driver of sustainable development strategies for shipping companies. This study examines the carbon emission reduction effect of ESG performance of shipping enterprises, empirically analyzing the relationship between enterprise ESG performance and carbon emission intensity, along with its regional heterogeneity. Using an unbalanced panel data of Chinese A-share listed shipping enterprises from 2009 to 2022, the findings reveal that enterprise ESG performance has a significant negative effect on carbon emission intensity; that is, the stronger the enterprise ESG performance, the lower the carbon emission intensity. This conclusion remains robust after a series of robustness tests, including alternative ESG measurement methods, exclusion of specific samples, and addressing endogeneity concerns. Further heterogeneity analysis indicates that the inhibitory effect of enterprise ESG performance on carbon emission intensity is more pronounced in the southern region of China.

The findings of this study have significant implications for policymaking and enterprise practices. The results demonstrate that the ESG performance of shipping enterprises contributes to reducing carbon emission intensity. Therefore, the government should accelerate the advancement of ESG governance, optimize the development of ESG-enabling advantages, and support shipping enterprises in achieving low-carbon transformation and sustainable development.

In 2024, several Chinese government departments issued a series of ESG-related policies, including the Guidelines on Sustainable Development Reporting for Listed Companies, the Guiding Opinions on Central Enterprises in the New Era to Fulfill Their Social Responsibilities with High Standards, and the Guidelines on Sustainable Disclosure for Enterprises — Basic Guidelines (Trial). These policies aim to position the disclosure of sustainable development information from listed companies as a fundamental link and key starting point for promoting sustainable development. This study focuses on shipping enterprises and empirically demonstrates that their ESG performance has a significant inhibitory effect on carbon emission reduction, highlighting the critical need to strengthen corporate ESG oversight and enhance ESG capabilities. Therefore, shipping enterprises can leverage these ESG policy opportunities to drive their low-carbon transformation. Specifically, three key strategies can be adopted.

First, capitalize on policy incentives, strengthen ESG practices, and narrow the gap between shipping enterprises and ESG leaders. This includes actively complying with the IMO carbon intensity and Energy Efficiency Design Index (EEDI) requirements, upgrading ship technology, and leveraging the IMO carbon intensity classification policy to obtain green ship certification and operational priority. Additionally, ship carbon emission data should be integrated into the carbon quota accounting system, with the costs of green transformation offset through carbon trading revenues. Core indicators such as ship energy efficiency, alternative fuel ratio, and crew welfare should be regularly disclosed to benchmark against leading international and domestic shipping companies. To ensure data authenticity and reliability, third-party audits should be introduced to verify carbon emission records.

Second, enhance the carbon emission accounting system and implement comprehensive carbon management across the entire life cycle of ships. This requires establishing a real-time monitoring platform for ship carbon emissions, integrating data on speed optimization, route planning, and other operational parameters to enable dynamic calculations of carbon emission intensity for individual ships. Additionally, innovation in the supply chain ESG carbon footprint model is essential. Collaborating with ports to implement the green port plan would allow prioritization of ports offering shore power and low-sulfur fuel refueling services, thereby reducing emissions during berthing. Suppliers should provide low-carbon ship equipment and green fuels, and contracts should incorporate carbon emission-related incentives and penalties to encourage shipowners to adopt energy-efficient technologies.

Third, develop dynamic carbon emission reduction and ESG incentive mechanisms for the shipping industry. This includes offering differentiated levels of construction and innovation subsidies for shipping enterprises that install energy-saving devices and collaborating with companies on zero-carbon innovation experiments in shipping. For high-risk projects such as nuclear-powered ships and carbon capture technologies, the government and enterprises should share both risks and benefits. Furthermore, the linkage between shipping enterprises' carbon emissions and ESG scores should be strengthened by establishing diversified incentive mechanisms and special rewards. A big data platform for shipping ESG should be developed to collect real-time data on ship fuel consumption and port operation carbon emissions, enabling the dynamic generation of comprehensive ESG and carbon emission performance metrics for shipping enterprises.

Additionally, it is noteworthy that according to the Guiding Opinions on Central Enterprises in the New Era to Fulfill Their Social Responsibilities with High Standards, Chinese central State-owned enterprises are considered pivotal for advancing the ESG initiatives of listed companies in China. Among the sample of listed shipping enterprises in this study, state-owned enterprises accounted for 91.67%, of which 26.92% were central State-owned enterprises and 73.08% were local enterprises. This highlights the importance of local enterprises as significant components of the state-owned sector in the shipping industry. Their ESG performance, therefore, warrants increased attention and support from relevant authorities. To capitalize on ESG opportunities, an increasing number of local governments are focusing on the low-carbon transformation of high-carbon industries, particularly through the lens of transformation finance. However, local enterprises face numerous practical challenges and obstacles in this process. As a high-carbon industry undergoing low-carbon transformation, shipping enterprises urgently require more policy support and financial guidance from the government, particularly in light of China's ongoing promotion of its logistics strategy to shift transportation from road to water. Compared to central State-owned enterprises, local enterprises tend to be smaller in scale, influence, and management capabilities. To ensure the healthy and sustainable development of local enterprises' ESG initiatives, local governments should actively promote their low-carbon transformation and support the use of green financial instruments. For instance, shipping enterprises demonstrating strong ESG performance could be offered preferential policies or financing advantages when seeking financial support for their low-carbon transformation from financial institutions.

Moreover, the rapid advancement of digital technologies and AI presents significant opportunities for enhancing enterprise ESG development. In particular, the application of digital technology in decarbonizing shipping is an obvious and important trend (Xiao et al., 2025). However, local enterprises often face a notable resource allocation and talent deficit in leveraging these technologies, compared to central State-owned enterprises. In response, local governments should take a proactive role in policy guidance, strengthening the integration of resources and coordination across areas such as digital infrastructure, data systems, technology innovation, and digital security. By building a robust digital infrastructure, they can assist in the low-carbon transformation of high-carbon industries like shipping, thereby fostering the sustainable development of these enterprises. In general, interdepartmental collaboration can enhance the carbon emission policy framework and ESG regulatory system within the shipping industry. Measures such as optimizing subsidies and tax incentives, strengthening environmental protection laws and regulations, and standardizing ESG disclosure mechanisms and rating standards can effectively guide shipping enterprises in improving their ESG performance, accelerating low-carbon transitions, and promoting long-term sustainability.

Furthermore, the heterogeneity analysis in this study indicates that the carbon emission reduction effect of enterprise ESG performance is significant in the southern region, but not in the northern region. In light of these findings, shipping enterprises in both regions should leverage the unique characteristics of their respective regional resource endowments, policy orientations, and market developments to devise differentiated ESG strategies aligned with low-carbon transformation. For shipping enterprises in the southern region, they can actively seek robust local financial policies to secure lower-cost financial resources and engage in carbon market trading, thereby converting carbon emission reduction benefits into economic gains. By leveraging their ESG performance advantages, they can drive low-carbon transformation. Additionally, the southern region's strengths — such as its extensive shipping along coastal and inland rivers, the development of the digital economy and digital technologies, as well as industrial features like port density and international routes — should be leveraged to optimize shipping technologies. This could include promoting zero-carbon transportation, developing green ports, building integrated shipping supply chains, and enhancing international cooperation in green industries. These efforts will further accelerate the low-carbon transformation of shipping enterprises.

Shipping enterprises in the northern region face certain limitations in ESG development and low-carbon transformation due to factors such as natural conditions, economic structure, and infrastructure. To address these challenges, shipping enterprises should focus on improving energy efficiency and promoting multimodal transport as key components of their future development strategy, while also working to build a regional green transport network. In terms of energy efficiency, shipping enterprises can effectively leverage policy support, such as the 2024 Rules for the Renewal of Subsidies for the Scrapping and Renewal of Old Vessels in Transport issued by the Ministry of Transport. This policy can accelerate the scraping of outdated vessels, promote the construction of new energy and clean energy vessels, reduce fuel consumption, and, ultimately, lower carbon emissions. In terms of multimodal transport, shipping enterprises can leverage the advantages of northern railway network and, with support from the Management Measures for Multimodal Transport Demonstration Projects (Interim) issued in 2022, strengthen cooperation with railway transport. By deepening the 'shipping + railway' combined transport model and promoting the 'scattered transformation' business model, they can build a regional green transport network that enhances transport efficiency and reduces carbon intensity.

It is also important to note that southern shipping enterprises may expand their business operations into the northern region, which will intensify competition in the northern shipping market and put greater pressure on local shipping enterprises with weaker technological and financial capabilities. This could limit their ESG development potential. In response, northern shipping enterprises can collaborate with southern enterprises to establish a technology-sharing and industrial cooperation model, fostering an ESG alliance ecosystem. This would involve extensive cooperation across the entire value chain, enabling a more rational allocation of resources and promoting the effective development of ESG initiatives. Additionally, cross-regional trading of carbon quotas in the shipping industry should be encouraged to enhance the connectivity of the carbon market within the industry. This would strengthen the operational efficiency of the shipping market and collectively drive the sustainable development of the shipping sector.

This study has several limitations. First, due to differences in legal requirements, regulatory environments, financing methods, and other factors, there are significant discrepancies in the information disclosure practices of Chinese enterprises, depending on whether they are listed or not. Given data availability, this study focuses on listed shipping enterprises with relatively comprehensive information disclosure, while excluding non-listed shipping enterprises with limited data. As a result, the carbon emission reduction effect of ESG performance across all shipping enterprises cannot be fully examined. Future studies should expand the sample size to include both listed and unlisted enterprises to enhance the generalizability of the findings.

Second, while multiple rating agencies assess ESG performance for Chinese enterprises, a unified ESG evaluation standard has not yet been established. Differences across agencies in terms of indicator selection, weight allocation, and evaluation methods in the three dimensions of environment, society, and governance result in variations in ESG ratings. Although this study accounted for different ESG performance measures in robustness tests, its comprehensiveness remains limited. Future research will benefit from the establishment of a standardized ESG assessment system, which would allow for more consistent and rigorous validation.

Third, the potential bias inherent in using a single ESG indicator represents a limitation of this study. The ESG focus of the shipping enterprises differs from that of other sectors, and a single ESG indicator may not adequately capture the unique characteristics of shipping enterprises. The ESG performance of the shipping enterprises is influenced by various specific factors, such as ship technology, route planning, and fuel type. Additionally, a single ESG index may fail to fully and accurately represent the relationship between ESG performance and carbon emission intensity in shipping enterprises, as different ESG evaluation systems prioritize distinct environmental, social, or governance dimensions, leading to potential distortions in research findings. Future research should reference the ESG Evaluation Standards for Shipping Companies and develop a multi-dimensional and detailed evaluation system that comprehensively reflects the ESG performance of shipping enterprises.

Finally, the regional heterogeneity analysis divides China into southern and northern regions based on geographical location, focusing on the physical locations of shipping enterprises. This approach overlooks the distribution of their business operations across different regions, which limits the ability to assess whether business location influences the research outcomes. As China continues to promote domestic circulation and accelerate the development of a unified domestic market, the efficiency of market resource allocation will improve, and inter-regional transactions will become more seamless. Future research should explore how the distribution of business operations and production factors across regions impacts the findings.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding authors.

Author contributions

JL: Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing. JS: Conceptualization, Data curation, Investigation, Methodology, Software, Writing – original draft. YH: Project administration, Supervision, Validation, Writing – review & editing. XS: Project administration, Validation, Writing – review & editing.

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Conflict of interest

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

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The author(s) declare that no Generative AI was used in the creation of this manuscript.

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