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ESG investment and its societal impacts

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ESG investment and its societal impacts

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Editorial: ESG investment and its societal impacts

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ESG, ESG investment, Societal Impacts, governance, environment, social

Editorial on the Research Topic
ESG investment and its societal impacts

ESG investing refers to companies' investment actions that consider the environment (Environment), society (Social), and corporate governance (Governance) together. "Environment" refers to activities such as reducing carbon dioxide emissions and energy consumption. "Social" refers to activities such as human rights issues and promoting women's activities. "Corporate Governance" refers to activities such as compliance and management transparency.

ESG began with the Principles for Responsible Investment (PRI) proposed by the United Nations in 2006 and has been attracting attention as a new indicator for measuring corporate investment value among institutional investors. The idea is that focusing on ESG requirements can lead to the sustainable growth of a company over the medium-to long-term and eliminate risks that are not visible from financial statements. The idea is that it is possible to eliminate risks that are not visible in financial statements.

"ESG Investment and Its Societal Impacts" are of significant academic and policy importance. This Research Topic aims to cover promising and new research trends in this area.

A total of 27 articles were published on this Research Topic; 18 of the analyses were based on data from China. This indicates that ESG impacts in China are receiving significant attention. A total of two articles on the impact of COVID-19 are also included, as are two analyses using SNS data.

A word cloud created from the abstracts of the 27 articles is presented in Figure 1. It is clear that, among ESG issues, there is a particularly strong interest in the environmental aspect of ESG.

The articles on COVID-19 yielded the following results. Zhou et al. analyzed the impact of the COVID-19 pandemic on different international curve sectors, using data from Germany and the United States. The results indicate that the impact of the pandemic on government bond yields varies across countries and valuation periods, particularly in the longer-term response, with German yields being more negative (indicating lower

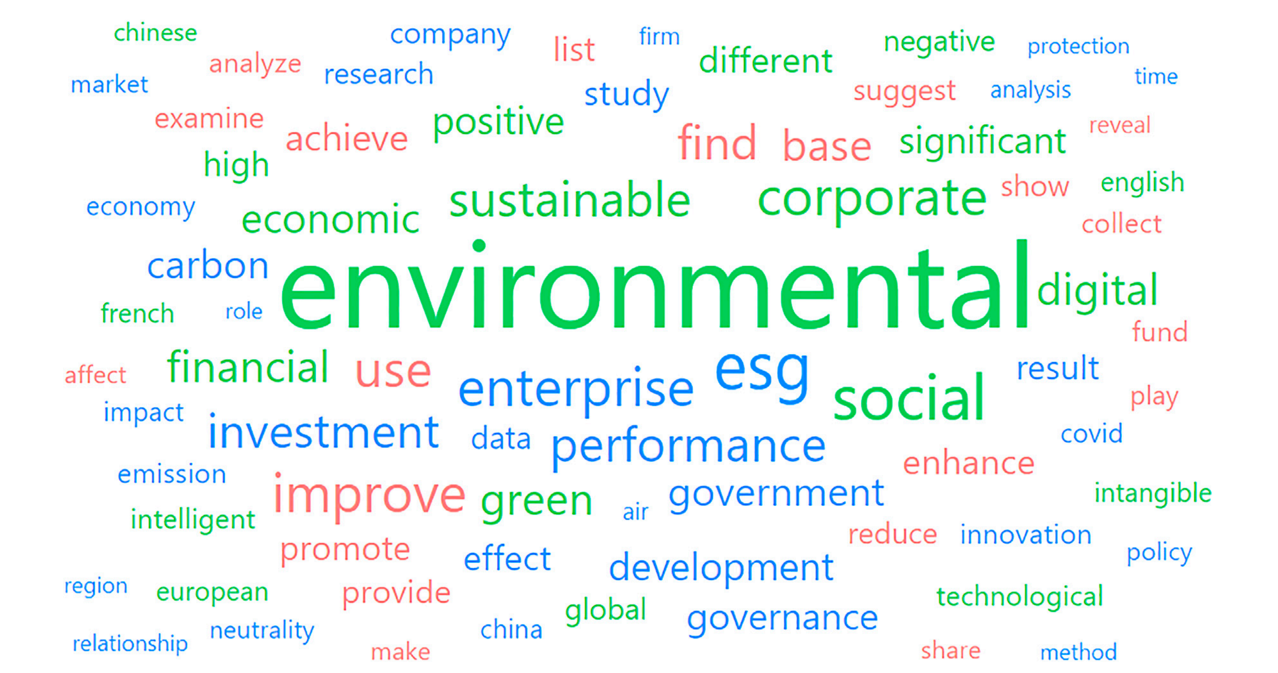

FIGURE 1
Word cloud.

yields) and U.S. yields being more positive (indicating informative yields). Chen et al. investigated the impact of the pandemic on ESG stock index performance in emerging, European, and global markets. The results reveal that the global pandemic and mortality risk of COVID-19 infection had a significant negative impact on ESG stock market performance in all markets.

The following results were obtained from the analysis using social networking data. Li et al. analyzed people's perceptions of carbon neutrality by collecting posts from Weibo, the most popular social platform in China. The results reveal that people believe that achieving carbon neutrality will help them pursue a better life. Yao et al. used Twitter data to compare the differences between French and English tweets on carbon neutrality. The results indicate that in France, negative tweets outnumbered positive tweets. This could be due to people's dissatisfaction with the government's current carbon neutrality policy.

Using data from China, Xu et al. analyzed the impact of environmental investment on firm innovation using a sample of industrial firms. The results reveal that firms that invest more in environmental protection receive more government subsidies and, subsequently, exhibit better innovation performance. Cai et al. examined the relationship between green innovation and carbon emissions. The results suggest that green innovation in the eastern and central regions effectively reduces carbon emissions. Strong spatial spillover effects among provinces were identified and green technological advances in one province had a negative impact on the carbon emissions of neighboring chapters. Jun et al. analyzed ESG score improvement and intangible capital. The results indicate that ESG disclosures contribute significantly to the performance of listed firms but that such disclosures and intangible capital exhibit an "inverted U" shape. Qi et al. investigated the relationship between government-led construction of national civilization cities and ESG investments, including social and environmental activities, in firms using panel data of listed firms. Firms' ESG performance was found to improve when their residence is rated as a national civilization. Li et al. analyzed the relationship between environmental scores and stock price crash risk using a sample of ESG-rated listed companies. The results reveal that companies with higher environmental scores have lower stock price crash risk. Li et al. examined the impact of corporate ESG-responsive investments on the investment size of sovereign wealth funds (SWFs). ESG performance was found to induce SWFs to invest by increasing ROA and reducing risk. Chen et al. determined the impact of the development of the urban digital economy on firms' ESG performance. The results indicate that the development of the urban digital economy significantly improves firms' ESG performance. Lu et al. analyzed the policy effects of the "Three-Year Action Plan to Win the Blue Sky War" on the steel industry and air pollution. The results suggest that ESG investments by steel companies lead to a significant decline in financial performance. Furthermore, emissions of sulfur dioxide and nitrogen oxides in flue gas were significantly reduced after the implementation of the "Blue Sky Plan." Chen et al. found that environmental subsidies significantly improve firms' environmental performance but have no significant impact on pollutant emissions disclosure or governance. Using data from the manufacturing sector, Jianqiang et al. established that ESG investments and the embedding of external data elements have no direct impact on firm performance but have an indirect impact through organizational agility. Moreover, environmental uncertainty negatively moderates the impact of ESG investments on organizational agility. Environmental uncertainty negatively moderates the impact of ESG investments on organizational agility. Wu et al. determined the spatiotemporal correlation between environmental governance investments and air quality in each province and revealed a negative spatiotemporal correlation between these factors. Cong et al. analyzed the relationship between ESG investment and carbon emissions and revealed that a 1% increase in environmental investment reduces CO_2 emissions by 0.246% and carbon emissions intensity by 0.558%. To further analyze the digital transformation mechanism of firms, Gao et al. analyzed the decision-making behavior of firms under financing constraints from the perspective of intermediary mechanisms. The results indicate that firms' decision to increase their intangible capital facilitates improves corporate performance and further improves their ESG scores. Li and Li examined the effects of environmental protection taxes on corporate ESG performance and green innovation. The results reveal that such tax can significantly improve firms' ESG performance and green technological innovation and that ESG performance exhibits a partial mediating effect in promoting firms' green technological innovation. Wang and Hu empirically examined the effects of performance-based budget (PBB) reforms on corporate ESG. The results demonstrate that PBB significantly optimizes firms' ESG. Furthermore, the environmental governance effects of PBB are more pronounced in regions with strong fiscal pressures and strong government audits. Using the Luenberger productivity index based on the data envelopment analysis (DEA) method, Huang et al. measured green total factor productivity (GTFP). The results reveal that environmental regulations on Taiwanese firms have a negative impact on GTFP. This means that Taiwanese-affiliated firms have to pay "compliance costs" due to the implementation of environmental regulatory policies by the Chinese local government. Zhang et al. analyzes the impact of the guidance on the quality of environmental disclosure by listed companies based on a quasi-natural experiment by China's Shenzhen Stock Exchange, which issued "Guidance on the Social Responsibility of Listed Companies" in 2006. The results indicate that the exchange's corporate social responsibility (CSR) regulations contribute to improving the quality of listed companies' environmental information disclosure.

In addition, using data from private commercial banks in Bangladesh, Guang-Wen and Siddik investigated the impact of CSR and green finance on the environmental performance of banking institutions. According to the results, CSR practices have a positive impact on environmental performance. Zhao et al. assessed the achievement of the EU and UN environmental targets for net zero emissions in 2050 as a result of green energy, digitalization, and technology. Zeng et al. collected 2,400 financial data items and ESG performance of 200 companies from the global "Clean 200" list of publicly traded companies. The study evaluated green supply chain performance based on financial indicators and company ESG performance. Operational performance was given the highest weight, followed by environmental performance, while profitability was ranked last. The results suggest that management should focus more on governance and the environment than on short-term financial gains.

Furthermore, Tong et al. investigated the predictive relationship between AI and intelligent automation in tourism, which has a mediating role in ESG investment. The results reveal that AI has a predictive relationship with intelligent automated tourism. Cai and Sakemoto examined the time-series impact of the El Niño Southern Oscillation (ENSO) on commodity prices. The results indicate that there is a strong relationship between ENSO and commodity prices and that this relationship has been particularly pronounced since 2000.

Finally, Li et al. is a state-of-the-art study on the incorporation of ESG in prefabricated buildings and the impact of economic development on the development of such buildings by visualizing the titles, authors, keywords, abstracts, and references of articles from Web of Science and Scopus. This study reviewed previous research.

These articles all contribute to the development of empirical finance by addressing a wide range of issues and topics related to ESG investment and its societal impacts.

While research has been conducted on a variety of issues in this research topic, the following issues remain to be addressed. First, the impact of geopolitical risk, as exemplified by Russia's invasion of Ukraine, can be pointed out. Analyzing the impact of geopolitical risk on ESG investments is an important remaining research issue. Next is the relationship between ESG investments and macroeconomic activities: empirical research on the spillover channels through which ESG investments affect macroeconomic activities such as GDP is an important issue for future study. In addition, it would be interesting to analyze the impact of further development of artificial intelligence on ESG investment in society.

Author contributions

SH, X-GY, LY, and MC contributed to the conception and design of the study. SH wrote the first draft of the manuscript. X-GY, LY, and MC reviewed and edited the manuscript. All

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authors contributed to the manuscript revision, read, and approved the submitted version.

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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Be Green to Be Innovative: The Role of Government Subsidies

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Corporate environmental investment has long been recognized as a non-market strategy that helps secure both economic and social benefits. However, we know much less about how environmental investment affects corporate innovation. We argue that investment in environmental protection is an important source of institutional legitimacy for firms to secure government resources, thus providing financial support for corporate innovation activities. Using a sample of Chinese industrial firms, we find that firms investing more in environmental protection can receive more government subsidies and then have better innovation performance. This study emphasizes the mechanism of government resources, which enriches our understanding of the effect of environmental investment on corporate innovation.

Keywords: environmental investment, corporate innovation, government subsidies, resource allocation, institutional legitimacy, China

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1 INTRODUCTION

The rapid development of Chinese industrial economy has brought new challenges to the environmental governance (Wang et al., 2018). Increasing environmental pollution not only destroys the ecological environment and threatens the health of the population (Liu et al., 2021), but also hinders economic development (Hao et al., 2018). In the face of severe environmental challenges, the Chinese government had gradually increased its attention to environmental protection and begun to guide firms to increase their investment in environmental protection. Firms are not only the cause of environmental pollution, but also should be responsible for eliminating the negative effects of pollution (Klettner et al., 2014). For firms, pollution emissions are the result of inefficient resource allocation (Porter and Van der Linde, 1995). Therefore, all investments to control environmental pollution and improve resource allocation efficiency can be regarded as environmental protection inputs (Shen et al., 2021).

Corporate environmental investment is closely related to resource allocation, while innovation as a complex task with huge economic and social benefits requires a large amount of resource investment (Jia et al., 2019). In this context, the relationship between corporate environmental investment and innovation performance is inconclusive. On the one hand, increasing environmental investment is an important source of institutional legitimacy for firms (Li et al., 2018). On the other hand, excessive investment in environmental protection has taken up a lot of resources (Eyraud et al., 2013), thus limiting the development of innovation activities. These ambiguous and paradoxical findings also drive us to investigate how environmental investment affects corporate innovation, which is the main research question of this study.

We argue that increasing investment in environmental protection can bring resource advantages, specifically from the government, thus providing financial support for corporate innovation activities. In China, the government holds key business resources, and firms need to implement active environmental strategies or political activities to obtain institutional legitimacy and external resources such as subsidies, tax incentives, etc. (Wang and Qian, 2011). Thus, one important purpose of corporate environmental investment is to secure more government resources to promote corporate innovation activities.

We use a sample of Chinese industrial firms from 1998 to 2008 to test our hypotheses, and the results well support our arguments. The main contribution of this study is that, in contrast to previous studies that emphasize the economic benefits of corporate environmental investment, this study focuses on its driving force on innovation, which contributes to understanding the role of firms in technological and social changes. Furthermore, we emphasize the mechanism of government resources, which enriches the knowledge of the literature in corporate environmental management and innovation.

2 BACKGROUND AND DEVELOPMENT OF HYPOTHESES

2.1 Research Background

Along with the rapid economic development, environmental pollution comes with it. Faced with serious environmental problems, the Chinese government has shown an unprecedented attention, specifically to the role of firms in pollution control. As reported in the 14th Five-Year Plan, the government should strengthen the establishment of corporate environmental governance responsibility systems, and guide social organizations and the public to participate in environmental governance. In addition, the government also promotes firms to implement environmental protection activities through a variety of channels, including adopting compulsory environmental regulations (Delmas and Montes-Sancho, 2011) and sending legitimacy signal to guide firms to implement active environmental strategies (Marquis and Qian, 2014). Faced with environmental regulatory pressure and legitimacy requirements, most firms will increase environmental protection investment or participate in environmental innovation activities (Berrone et al., 2013).

On the other hand, after the reform and opening up, China's total economic volume has risen rapidly, but the quality of economic and social development is still lacking due to the lack of overall independent innovation capabilities. Under the new situation that China's economy is shifting from high-speed growth to high-quality growth, the Chinese government has placed innovation at the center of the national development and actively guided firms to participate in innovation activities. Innovation is not only an important driving force for the development of social productivity, but also an important force for the transformation of social production relations and the development of human culture, and hence has important social benefits. However, innovation is fraught with uncertainty and has a high risk of failure (Holmstrom, 1989), and is influenced by many factors, such as corporate and public governance (Jia et al., 2019), the nature of ownership (Choi et al., 2011), government support (Ji and Miao, 2020) and political connections (Hou et al., 2017). The government provides policy guidance for corporate innovation, and the resources it has are also an important factor in supporting corporate innovation activities, such as special government subsidies for firms to promote technological innovations in specific government-encouraged areas.

2.2 Corporate Environmental Investment and Innovation

Existing research shows that the survival and development of organizations need resources. However, the organization does not usually produce such resources, and its performance depends on its ability to interact with the environment to obtain key resources (Hillman et al., 2009). The same is true for corporate innovation. When a firm lacks sufficient resources to maintain innovation activities, its innovation performance will suffer huge losses. In China, most of these resources are controlled by the government (Li et al., 2008), and the allocation of resources is inefficient, so that firms with better institutional legitimacy may receive more resources, such as government subsidies (Lin et al., 2015). Therefore, proper interaction with the government is one of the important means of obtaining resources.

We have mentioned that environmental pollution has attracted important attention from the Chinese government. Facing the government's environmental protection appeal, appropriate feedback on government behavior is one of the important channels for firms to obtain the institution legitimacy (Marquis et al., 2011). In China, the lack of a sound legal governance system makes the government's decision-making process less transparent and inefficient in the allocation of some resources (He and Tian, 2008). In order to obtain resources and reduce the uncertainty in the business process, firms may choose to actively respond to the government's call to obtain legitimacy and important commercial resources (Marquis and Qian, 2014). Therefore, we argue that firms that choose to increase environmental investment are more likely to obtain institutional legitimacy and government subsidies. As a key political resource, government subsidies can provide sufficient financial support for the innovation activities and help firms reduce the costs and risks during the innovation process (Wang et al., 2017). We propose:

Hypothesis 1. Increasing investment in environmental protection can help firms obtain more government subsidies, thereby improving corporate innovation.

3 METHODOLOGY

3.1 Sample and Data Collection

In order to investigate the impact of environmental investment on corporate innovation, A total of 31,024 Chinese industrial firms from 1998 to 2008 were used as the research sample. During the 10 years from 1998 to 2008, the Chinese government issued the Ninth and Tenth Five-Year Plans, which have been mentioned many times to increase environmental governance and guide firms to control environmental pollution, providing us an ideal context to test our hypotheses. The industrial firm data was collected from the Annual Census of Industrial Enterprises (ACIE), which includes all industrial firms above designated size in China. Corporate environmental data came from the Environmental Survey and Reporting (ESR) database compiled by the Ministry of Ecology and Environment of China. Corporate patent data was sourced from the Chinese Patent database. Regional characteristic data were obtained from the "China Statistical Yearbook" and the "China City Statistical Yearbook."

3.2 Measures

3.1.1 Corporate Innovation

We used the total number of patent applications of a firm in a given year to measure Corporate innovation (Jia et al., 2019). In addition, we also used the sales revenue of new products as an alternative measure for corporate innovation.

3.1.2 Environmental Investment

We used the natural logarithm of the number of wastewater treatment facilities to measure the level of corporate Environmental investment. Wastewater treatment is one of the important contents of the Chinese government's environmental pollution governance, and the quality of the water environment is also listed as one of the main indicators of ecological environmental protection in the 13th Five-Year Plan.

3.1.3 Other Variables

Government subsidies was measured by the natural logarithm of corporate subsidy incomes from the government. Firm size was measured by the natural logarithm of firm total assets. Firm age was measured by the years of a firm's establishment. Debt ratio was measured as a firm's debt-to-asset ratio. Financial performance was measured as the return on assets. Government jurisdiction captures the level of government to which a firm is affiliated, and was measured as an ordered variable, coded as 1 for town-level government and below, 2 for county-level government, 3 for prefecture-level government, 4 for provincial government, and 5 for central government. Regional marketization was expressed by the marketization index. Regional corruption was calculated by the number of cases of corruption per 10,000 civil servants at the provincial level. Regional economic development was measured as the natural logarithm of the municipal gross domestic product (GDP).

3.3 Estimation Method

In order to test the role of environmental protection investment and government subsidies on corporate innovation, this study used a stepwise test coefficient method to test the mediating role of government subsidies between environmental investment and corporate innovation performance with a bootstrap model to perform 500 cycles of calculation (Baron and Kenny, 1986). We conducted an ordinary least-squares (OLS) regression absorbing year-level and industry-level fixed effect with a robust variance covariance estimator. The model was set as follows:

$$\text{Corporate innovation} = \beta_0 + \beta_1 \text{Environmental investment} + \beta_2 \text{Controls} + \varepsilon$$

$$\text{Government subsidies} = \beta_3 + \beta_4 \text{Environmental investment} + \beta_5 \text{Controls} + \varepsilon$$

$$\text{Corporate innovation} = \beta_6 + \beta_7 \text{Environmental investment} + \beta_8 \text{Government subsidies} + \beta_9 \text{Controls} + \varepsilon$$

where β_1, β_4, β_7 and β_8 are used to test **Hypothesis 1**; "Controls" is the set of control variables; ε represents the random error term.

4 RESULTS

4.1 Descriptive Statistics and Correlation

Table 1 reports the results of descriptive statistics and correlations of all variables. It can be seen that environmental investment and corporate innovation are positively correlated ($p < 0.05$), and the correlation coefficient between the independent variable and any other variables is less than 0.5. In addition, the average value of the variance inflation factor (VIF) is 1.28, which is significantly less than 10. Therefore, the risk of multicollinearity in this study is excluded.

4.2 Hypotheses Testing

Table 2 reports the regression results estimated by government subsidies and corporate innovation. Hypothesis 1 states that environmental investment can improve corporate innovation performance through obtaining government subsidies. As shown in Model 2, the coefficient on environmental investment is positive and significant at the 0.1% level ($\beta = 0.166$, $p < 0.001$), suggesting that firms investing more in environmental protection can receive more government subsidies. In Model 3, the coefficient on government subsidies is positive and significant at the 0.1% level ($\beta = 0.008$, $p < 0.001$), suggesting that firms that received more government subsidies can have better innovation performance, thus supporting for **Hypothesis 1**.

We also conducted several analyses to test the robustness. An alternative measure of the dependent variable to check the significance was used in the regression (Yao et al., 2021). In Models 4–6 of **Table 2**, we used the natural logarithm value of new product sales revenue to measure corporate innovation and found that the results remained similar. Furthermore, government subsidies and patents may have many zero values. To fill this gap, we used a Tobit regression for robustness check. As show in Model 7–9 of **Table 2**, the regression results still support for **Hypothesis 1**.

5 DISCUSSION AND CONCLUSION

Innovation is an important source for firms to maintain vitality and improve competitiveness. In the context of increasingly stringent environmental supervision, how to balance the development of environmental governance and innovation activities has become an important issue that firms need to solve in the future. We used an empirical analysis to investigate how environmental investment affects corporate innovation. We found that increasing investment in

TABLE 1 | Descriptive statistics and correlation matrix.

Variables	Mean	SD	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) Corporate innovation (patent)	0.101	0.436										
(2) Firm size	10.951	1.552	0.290									
(3) Firm age	15.959	16.829	0.105	0.220								
(4) Debt ratio	0.584	0.231	−0.018	0.014	0.093							
(5) Financial performance	0.056	0.259	0.004	−0.046	−0.064	−0.129						
(6) Government jurisdiction	1.812	1.167	0.139	0.377	0.471	0.031	−0.083					
(7) Regional marketization	7.323	1.959	0.051	−0.011	−0.164	−0.033	0.047	−0.313				
(8) Regional corruption	33.357	10.008	−0.035	−0.053	0.094	0.062	−0.034	0.099	−0.355			
(9) Regional economic development	16.161	1.036	0.100	0.130	0.064	−0.021	0.018	0.014	0.497	−0.180		
(10) Subsidy income	1.377	2.749	0.125	0.268	0.094	0.018	−0.016	0.113	0.061	−0.003	0.037	
(11) Environmental investment	0.592	0.493	0.124	0.304	0.012	−0.018	0.024	0.075	0.072	−0.116	0.032	0.106

Note: N = *85,279; correlation greater than |0.02| are significant at the 0.05 level.*

TABLE 2 | Estimates for corporate innovation performance.

Variables	DV: Patent	DV: Subsidy	DV: Patent	DV: Sales	DV: Subsidy	DV: Sales	DV: Patent	DV: Subsidy	DV: Patent
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
Firm size	0.078***	0.454***	0.065***	0.659***	0.454***	0.643***	0.776***	1.693***	0.743***
	(0.002)	(0.008)	(0.002)	(0.011)	(0.008)	(0.011)	(0.013)	(0.030)	(0.015)
Firm age	0.001***	0.008***	0.001***	0.023***	0.008***	0.023***	0.006***	0.026***	0.006***
	(0.000)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.003)	(0.001)
Debt ratio	0.008***	0.143***	−0.037***	0.144***	0.143***	0.010	0.111***	0.656***	−0.361***
	(0.002)	(0.035)	(0.006)	(0.009)	(0.035)	(0.058)	(0.011)	(0.178)	(0.080)
Financial performance	0.010***	−0.020	0.026	0.123***	−0.020	0.287	0.100***	−1.613***	0.164***
	(0.002)	(0.028)	(0.019)	(0.018)	(0.028)	(0.237)	(0.019)	(0.327)	(0.044)
Government jurisdiction	0.010***	0.093***	0.008***	0.349***	0.093***	0.322***	0.109***	0.338***	0.097***
	(0.002)	(0.012)	(0.002)	(0.016)	(0.012)	(0.018)	(0.015)	(0.041)	(0.016)
Regional marketization	0.008***	0.147***	0.008***	0.132***	0.147***	0.119***	0.116***	0.729***	0.125***
	(0.001)	(0.007)	(0.001)	(0.009)	(0.007)	(0.010)	(0.012)	(0.03)	(0.013)
Regional corruption	0.000	0.016***	0.000	0.026***	0.016***	0.026***	0.003	0.076***	0.002
	(0.000)	(0.001)	(0.000)	(0.001)	(0.001)	(0.002)	(0.002)	(0.005)	(0.002)
Regional economic development	0.011***	−0.102***	0.010***	−0.139***	−0.102***	−0.121***	0.101***	−0.370***	0.097***
	(0.002)	(0.011)	(0.002)	(0.014)	(0.011)	(0.014)	(0.018)	(0.045)	(0.020)
Environmental investment	0.052***	0.166***	0.048***	0.224***	0.166***	0.182***	0.172***	0.362***	0.130***
	(0.005)	(0.022)	(0.005)	(0.031)	(0.022)	(0.033)	(0.034)	(0.084)	(0.035)
Government subsidies			0.008***			0.080***			0.049***
			(0.001)			(0.006)			(0.006)
Constant	−1.041***	−4.030***	−0.876***	−6.317***	−4.030***	−6.327***	−16.604***	−29.311***	−15.949***
	(0.032)	(0.169)	(0.031)	(0.227)	(0.169)	(0.239)	(0.422)	(0.908)	(0.463)
Industry dummies	Included	Included	Included	Included	Included	Included	Included	Included	Included
Year dummies	Included	Included	Included	Included	Included	Included	Included	Included	Included
Adj R-squared	0.105	0.120	0.233	0.224	0.105	0.233	0.176	0.040	0.176
Wald/LR chi2	2,927.21***	5,713.72***	2,376.34***	7,728.73***	5,713.72***	8,278.8***	13,057.78***	7,756.80***	10,401.73***
Observations	96,906	85,849	85,279	84,034	85,849	70,481	96,908	85,852	85,282

Note: ****p < 0.001, **p < 0.01, *p < 0.05; standard errors are in parentheses.*

environmental protection can significantly promote corporate innovation. As investment in environmental protection is an important mean to secure institutional legitimacy, firms can obtain resources controlled by the government by implementing active environmental strategies, thereby helping firms with more resources to invest in innovation activities.

5.1 Contribution

The main contribution of this study is that we emphasize the mechanism for firms to obtain effective resources to promote innovation through environmental investment, which enriches the knowledge in the literature of both corporate environmental management and innovation (Staub et al., 2016; Boone et al., 2019). Furthermore, compared with the previous literature focusing on the economic benefits of environmental, social and governance (ESG) investment (Baron and Kenny, 1986), we pay more attention to its social impact.

More practically, this study responds to the call for environment protection, and provides new insights for policy makers to better manage corporate environmental action. For firms, this study provides empirical evidence for how firms can interact with government effectively to obtain external resources and improve corporate innovation.

5.2 Limitation and Future Research

Our study has some limitations. First, our sample only includes the industrial firms above designated size and lacks the consideration for some small and medium-sized firms, which should be considered for future research. Second, considering the diversity of pollutant emissions, we have limitations in capturing corporate wastewater treatment facilities to measure environmental investment. Future research may consider more effective indicators to measure corporate environmental investment.

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

WL and RP led the conceptual design of the manuscript, YBX wrote the initial drafts, RP advised the formal analysis and all authors reviewed the manuscript and provided comments and feedback.

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How Does Green Technology Innovation Affect Carbon Emissions? A Spatial Econometric Analysis of China's Provincial Panel Data

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Due to an increasing number of issues such as climate change, sustainable development has become an important theme worldwide. Sustainable development is inseparable from technological innovation. Only by making technological breakthroughs can we ensure the overall integration of economic development and environmental protection. Here, based on China's inter-provincial panel data from 2006 to 2019, we examine the relationship between green technological innovation and carbon dioxide (CO_2) emissions in 30 provinces (excluding Hong Kong, Macao, Taiwan, and Tibet) and sub-regions (eastern, central, and western China) in China using a space panel econometric model based on the STIRPAT equation. Additionally, we use geographic information analysis methods to analyze the spatial pattern and evolution characteristics of CO_2 emissions. Our major finding is that, from the perspective of the whole country, green technology innovation has a negative correlation with carbon emissions, but the effect is not obvious. In addition, from the regional sample, green technology innovation in the eastern and central regions can effectively reduce carbon emissions, while in the western region, green technology innovation can promote carbon emissions in the province. At the same time, the research results show a strong spatial spillover effect of inter-provincial carbon dioxide emissions, and the progress of green technology in neighboring provinces has a negative impact on carbon emissions in their own provinces. Therefore, cross-province policies and actions for reducing carbon emissions are necessary. Additionally, our results show that carbon-emission driving factors, such as economic development, industrial structure, energy consumption structure, and population, have a significant positive effect on carbon dioxide emissions. Based on the above research results, we put forward corresponding policy recommendations.

Keywords: sustainable development, green technology innovation, carbon emissions, carbon emissions spatial effect, spatial panel model

1 INTRODUCTION

In recent years, the continuous accumulation of carbon dioxide emissions has produced a series of environmental problems, such as global warming and frequent outbreaks of extremely severe weather. Therefore, carbon emission reduction has become an important topic of concern to all countries globally, and green development has also become an important factor in promoting the transformation of the global economic structure (Shao and Zhong, 2021a).

The Chinese Government has realized the serious environmental problems caused by massive CO_2 emissions. It has not only introduced a series of relevant policies and measures but also promised at the Paris Climate Conference to reduce CO_2/GDP by 60–65% by 2030 compared with 2005 and peak carbon emissions around 2030 (Mi et al., 2017). The Chinese Government also attaches great importance to promoting the environmental society and Governance (ESG) system (Coleman et al., 2010; Blank et al., 2016), and issued the reform plan of the legal disclosure system of environmental information in 2021, clearly pointing out that the mandatory disclosure system of environmental information should be basically formed by 2025. In addition, at the Fifth Plenary Session of the Nineteenth Central Committee, "support for green technological innovation" was particularly emphasized. Hence, there is a need for innovation on the existing operations so that maximization of the growth can be achieved with the least possible cost to the environment (Li et al., 2020; Meirun et al., 2021). Therefore, green technological innovation makes economic activities more environmentally friendly and can be a potential solution for planned reduction of carbon emissions, which has attracted the attention of experts around the world (Nikzad and Sedigh, 2017; Shao and Zhong, 2021b). Additionally, how does green technology innovation affect CO_2 emissions? Can green technological innovation reduce CO_2 emissions in economies of scale? This is the focus of attention of governments at all levels and related scholars.

The concept of green technological innovation was first proposed by Braun and Wield (1994). They believed that green technological innovation refers to producing green products based on reducing environmental pollution, raw materials, and energy consumption through the use of technological processes. Based on existing literature research (Wang et al., 2021), our understanding of green technology innovation is that green technology innovation takes the promotion of energy conservation, environmental optimization, and economic development as its core concepts, and its results are mainly reflected in technological progress that contributes to energy conservation and emission reduction (Long et al., 2017; Sellitto et al., 2020). The fundamental difference between green technological innovation and traditional innovation is that environmental output is considered. The lower the pollution degree to the environment in the process of technological innovation, the higher the degree of green technological innovation.

Theoretically it is assumed that technology innovation can promote the transition toward environmentally oriented lifestyles and reduce carbon emissions. And it is frequently considered as the crucial way to achieve green growth (Albino et al., 2014; Cheng et al., 2018; Shao and Zhong, 2021a). However, scholarly evidence on the association between green technology and carbon emissions are mixed and even contradictory based on empirical analysis because of the different scenarios. For example, according to Braungardt et al. (2016), green technology effectively resolved the trade-off between economic growth and environmental protection, while, there may exist a rebound effect. That is, green technological innovation has a direct effect and scale effect on carbon dioxide emissions. One is that green technological innovation can effectively reduce carbon emissions by improving energy utilization efficiency, that is, the direct effect of green technological innovation on carbon emissions. The other is that green technology innovation promotes the expansion of economic scale and output level, which requires more energy consumption and indirectly causes the level of carbon emissions to rise, that is, the scale effect of green technology innovation on carbon emissions (Fisher-Vanden and Wing, 2008; Abdouli and Hammami, 2017; Khan and Su et al., 2021). Therefore, the direction of this combined effect is not clear. Just as Sinn (2008) argues, good intentions do not always lead to good behaviors. Here, this study uses empirical analysis to test the comprehensive effect of green technological innovation on CO_2 emissions and to judge whether China's green technological innovation has achieved its goal of energy saving and emission reduction.

Regarding the influence of technological innovation and other factors on carbon emissions, scholars have conducted much research, mainly focusing on the following three aspects. The first one is focused on the relationship between technological innovation and CO_2 emissions. Sun et al. (2010) used the Laspeyres index decomposition method to analyze the influencing factors of carbon emissions and found that the increase in GDP was the main driving force, and technological progress was the main reason for the reduction in carbon emissions. Suki et al. (2022) found that, on the one hand, endogenous technological progress increases carbon emissions through economic scale effects, but on the other hand, it reduces CO_2 emissions through efficiency improvements. The overall environmental effects of technologies are uncertain in the short term. In addition, Erdoğan S, (2020) investigated the impact of innovation on CO_2 emissions based on the sectors for fourteen countries in the G20. The results showed that the carbon emissions in several sectors, such as energy sector, and transport sector is not significantly influenced by technology innovation in the long run. Ang (2009) found that technological innovation can curb CO_2 emissions. Meanwhile, Carrión-Flores et al. (2013) analyzed the impact of technological innovation on polluting gases in 127 manufacturing industries and found that there is a two-way causal relationship between technological innovation and polluting gases. However, some studies drew opposite conclusions. For example, Shen (2012) built technological progress on the basis of the endogenous growth model of Aghion and Howitt (1992). They showed that the degree of technological progress is not enough to achieve both economic growth and the dual goal of reducing CO_2 emissions. Similarly, Tobelmann and Wendler (2020) used data from the 27 EU countries and showed that environmental innovation can help reduce CO_2 emissions, while general innovation activities will not lead to a reduction in emissions.

The second one is focused on the timing difference of the impact of technological progress on carbon dioxide emissions. Li KJ (2012) used the vector error correction model to analyze the relationship between technological progress and carbon emissions and found that technological progress can reduce CO_2 emissions in the long run, but the short-term effect is not obvious. Similarly Shao and Zhong (2021b) found the negative and significant impact of green technology innovation with carbon emission in the long run in N-11 countries, but the short-run association of green technology innovation is not significant. Zhang W (2014) reached similar conclusions. They found that technological progress at different development stages has different effects on CO_2 emissions. Guan and Chen (2010) suggest that technological progress is the key to addressing climate change. Their research found that under the effect of technological progress, China's carbon emissions over time present three inverted U-shaped curves, and the driving factors of each stage are different.

The third focus of attention is the spatial difference in the impact of technological progress on carbon dioxide emissions. Research by many scholars found that ordinary panel data does not consider the possible spatial effects of CO_2 emissions, which is unreasonable. Therefore, some scholars have realized the importance of spatial correlation and heterogeneity on the research of carbon emission factors and have begun to use spatial measurement models for empirical testing (Hao et al., 2021; He and Zhang et al., 2021). Auffhammer and Carson (2008) used a spatial measurement model to predict China's carbon dioxide emissions and found that introducing a spatially dependent regression model makes the prediction more reliable. Gu and Chu (2020) discovered that technological innovation has spatial spillovers, and regional carbon emission intensity has an obvious spatial correlation.

On the whole, technological innovation is an important factor influencing carbon dioxide emissions, but related research mainly focused on the impact of technological innovation on CO_2 emissions, and few studies consider the impact on CO_2 emissions from the perspective of green technology innovation with the goal of energy saving and emission reduction. In addition, scholarly evidence on the association between green technology and carbon emissions are mixed and even contradictory because of the different scenarios. Also, most existing research ignores the spatial correlation between neighboring units and lacks spatial panel data analysis. In response to the abovementioned problems, this study extends previous research in three ways. First, the effect of green technology innovation on carbon emissions is investigated. Second, because of potential spatial correlations in carbon emissions, we analyze the spatial effect of this influence by using appropriate econometric models. Third, because the effect of green tech innovation on carbon emissions varies with the level of economic development, this study explores the impact of the former from multiple perspectives across China and the eastern, central, and western sub-regions. In summary, we use China's provincial panel data from 2006 to 2019 to analyze the temporal and spatial characteristics of CO_2 emissions and examine whether green technological innovation has played an environmentally friendly role. It helps us to have a comprehensive understanding of the influencing factors behind the evolution in China's CO_2 emissions.

2 THEORETICAL BACKGROUND AND METHODS

2.1 Theoretical Base

Most scholars use the IPAT model, the STIRPAT model, and the Kaya model for research to explore the relationship between human activities and carbon emissions, and **Figure 1** shows the relationship between human activities and carbon emissions (York et al., 2003). With accelerating urbanization and industrialization, rapid population growth and economic development may consume more energy and emit more environmental pollutants. However, with the development of technology and the economy, the impact of human activities on the environment may be mitigated. That is, environmental issues (I) are the result of the combined effects of the three key factors: population (P), affluence (A), and technology (T).

However, due to the irrationality of the same proportional changes among its variables, York et al. (2003) constructed the STIRPAT model based on the IPAT model, which can more reasonably analyze the non-proportional impact of human activities on the environment. Based on the STIRPAT model, this paper takes CO_2 emissions as the explanatory variable and green technology innovation level as an explanatory variable, and establishes a spatial panel measurement model to analyze the relationship between the two. In addition to technological innovation, many of previous studies have explored other drivers affecting carbon emissions. And some factors have been widely accepted, such as energy consumption structure (Dong et al., 2016), industry structure (Wang et al., 2016; Cheng et al., 2018), economic level (Huang, 2018; Shao and Zhong, 2021a), population (Zhang and Tan, 2016). Therefore, we introduce four control variables (economic level, population, industry structure, and energy consumption structure).

2.2 Calculating Carbon Emissions

Since carbon dioxide is mainly produced by fossil fuel combustion and cement production, we draw on the practice of most scholars, such as Wu ZX (2014) and Zhang W (2014), to calculate the CO_2 emissions from fossil fuel combustion and cement production.

First, we adopt the methods recommended by the IPCC to estimate carbon emissions from the burning of fossil fuels. The computing method is as follows:

$$EC_t = \sum_{j=1}^{8} E_{jt} \times NCV_j \times CEF_j \times COF_j \tag{1}$$

Here, CO_t represents the provincial carbon emissions produced by types of energy consumption at year t; E_j stands for the total energy consumption of type j at year t; according to the

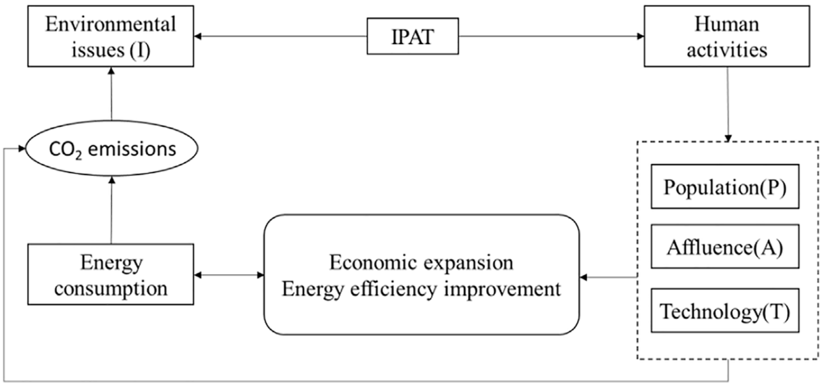

FIGURE 1 | Human activities and carbon emissions.

TABLE 1 | Net heating value and carbon emissions factor of every energy source.

	Coal	Coke	Gasoline	Kerosene	Diesel oil	Fuel oil	Natural gas
NCV_j	20908	28435	43070	43070	42652	41816	38931
CEF_j	95333	107000	69300	71500	74100	77400	56100

classification of the final energy consumption by the China Energy Statistical Yearbook, we know there are coal, coke, gasoline, kerosene, dieseluel oil, natural gas, and electricity. However, electricity is produced by other energy, so in order to avoid double-counting, we did not calculate carbon emissions that come from electricity. NCV_j stands for the net heating value(unit: KJ/kg or KJ/m^3) according to the China Energy Statistical Yearbook. CEF_j is carbon emissions factor (unit: kg/TJ or m^3/TJ); COF_j is energy carbon oxidation factor; furthermore, both CEF_j and COF_j are from IPCC (2006), shown in **Table 1**.

Second, regarding the CO_2 emissions in the cement production process, the calculation formula is:

$$CC_t = Q_t \times \partial \tag{2}$$

Here, CC_t represents the CO_2 emissions during the cement production process of the province in year t; Q_t represents the total cement production of the province in year t; ∂ represents the CO_2 emission coefficient of cement production, referring to Du (2010), with a value of $0.5270t\ CO_2/t$.

Therefore, the formula for calculating the total carbon dioxide emissions of China's 30 provinces from 2006 to 2019 is:

$$CO_{2t} = EC_t + CC_t \tag{3}$$

2.3 Green Technological Innovation Efficiency Measurement

Green technological innovation (GI) is an intangible variable and cannot be directly measured. Based on the difference in understanding of the connotation of green technology innovation, there are mainly three measurement methods. The first is the direct measurement of innovation achievements, which uses a single indicator of green technology patents to measure the green technology innovation (Jia J, 2014). The second is the factor analysis method, which builds an indicator system based on innovation output to evaluate the regional green technology innovation level (Wang, 2012). The third is based on the efficiency measurement method of green innovation input and output using the parametric method represented by stochastic frontier analysis (SFA) and the non-parametric method represented by data envelopment analysis (DEA) to measure the efficiency of green technology innovation. Thus, the efficiency of green technological innovation is used to characterize the green technological innovation (Guan and Chen, 2010). Efficiency is a relative indicator. Compared with direct output indicators, the level of efficiency can better reflect the innovation level of a region. Therefore, this paper uses the efficiency of green technology innovation to measure the green technology innovation of each province and uses the input-oriented DEA method to measure the efficiency of green technology innovation. The green technology innovation efficiency measurement indicators are selected as follows:

Two indicators of innovation investment are selected as R&D expenditure and the full-time equivalent of R&D personnel, which are, respectively, used as capital investment and human investment. The expected output indicators select the sales revenue of new products as the economic benefit and the number of patent authorizations as the innovation benefit, and the comprehensive utilization rate of solid waste and the harmless treatment rate of domestic garbage as the environmental benefits. Unexpected output mainly refers to environmental benefits, and the discharge of wastewater, waste gas, and solid waste in various regions is selected. Since the undesired output is a negative output, the environmental indicators are taken as the input part for measurement.

In addition, the measurement of several control variables is described as below. Energy consumption structure (*ES*) is measured by the proportion of the province's coal consumption in total energy consumption. Additionally, economic level (*GDP*) is measured by per capita GDP. Population (*P*) is measured by the province's proportion of the national population. The industrial structure (*IS*) is measured by the proportion of the output value of the secondary industry in the total output value of the province.

2.4 The Spatial Panel Models

According to the Geographic First Law, a spatial link exists between any two things, and the factors in different areas are spatial heterogeneity and spatial correlation. If we do not consider the space effect while building a model, there will be an estimation error. Thus, based on the improved STIRPAT model, we set up the following three spatial panel models to estimate the effects of green technology innovation on carbon emissions.

If there is an endogenous interaction effect between carbon dioxide emissions, that is, the carbon dioxide emissions of the local area depend on the carbon dioxide emissions of neighboring areas in some way, then the spatial lag panel data model (SLPDM) needs to be used:

$$\begin{aligned}\ln CO_{2it} &= \partial + \rho \sum_{j=1}^{N} w_{ij} CO_{2it} + \beta \ln GI_{it} + \gamma_1 \ln ES_{it} + \gamma_2 \ln GDP_{it} \\ &+ \gamma_3 \ln P_{it} + \gamma_4 \ln IS_{it} + \mu_i + \nu_t + \varepsilon_{it}\end{aligned} \tag{4}$$

where i is the different provinces of the cross-section (i = 1,2, . . . ,30), and t is the time series of the study (t = 1,2, . . . ,14). w_{ij} is an element of spatial weight matrix, and we used adjacency matrix to build the spatial weight matrix. We standardized the matrix at the same time.

The dependent variable CO_{2it} is identified as CO_2 emissions(tco_2), and the core interpretation variable GI_{it} is the efficiency of green technology innovation. The control variables (ES_{it}、GDP_{it}、P_{it}、IS_{it}) are defined as above. β is the coefficient of the control variable. ∂ is the constant term. ρ is the spatial lag coefficient, which reflects the influence degree of the observed value of adjacent region on the observed value of local region. Additionally, μ_i stands for the spatial effect. ν_t stands for the time effect. ε_{it} is the stochastic error, and $\varepsilon it \sim i.i.d\ (0,\sigma^2)$.

If the emissions in this area are to some extent impacted by the emissions errors in neighboring areas, the spatial error panel data model (SEPDM) needs to be used:

$$\begin{aligned}\ln CO_{2it} &= \partial + \beta \ln GI_{it} + \gamma_1 \ln ES_{it} + \gamma_2 \ln GDP_{it} + \gamma_3 \ln P_{it} \\ &+ \gamma_4 \ln IS_{it} + \phi_{it} \\ \phi_{it} &= \lambda \sum_{j=1}^{N} w_{ij} \phi_{2it} + \varepsilon_{it}\end{aligned} \tag{5}$$

Here, ϕit is the error term of spatial autocorrelation. λ is the coefficient of spatial error.

In addition to the spatial spillover effect and related error terms of emissions in adjacent regions, if exogenous interaction effects exist, that is, explanatory variables in adjacent regions also have an impact on regional emissions, the spatial Durbin panel data model (SDPDM) needs to be used:

$$\begin{aligned}\ln CO_{2it} &= \rho \sum_{j=1}^{N} w_{ij} \ln CO_{2it} + \beta_1 \ln GI_{it} + \beta_2 \ln ES_{it} + \beta_3 \ln GDP_{it} \\ &+ \beta_4 \ln P_{it} + \beta_5 \ln IS_{it} + \eta_1 \sum_{j=1}^{N} w_{ij} \ln GI_{it} \\ &+ \eta_2 \sum_{j=1}^{N} w_{ij} \ln ES_{it} + \eta_3 \sum_{j=1}^{N} w_{ij} \ln GDP_{it} \\ &+ \eta_4 \sum_{j=1}^{N} w_{ij} \ln P_{it} + \eta_5 \sum_{j=1}^{N} w_{ij} \ln IS_{it} + \mu_i + \nu_i + \varepsilon_{it}\end{aligned} \tag{6}$$

Here: $\sum_{j=1}^{N} w_{ij} \ln GI_{it}$, $\sum_{j=1}^{N} w_{ij} \ln ES_{it}$, $\sum_{j=1}^{N} w_{ij} \ln GDP_{it}$, $\sum_{j=1}^{N} w_{ij} \ln P_{it}$, and $\sum_{j=1}^{N} w_{ij} \ln IS_{it}$ stand for spatial lag term of adjacent region's interpretation variables; $\beta_1 - \beta_4$ and η1 −η4 are the regression coefficients. The null hypothesis H0: η+ρβ = 0 can be used to test whether the model can be reduced to a spatial error model or the null hypothesis H0: η = 0 can be used to test whether the model can be reduced to a spatial lag model (YM, 2014; Belotti et al., 2017).

According to the research of Elhorst (2003), Elhorst (2014), it is necessary, first, to determine whether there is a spatial effect for the estimation of the spatial panel model; second, to select the type of model (SLPDM or SEPDM); and finally, to determine the individual effect or the period effect (fixed effect or random effect). Specifically, we use Morans' I test method for the spatial correlation test. Additionally, we use LM spatial lag, LM spatial error, Robust LM spatial lag, and Robust LM spatial error test methods to determine which model to use. In addition, we use Wald and likelihood ratio LR test to judge whether SDPDM can be simplified to SLPDM or SEPDM, and the Hausman test method is used to determine fixed effects or random effects.

2.5 Data Source

This paper selects a balanced panel dataset of 30 provinces in China over the period 2006–2019 (Hong Kong, Macao, Taiwan, and Tibet are not included due to lack of data). Because of 2006 is the first year of the Twelfth Five-Year Plan for national economic and social development of the People's Republic of China, we began to select sample data in 2006. In 2020, due to the epidemic, many companies and factories in China suspend work and production, which may affect the data indicators greatly. Therefore, this paper does not collect sample data for 2020 in order to avoid interference with research issues. Additionally, in the empirical process, the original data are processed by natural logarithm to eliminate the instability and heteroscedasticity of the data. The original data are derived from the China Statistical Yearbook, the China Energy Statistical

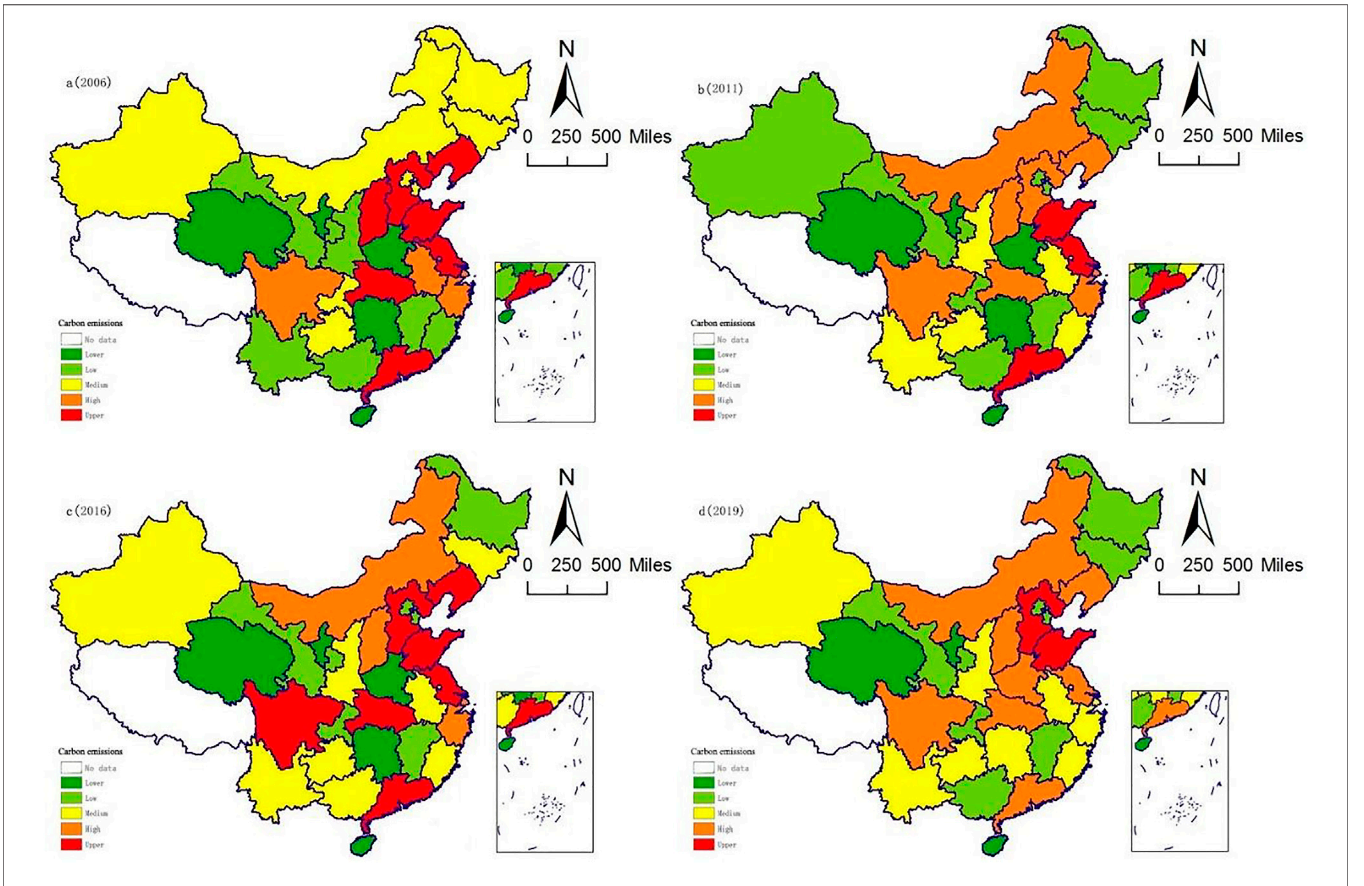

FIGURE 2 | Spatial distribution for 30 provinces in China between 2006 and 2019.

Yearbook, the China Environment Statistical Yearbook, and statistical yearbook of every province and IPCC, etc. We used sample interpolation method to supplement the missing values in some variables.

3 SPATIAL PATTERN OF CARBON EMISSIONS AND THEIR EVOLUTION

3.1 Evolution of Carbon Emission Types in China

To explore the distribution regularity of China's carbon emissions from time and space perspective, the provincial carbon emissions were divided into four grades by natural fracture method in this study: low carbon emissions, medium carbon emissions, high carbon emissions, and upper carbon emissions (**Figure 2**). According to the spatial distribution for 30 provinces, high carbon emission areas are mainly concentrated in the eastern and central areas. Over the period 2006–2019, the number of high carbon emissions reduced initially but then increased, and the high carbon emissions areas spread from the east to the middle. The medium-carbon emission regions gradually developed into the medium-high carbon emission type. Thus, the number of provinces of this type is decreasing year by year. Additionally, the number of low carbon emission provinces remains unchanged. On the whole, it has formed a pattern in which there are many provinces with high and medium-high carbon emissions, while provinces with medium and low carbon emissions are few, and there is a trend of shifting from the low carbon emission type to the high carbon emission type.

3.2 Three-Dimensional Trend Characteristics of Carbon Emissions

To reveal the overall spatial trend of China's carbon emissions, we conducted a trend analysis of China's carbon emissions to obtain a three-dimensional perspective based on the spatial coordinates and CO_2 emissions of each province, shown in **Figure 3**. The *X*-axis direction indicates the east–west direction, the *Y*-axis direction indicates the north–south direction, and the *Z*-axis indicates the amount of carbon emissions. Each vertical line in the figure represents the location of each province and its carbon emissions. All vertical lines are projected on the east–west and north–south orthogonal planes to obtain the projection point. We obtain the best-fitting curve through the projection point, which reflects the upward trend of CO_2 emissions from east to west and north to south.

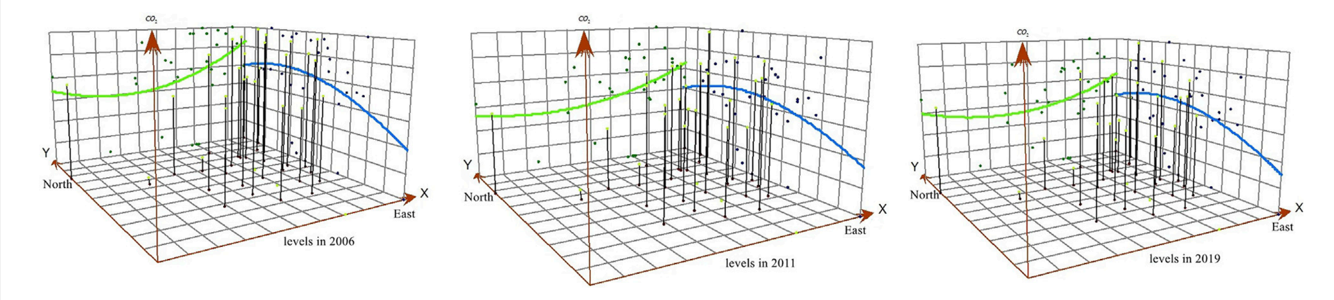

FIGURE 3 | Trend analysis of carbon emissions in China between 2006 and 2019.

TABLE 2 | Moran's I test results of provincial carbon emissions between 2006 and 2019.

	2006	2008	2010	2012	2014	2018	2019
Moran's I	0.3221	0.3250	0.3371	0.3435	0.3410	0.3351	0.3359
p-value	0.002	0.003	0.001	0.002	0.000	0.002	0.001

Specifically, from China's 2006 carbon emission fitting curve, we can find that CO_2 emissions increase in a curve from west to east, and in the north–south direction, the central part is larger than the northern part and the southern part. From the shape of the fitted curve, we can observe that the east–west projection line is approximately a straight line, while the north–south projection line is an inverted U-shaped curve. This means that, relatively speaking, the difference in carbon emissions between the northern and southern provinces is greater than the difference between the east and the west. From the perspective of time evolution, the fitting curve of China's carbon emissions in 2011 still showed a linear and slow growth trend from west to east. In the north–south direction, the central part is still larger than the northern part and larger than the southern part. However, compared with 2006, the east–west gap and the north–south gap has shown a narrowing trend. Judging from the fitting curve of CO_2 emissions in 2019, the spatial distribution of China's inter-provincial CO_2 emissions is similar to before. This shows that carbon emissions from 2006 to 2019 have a stable trend of being high in the east and low in the west, and high in the north and low in the south.

An obvious path dependence exists in China's massive economy according to the stable spatial situation of carbon emissions. That is, if the region chooses a development path, then various economic activities in the region will adapt to this model in the longer development process. A strong exogenous shock is needed to change this development path in the short term. Therefore, if high-emission areas want to reduce carbon emissions and develop a green economy, the government should introduce strong regional economic policies. At the same time, the spatial differences in carbon emissions also indicate that China's energy conservation and emission-reduction measures must take regional differences into account.

4 EMPIRICAL RESULTS AND DISCUSSIONS

4.1 Spatial Correlation Test of Carbon Emissions

It is necessary to determine whether there is a spatial effect before using the spatial panel model. Based on the spatial weight matrix, we calculated the spatial correlation Moran'I index value of the provincial carbon emissions during 2006–2019, shown in **Table 2**. The results show that the Moran's I smoothly remain at around 0.33 between 2006 and 2019, and the significance level is still less than 5%. Thus, we can conclude that there are significant positive spatial correlations between provincial CO_2 emissions. That is, provinces with higher CO_2 emissions and provinces with lower CO_2 emissions tend to be close. Therefore, we need to consider spatial correlations when building a model.

4.2 Spatial Panel Model Estimation

We use MATLAB 2012a software to estimate models (4)–(6). First, we use the LMlag and LMerr and Robust LMlag and Robust LMerr tests to determine whether to use the spatial error model or the spatial lag model. The estimation results of the standard panel model (**Table 3**) show that the LM and Robust LM tests of the spatial lag panel model passed the 1% level of significance test and that the Robust LM of the spatial error panel model failed the 1% level of significance test. Therefore, the spatial lag panel model is better than the spatial error model. Second, the LR value of time-fixed effects was 122.0832 (p = 0.0000), and the LR value of individual fixed effects was 693.2063 (p = 0.0000). This indicates that the model has a double fixed effect of individual and period. Based on the above results, considering that the log-likelihood value of the individual fixed-effects model LogL is 225.4033, and the goodness of fit is relatively high (0.8575), we believe that it is more reasonable to use the individual fixed-effects spatial lag regression model (LeSage and pace, 2010).

Thirdly, we need to decide whether to use a random-effects model or a fixed-effects model. Since the Hausman test result was 10.0792 (p = 0.7183), it failed the 5% significance test and accepted the assumption that the spatial effect does not involve the explanatory variables. It means that the random-effects model is preferable (Elhorst, 2010). Finally, we use the

TABLE 3 | Standard panel estimation results of provincial carbon emissions.

Variables	No fixed effects	Spatial-fixed effects	Time-fixed effects	Spatial- and time-fixed effects
i	1.1657 (3.0024)***			
lnGI	–0.3123 (–5.1723)	–0.0714 (–2.6240)***	–0.2311 (–5.1944)***	–0.0389 (–1.4202)
lnES	0.0102 (0.8174)***	–0.0176 (–0.6944)	0.2072 (6.0658)***	0.1579 (6.5259)
lnGDP	0.5474 (22.0912)	0.6083 (35.3643)***	0.5136 (17.5249)***	0.2010 (3.2758)
lnIS	0.4687 (5.3576)***	0.6334 (5.7928)***	0.4039 (4.6275)***	0.5961 (5.65929)
lnP	0.6931 (35.0016)***	0.3498 (2.0124)**	0.7102 (37.0027)***	0.2417 (1.3843)
R^2	0.8652	0.8575	0.8126	0.2493
LogL	–81.0278	225.4033	–65.0761	279.9320
DW	1.0257	1.9918	1.4021	2.1995
LM test no spatial lag	7.5104***	12.9421***	10.8733***	9.1129***
Robust LM test no spatial lag	1.7687***	34.9780***	4.9654**	3.5681**
LM test no spatial error	11.1702***	0.0105	7.9018***	6.5121***
Robust LM test no spatial error	5.5070***	22.1029***	1.8973	0.8394

Notes*: The figures in brackets are* t *values. *, **, and *** stand for the significance levels of 10, 5, and 1%, respectively.*

TABLE 4 | SPDM estimation results of national/provincial carbon emissions.

	SLPDM		SDPDM
Variables	No fixed effects	Spatial-fixed effects	Random spatial effects of the SDPDM
lnGI	–0.0740 (–2.1808)**	–0.0712 (–2.3112)**	–0.0611(–0.7035)*
lnES	–0.0008 (–0.1203)	0.1332 (5.4575)***	0.1703 (6.80413)***
lnGDP	0.4270 (12.6951)***	0.2614 (4.5127)***	0.2418 (4.1310)***
lnIS	0.5975 (5.8219)***	0.7132 (6.6017)***	0.6701 (6.9043)***
lnP	0.2043 (1.1641)	0.1915 (0.9719)	0.5937 (9.214)***
W*lnGI		0.0633 (1.3162)	0.1896 (3.5312)***
W*lnES		–0.2136 (–5.8612)***	–0.0096 (–0.2564)
W*lnGDP		0.1713 (2.6809)***	–0.0531 (–0.4701)
W*lnIS		0.5501 (2.7140)***	–0.1727 (0.7038)*
W*lnP		0.6739 (1.5327)*	0.1837 (1.3326)*
W*dep.var	0.1593 (3.180350)***	0.0636 (1.0328)	–0.1713 (–2.8212)***
teta			0.1603 (5.4971)***
R2	0.9774	0.9801	0.9618
LogL	228.0837	259.2831	213.0713
Hausman_p		10.0792	

Notes*: The figures in brackets are* t *values. *, **, and *** stand for the significance levels of 10, 5, and 1%, respectively.*

Wald test and LR test of random effects to determine whether the spatial Doberman model can be simplified to a spatial lag model or a spatial error model. The results show that the values of the Wald_spatial_lag and LR_spatial_lag are 15.2712 (p = 0.001) and 13.9613 (p = 0.001)); the values of the Wald_spatial_error and LR_spatial_error are 14.2971 (p = 0.0210) and 13.3089 (p = 0.0015), respectively. Both Wald and LR tests pass the 5% significance test, indicating that the spatial Durbin model cannot be reduced to a spatial lag model or a spatial error model. Therefore, we chose the random-effect spatial Dubin model to analyze the impact of green technology innovation on carbon emissions.

From the random-effect spatial Dubin model estimation results (**Table 4**), it can be seen that the elasticity coefficient of national green technology innovation is significantly negative, which negates the view that green technology innovation has a dual impact on carbon emissions from the beginning of this paper. This shows that the current level of China's overall green technology innovation has a direct effect on carbon emissions greater than the scale effect. That is, the improvement of green technology innovation can reduce carbon emissions. However, we found that the effect of green technological innovation on reducing carbon emissions is not obvious. This may be because China's extensive economic growth has caused a substantial increase in carbon dioxide emissions, and the industrial structure dominated by the secondary industry and the energy consumption structure dominated by coal are not conducive to reducing carbon dioxide emissions. Since the reform and opening, the focus of China's technological innovation has been to increase productivity and expand the scale of the economy. Therefore, the emphasis on green technology innovation is insufficient, which has led to a relatively low level of overall green technology innovation. It can be seen that the improvement of technology plays a very limited role in reducing carbon emissions, and the final result is a continuous increase in carbon emissions.

In addition, it can be found that the elasticity coefficients of the control variables, such as industrial structure, economic growth, energy consumption structure, and population, are all positive values, which means that the control variables all have a positive effect on carbon emissions. The possible reason is that the secondary industry is the main sector of energy consumption, and high energy consumption and high emissions are still the main characteristics of China's industry. Therefore, secondary industry has become the main production sector of carbon dioxide. However, during the period 2006–2019, the proportion of the output value of the secondary industry in GDP dropped from 49.7 to 39.1%, and the tertiary industry rose from 38.9 to 53.7% (NBSC, 2007-2020a). Thus, the industrial structure has been significantly optimized. Although in the short term, the optimization and upgrading of the industrial structure cannot reduce carbon dioxide emissions immediately, in the long run, adjusting the industrial structure and gradually reducing the excessive dependence of economic development on the secondary industry is an important measure to reduce carbon emissions. In addition, the coefficient of energy consumption structure is significantly positive, which indicates that the current energy structure does not play a positive role in reducing carbon emissions. During 2006–2019, the proportion of coal in primary energy consumption remained stable between 65 and 70% (NBSC, 2007-2020b). Although the proportion of coal consumption has declined, the energy structure dominated by coal is still the basic feature of China's energy consumption. Such an energy consumption structure still promotes CO_2 reduction. The coefficient of the population is significantly positive, which shows that the population has a promoting effect on carbon emissions. Similarly, economic levels also have a positive effect on carbon emissions.

Among the interaction terms of each explanatory variable and the explained variable, green technology innovation in the neighboring area has a positive effect on the increase in carbon emissions in the region according to the results of the random effects space Dubin panel model. It shows that when the efficiency of green technology innovation in neighboring areas increases, it will promote the increase in CO_2 emissions in the focused region. This may be because the improvement of the efficiency of green technology innovation in the neighboring area will give the region a comparative advantage in certain industries. Thereby, neighboring will attract advantageous resources of these industries in the focused region, which in turn promotes the improvement of green technology innovation in the neighboring region. Eventually, the region's investment in these industries will shrink, technological innovation efficiency will decline, and carbon dioxide emissions will increase.

Furthermore, the industrial structure has a negative effect on the increase in carbon emissions in the region. This may be because the development and growth of the secondary industry in the neighboring areas prompt the agglomeration of resource-based industries in the neighboring areas. Additionally, the high-energy-consuming industries in the region are gradually shifting to neighboring areas. Thus, the industrial structure shows a negative spillover effect. At the same time, the population also shows a negative spatial spillover effect. The spatial effect of energy consumption structure and economic level on carbon emissions is not statistically significant.

TABLE 5 | SLPDM estimation results of the eastern, central, and western carbon emissions.

Variables	Eastern region	Central region	Western region
	Time-fixed effects	Time-fixed effects	Time-fixed effects
lnGI	−0.5675***	−0.2064***	0.0037*
lnES	0.0441	0.4970***	0.1733***
lnGDP	0.4816***	1.0635***	0.4795***
lnIS	0.6448***	0.9635***	2.1132***
lnP	0.5825***	0.5470***	0.8919***
W*lnGI	−0.1325		0.2702
W*lnES	0.0522***		0.1335*
W*lnGDP	0.4045***		−0.1371**
W*lnIS	0.7918***		−0.3960*
W*lnP	−0.1518***		−0.3462

4.3 Analysis of Regional Results

An empirical test of the national provinces suggests that green technology innovation for carbon emissions is negative; namely, innovative efficiency can reduce carbon dioxide emissions. Given the large differences in regional economic level and industrial structure, this paper does further sub-regional research on the impact of green technology innovation in carbon emissions. The selection criteria of the sub-regional spatial panel model are consistent with the national study of the province. **Table 5** shows the estimation results of the eastern, middle, and western panel models.

Table 5 shows the elastic coefficient of regional green technology innovation level to carbon emissions. The elastic coefficient is, respectively, −0.5675 in the east, −0.2064 in the middle region, and 0.0037 in the west. Obviously, it is negative in the east and middle and positive in the west. That is to say, both in the east and middle region, the improvement of green technology innovation efficiency can reduce CO_2 release, and innovation in the eastern region has the most obvious effect on carbon emission reduction. This result was not as expected, and the possible reasons might be as follows.

The eastern region has absorbed foreign advanced technology relatively early and has a developed economy. Therefore, it has the necessary capital and talents for green technology innovation. The eastern region has become China's main low-carbon-technology innovation area. Due to the pressure of economic development in the central and western regions, the government often sets lower environmental protection standards to prioritize economic development. Additionally, the degree of environmental regulation and investment in green technology innovation is naturally weaker than those in the eastern region.

Due to the early transformation of the economic structure, the eastern region closed down and transferred some high-energy and high-emission enterprises (Wang and Xiong et al., 2021), and they continued to introduce international environmental protection technologies to enhance the ability of green technology innovation. Moreover, the eastern region attaches great importance to the development of environmentally friendly products to meet the demand for green products in foreign trade. For the central region, most production still relies on traditional technology, and its technological innovation is mainly focused on increasing productivity. Furthermore, the improvement of green technology is slightly insufficient. Therefore, the effect of green technology innovation in the central region on carbon emission reduction is not as good as that in the eastern region. The western region takes development as its main task. The western region has not paid enough attention to green technological innovation and ecological civilization construction, which are conducive to long-term development. Additionally, the industrial structure of the western region is dominated by the energy industry. In high-energy-consuming industries, technological innovation may have an energy-rebound effect in the short term. That is to say, although green technological innovation can improve energy efficiency and save resources, the improvement of energy efficiency will reduce the production cost and price of products, which will promote product consumption and production. Thus, it will lead to a further increase in energy demand. From this point of view, the final result is that the reduction effect of green technological innovation on CO_2 emissions is not enough to offset the increased effect of additional energy consumption on carbon dioxide emissions in the western region. Therefore, it is not surprising that the efficiency of green technology innovation has increased carbon dioxide emissions in the western region.

From the perspective of the characteristics of technological innovation, due to the location-locking effect of innovation, innovation capability itself also depends on the original innovation capability. After the continuous accumulation of technological innovation in the eastern region, it is easier to form a technological innovation center. In addition, technological innovation has the characteristics of exclusivity and competitiveness, so the eastern region will not be easily transferred as a technological innovation center. In addition, technological innovation has the characteristics of exclusivity and competitiveness, so the eastern region will not easily transfer as a technological innovation center. Naturally, the green technological innovation capabilities of the central and western regions are far weaker than those of the eastern region, and their green technology innovation in reducing CO_2 emissions is also far weaker than that of the eastern region.

5 DISCUSSION

Based on the STIRPAT model, this study confirms that green technology innovation is an effective means of reducing carbon emissions. Additionally, for regions at different stages of economic development, green technological innovation has different effects in reducing carbon emissions. Specific conclusions of this study are presented below.

The empirical results show that the spatial pattern of China's inter-provincial carbon emissions is relatively stable. It shows obvious regional characteristics of being high in the east and north and of being low in the west and south from the spatial perspective. Moreover, the gaps between the east and the west and between the south and the north tend to narrow. From the timing point of view, during the period 2006–2019, the number of high-carbon emission provinces decreased first and then increased, the medium-high carbon emission provinces gradually increased, and the medium carbon emission provinces decreased year by year, while the number of low carbon emission provinces was relatively stable. Therefore, the overall trend is to shift from low carbon emissions to high carbon emissions. The stable state of this spatial trend reflects the obvious path-dependence characteristics of China's regional economy.

Furthermore, the direct effect of green technology innovation in China's 30 provinces (autonomous regions and municipalities) from 2006 to 2019 on carbon dioxide emissions is greater than the scale effect. Therefore, the overall effect is that the improvement of green technology innovation can help reduce carbon emissions, but the effect is not significant. Control variables, such as industrial structure, energy consumption structure, per capita GDP, and population, all have a significant positive role in promoting CO_2 emissions. However, due to the large differences in regional development in China, there are significant regional differences in the impact of green technological innovation on CO_2 emissions. Specifically, the improvement of green technology innovation in the eastern and central regions helps to reduce CO_2 emissions, and the degree of influence in the eastern region is higher than that in the central region. However, improvements in green technology innovation in the western region will increase carbon dioxide emissions.

At the same time, China's inter-provincial carbon dioxide emissions have a strong spatial spillover effect. The carbon emissions in this region not only are related to their own factors but also are affected by the factors of neighboring regions. Specifically, the green technological innovation and the improvement of the industrial structure in the neighboring regions have a depressing effect on the carbon emissions of the region. However, the population has a positive role in promoting carbon emissions in the region. The impact of energy consumption structure and economic level is not statistically significant.

Based on the analysis results, this study emphasized the policies related to carbon emission reduction from several aspects. For instance, the present study fully highlights the need for green technology innovations to reduce CO_2 emissions in China. Since economic development and energy consumption in western China, carbon emissions are not reduced adequately in despite of energy savings through green technology innovation. In western China, subsidies need to be given to encourage green technology innovation. Taking the spatial spillover effect of carbon emissions into account, it is necessary to establish a regional carbon-emission-reduction linkage mechanism and to conduct cross-regional governance of carbon emission reduction.

Although this paper investigates the spatial correlation of the factors influencing carbon emissions in China, there are still significant shortcomings. First, the construction of a green technology innovation-level calculation system is not comprehensive enough to consider more specific green innovation outputs and more undesired outputs. Also, this research has observed the general background of green technology innovation without specific divisions of it to understand better which type of innovation is more conducive to reducing China's carbon emissions. However, the current data are not sufficiently comprehensive, and the amount of publicly available data cannot yet support the establishment of a more comprehensive green technology innovation measurement system, so other methods are not used in this paper at this time. In addition, this research is only exploring the impact of green technology innovation on carbon emissions from the perspective of the region as a whole, while ignoring the impact between sectors, such as transportation sector. A detailed interpretation of the data is needed in subsequent studies.

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

LC and SZ led the conceptual design of the manuscript, AC wrote the initial drafts, HY and UC advised the data model and all authors reviewed the manuscript and provided comments and feedback.

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Artificial Intelligence Influences Intelligent Automation in Tourism: A Mediating Role of Internet of Things and Environmental, Social, and Governance Investment

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Intelligent automation in travel and tourism is likely to grow in the future, which is possible due to advances in artificial intelligence (AI) and associated technologies. Intelligent automation in tourism is a socio-economic activity, which needs an explanation of theory and practice. The study objective is to know the predictive relationship between AI and intelligent automation in tourism with mediating role of the internet of things (IoT), sustainability, facilitating adoption, and environmental, social, and governance (ESG) investment. Designing valuable AI, promoting adoption, analyzing the implications of intelligent automation, and establishing a sustainable future with artificial intelligence are the fundamental constructs of this study. Research in these areas enables a systematic knowledge creation that shows a concentrated effort on the part of the scientific community to ensure the positive uses of intelligent automation in the tourist industry. A quantitative research approach was used to collect and analyze data. A purposive sampling technique was applied, and data were collected from four hundred two ($N = 402$) respondents. The results revealed that AI has a predictive relationship with intelligent automated tourism. Similarly, IoT, sustainability, facilitating adoption, and ESG have influenced tourism. As a conclusion, AI design can improve tourism department if the intelligent automated framework was applied to it.

Keywords: artificial intelligence, automation, tourism, internet of things, ESG investment

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INTRODUCTION

The focus is on artificial intelligence and intelligent automation in tourism. Defining, visualizing, designing, and delivering artificial intelligence (AI) solutions to the travel and tourist business needs proper critical evaluation impossible with intelligent automation (Zhao et al., 2011). AI knows which type of systems can be reliable for the tourism sector and how they could be constructed for future tourists. The problem is that AI systems need high resources and concentration to sustain the structure. For this reason, an intelligent automated system could be developed to improve the tourism sector. There has been an increased recognition that more attention needs to be paid to AI, the internet of things, environmental, social, and governance (ESG), sustainability, adoption, and intelligent automation in the tourism sector. In recent years, AI technology has emerged as a desirable domain for tourism. An understanding of artificial intelligence automation may prove essential in recognizing tourism experiences and tourist observations in the future. The study explains the cause-and-effect relationship of new artificial intelligence technologies. It is a projective influence on intelligent automation tourism, which can sustain ESG criteria—identifying how intelligent automation might improve tourists' knowledge and visitor's trip with the artificial intelligence automated framework. This method attempts to bypass some of the common problems faced by tourists in the past.

A slightly more advanced method has been proposed with the help of artificial intelligence automation, and it may improve the tourism departments and their client's enthusiasm toward trips and travel (Yue et al., 2012). The combination of artificial intelligence is crucial to constructing intelligent automated technologies for the future sustainability of tourism. Multidisciplinary perspectives are working in tourism and its relationship with AI automation, such as psychology, anthropology, behavioral science, business studies, and human–computer interaction (HCI), as well as design research methodologies such as cybernetic thinking (Martelaro and Ju, 2018; Tuomi et al., 2019), speculation technique (Wong, 2018), prototyping (van Allen, 2018), ESG factors for travel and tourism industry (Ionescu et al., 2019), and multidisciplinary approach with artificial intelligent automation that can be helpful to the tourism field (Churchill et al., 2018). Creating unforgettable travel experiences requires a careful choreography of many components based on an in-depth knowledge of the needs of tourists (Tussyadiah, 2014). Designing tourist experiences means considering the entire journey, from planning to post-trip reflection, and focusing on ways to encourage participation and involvement. Explaining AI's role in enhancing, augmenting, or substituting tourist encounters is critical in the context of user experiences (Lindvall et al., 2018). ESG investment in artificial intelligent tourism can be possible with the internet of things (IoT). These factors previously mentioned are helpful for the visitors. The development of criteria for functional AI systems is aided by various desirable behaviors for systems tackling particular concerns and tourist contact points.

Most importantly, the design is critical to determine how intelligent automation affects tourism. AI systems implementation can adjust best tourist locations and social (and physical) structure in the future tourism department. Tourists may be persuaded to visit well-known places through predictive analytics and virtual tourism information. The "automated tourist experiences" can only be conceptualized if research explains the causal relationship between artificial intelligence and intelligent automation in tourism. ESG investment and IoT can make a more sustainable future for tourism. As a result, artificial intelligence thoughts can design intelligent automation tourism environment.

LITERATURE REVIEW

The design of valuable artificial intelligence is focused on finding technology answers to long-standing design issues, such as psychology, cognitive and behavioral sciences as well as information systems that would be used to shed insight on the persistent behavioral problems that tourists display, such as lack of discipline, insufficient attention, or absence of cognition. These challenges should be addressed by requiring AI systems to discourage visitors from making misinformed judgments that result in inadequate practices (Tussyadiah, 2020). For instance, digital nudging (Schneider et al., 2018) and nudge theory aspect involvement (Thaler and Sunstein, 2009) may be used to achieve this goal in the tourism industry (Tussyadiah et al., 2019; Tussyadiah and Miller, 2019). Automated systems may solve issues that need immediate attention to the flow of visitors at a destination and give help then sending push notifications and recommending alternative destinations. In this regard, Fogg (2009) described Captology as a computer technology mediation that is essential to save the environment and maintain social satisfaction, which is persuasive for human beings. Tussyadiah (2017) delineated quantitatively that human–computer interaction may be used as lenses for research, and ESG investors should plan for the implementation (Tung and Law, 2017). Another work exploits the value perceived by the tourist and the attachment to intelligent voice assistants (IVA) and the quality of the human–VAT relationship in the field of hospitality (Loureiro et al., 2021). Online analysis of tourism service consumers supports their policy of continuous improvement, creating a positive impact on customer satisfaction, which ultimately leads to the intention to continue digital platforms (Filieri et al., 2021).

Designing valuable artificial intelligence from a technological standpoint necessitates highlighting the necessity of critical artificial intelligence (Russell et al., 2015; Tadapaneni, 2020). Robustness against requirements, exploits, defects, and cyberattack risks are all factors to consider (He et al., 2019; Luo et al., 2020; Shao et al., 2020; Fan et al., 2021; Khan et al., 2021; Wang et al., 2021). Russell et al. (2015) emphasize the necessity of verification in the form of "correct system design" and also validation with correct system design, which was also argued earlier by Menzies and Pecheur (2005). The first point to be considered is that the AI systems need access to a vast quantity of data; in tourism, these data mainly comprise personal information collected from tourists. ESG criteria should be built to make the most out of data while causing the least amount of intrusion into people's privacy and a feasible environment (Lords, 2018; Sethu, 2019; Tussyadiah et al., 2019). Techniques may address this problem to data anonymization and de-identification in the tourism department (Garfinkel, 2015; Khalila and Ebner, 2016). The second predictive stage focuses on the developers' perspectives, consumers, and the regulators' need to comprehend and justify artificial intelligence for any industry (Lords, 2018; Monroe, 2018). Another area of study should be improving artificial intelligence's technological openness and decreasing prejudice, which is essential for the future. In the third stage, building artificial intelligence with the perspective of IoT to solve security challenges necessitates the development of guidelines to guide behavior in safety-critical circumstances, identify infiltration and possible exploitation, and avoid hazardous occurrences (Russell et al., 2015). Finally, given the autonomy of these systems, research should be performed on how to maintain some meaningful human control. AI autonomy involves putting notions like "human in the loop" or "human on the loop" into action and relationships with social agent (Dautenhahn, 1998; Schirner et al., 2013; Lugrin, 2021; Schoenherr, 2021).

The next step is to make it easier for tourism businesses, workers, and visitors to implement (positive) intelligent automation. The present adoption pattern and prospects and the key drivers and impediments to adoption must all be determined *via* research. Theories and models that evaluate innovation diffusion, acceptability, resistance, use, and ease of service and those that assess innovation diffusion, acceptability, resistance, use, and discontinue of use were previously valuable in this field. Examples are the role of "diffusion innovation theory" (Rogers, 2003, 2003), "theory of reasoned action" (Fishbein and Ajzen, 1975), "theory of planned behavior" (Ajzen, 1991), "the technology adoption model" (TAM; Davis, 1989), "the extended TAM2 model" (Venkatesh and Davis, 2000), "the Unified Theory of Acceptance and Use of Technology" (UTAUT) and UTAUT2 (Venkatesh and Davis, 2000), "and the Unified Theory" (Venkatesh et al., 2003; Venkatesh et al., 2012).

At a personal level, in combination with the drivers and obstacles to general technology adoption, such as simplicity of use, usefulness, and technological self-efficacy, research efforts should be focused on discovering characteristics specific to artificial intelligence, robots, and the IoT that affect the appropriateness of innovation, such as trustworthiness and vulnerability parameters of the ESG investment necessary for the field of tourism. Researchers had argued that if it comes to engaging with robots, there is a certain amount of nervousness in society, which leads to an unfavorable attitude toward robots (Nomura et al., 2006; Nomura et al., 2006). Negative views regarding AI and robots in the news media may increase this mentality. To better comprehend tourist customers' and staff attitudes toward intelligent robots in tourist service environments, reference theories are underpinning technophobia (Brosnan, 2002) and the gravitational lensing hypothesis (Mori, 2017; Murphy et al., 2019), technological social inclusion (Wang and Wu, 2021). Kurtessis et al. (2017) derived that organizational support theory is management theory, which may help get employee support for intelligent automation in the industry. Consumers' attitudes and intentions to use intelligent devices have been measured (Tussyadiah and Park, 2018; Lu et al., 2019), while workers' attitudes and intentions have indeed been measured (Li et al., 2019).

To enable and expedite intelligent automation implementation in tourism, it is necessary to identify variables affecting the acceptance of innovation at an organizational level. Therefore, knowing the limitations of innovation dissemination in organizations can assist in comprehending the constraints to sector acceptance. The management literature has information on principles underpinning organizational adoption and dissemination of innovation (Frambach and Schillewaert, 2002; MacVaugh and Schiavone, 2010; Sun et al., 2020; El-Kassar et al., 2022) as well as transformational leadership (Bass, 1990; Haeruddin et al., 2021), a factor proved in the literature to speed up technology advancement in corporations (Frambach and Schillewaert, 2002; MacVaugh and Schiavone, 2010; El-Kassar et al., 2022). Intelligent automation could be studied to see how it fits into the strategic priorities of commercial and public tourist organizations and the competitiveness conditions throughout the sectors (Rydzik and Kissoon, 2021). ESG investors collaborate with the present government and attempt to stimulate adoption (advocacy, funding), and organizational activities to educate prospective users might then be offered to eliminate obstacles and enhance responsible adoption in the organization (Oyewole, 2021).

To maximize the advantages of intelligent automation in tourism, it is crucial to foresee the spectrum of automation's good and bad effects on people (tourists, personnel), the industry, and society. The functions and effects of intelligent systems in the tourism department are essential for the future of sustainability (Gretzel, 2011; Gajdošík and Valeri, 2022). However, the study did not concentrate primarily on artificial intelligence. Furthermore, Lin et al. (2011) identified three areas of ethical concern coming from the use of robots: safety and mistakes, law and ethics, and societal consequences. Anticipating service failure due to technical (programming) faults during human–robot contact is an essential part of intelligent machine adoption. As a result, research must focus on ways to reduce the potential of damage through artificially intelligent actors in a variety of service contact scenarios. Psychological effects of human–robot contacts, such as concerns of privacy (monitoring) and data protection, are mandatory for the satisfaction of tourists (Pagallo, 2016; Chatzimichali et al., 2021). On the other hand, there are emotional reactions to the proximity of robot appearance to humans (Walters et al., 2008; Mori, 2017; Akdim et al., 2021) and technostress (Ayyagari et al., 2011; Beltrame and Bobsin, 2021; Tuan, 2021). In a nutshell, societal challenges, safety, privacy consequences, and technostress have crucial influence on the structure and quality of tourist experiences in the future, which make it unsustainable (Beltrame and Bobsin, 2021; Chatzimichali et al., 2021; Tuan, 2021).

Another central area of study is the modifications intelligent automation can introduce to the tourism sector, such as alterations to organizational decision-making processes as artificial intelligence substitutes portfolio managers (Javelosa, 2017) and the unintentional effects of AI (-assisted) judgments (Jarrahi, 2018). Likewise, Larivière et al. (2017) described that cooperative decision-making, work allocation, and special scientists can look at the balance of people and then make intelligent systems. Furthermore, again it was conceptualized that automated tourism, accommodation service experience's creation, and expenditure considering intelligent automation are possible due to artificial intelligence system. The study found that artificial automation could modify the roles of employees and customers in automated intelligent services. Artificial intelligence framework positively influences work performance and an intelligent artificial sustainable system.

The social and economic effects of intelligent automation on the tourist sector, local citizens, and economy bring effectiveness when the degree of hospitality and tourism can become replaced by intelligent machines. In response, intelligent machines can generate valuable earnings, revenue redistribution (disparities), while overcoming gender problems, and total wealth in the tourism sector. In terms of labor, automation raises worries about the loss of skills and knowledge in society as a result of over-reliance on technology, as well as the possibility of a future jobless society (Lin et al., 2011; Chessell, 2018; Pham et al., 2018; Samuels, 2021). Additional implications of intelligent machine progress had already been questioned in the specific situation of technological singularity, a concept in which technological progress would become challenging to control and unrecoverable, and artificial intelligence surpasses human intelligence, resulting in the extinction of human society (Eden et al., 2012; Roli et al., 2021). The same may be said for evaluating social effects, particularly guest–host relationships and local support for tourist growth. Approaches such as future (for example, visualizing futures) and future-making (Hajer and Pelzer, 2018; Szántó, 2018; Szántó et al., 2020) could be used in addition to machine learning approaches to increase prediction and forecasting efficiency in the industry (Ahmed et al., 2010; Kamolov et al., 2021).

Ideally, academic efforts can discover how intelligent automation may assist the tourist industry in becoming more futureproof. After learning about the many advantages and issues that may arise from implementing intelligent automation, the next step is to recognize the various ways of minimizing adverse effects and maximizing the benefits of automation in tourism. The principle of sustainability changeover (Markard et al., 2012; Safarzyńska et al., 2012; Turnheim et al., 2015; Yue et al., 2021; Bauer et al., 2022) is crucial for guiding exploration in this area, particularly in identifying how AI systems could perhaps be used to structure transition mechanisms to sustainable progress across tourism. Government policy is critical in addressing the profession's and society's possible negative consequences of intelligent automation. Policy interventions via education and training programs to address skills shortages in AI-related occupations or minimize capacity loss due to automation dependency, encouragement to promote labor-intensive sectors like hospitality, and a guaranteed basic income to improvement in primary mass jobless due to automation are just a few examples. Furthermore, tourism organizations and other stakeholders may utilize a variety of intervention tactics to encourage visitors and staff to engage in responsible conduct (Navío-Marco et al., 2018; Xiang, 2018).

Intelligent automation can significantly change tourism in the not-too-distant future, reducing the necessity for human, face-to-face contact between visitors and inhabitants (tourism staff) even more than it now does. Lack of socialization may result in the loss of shared values necessary for structured social life, including care for others' well-being and environmental preservation such as ESG criteria (Han et al., 2019; Bao et al., 2020; Yue et al., 2020; Zhumadillayeva et al., 2020; Pan and Yue, 2021). The task at hand is to determine how much artificial intelligence and robotics can contribute to solving these emergent problems. As individuals become more reliant on virtual advisers and robots to help them manage their everyday lives and travel requirements, we must fundamentally transform our perspective of intelligent agents from simple tools to vast and complicated social players. Humans can be guided, informed, and mentored by computational systems that raise public awareness of physical and biological thresholds and human well-being while boosting answerable and resource-efficient behavior. Humans and the environment hold the key to efficient human–robot interaction for a sustainable society. As a result, more research is needed to figure out how to humanize humans in the age of intelligent machines and add value to the expansion of robotics (Kopacek and Hersh, 2015; Fusté-Forné and Jamal, 2021). Also, exploration can be focused on developing scientific, cultural, and technological instruments to support and stimulate current trends for the progress of society and people, as well as to assist in avoiding the exploitation, mistreatment, indifference, and misuse of artificial intelligence and robots (Kopacek and Hersh, 2015; Fusté-Forné and Jamal, 2021). The fundamentals of robotics must also be considered when developing specifications for robust artificial intelligence, establishing a feedback loop that leads to the development of beneficial AI (Tussyadiah, 2020).

Research Method

The study used a positivistic and quantitative approach to explain the relationship between artificial intelligence, ESG, IoT, creating a sustainable future, facilitating adoption, tourism, and intelligent automation in tourism. Quantitative research knows the facts objectively (Creswell, 2010). The rationale behind this approach was to understand the projective association between artificial intelligence, ESG, and artificial automation in tourism.

The study's main objective was to highlight the importance of artificial intelligence, ESG, IoT, facilitating adoption, creating a sustainable future, and intelligent automation tourism of China. Ethical considerations and consent forms were initially filled, followed by the COVID-19 standard operating procedure (SOP). However, the study did not mention the specific tourist place due to ethical issues, because respondents did not disclose their anonymity.

Moreover, the working hypotheses are correlated with the objectives of the study, respectively:

1) The first hypothesis is that artificial intelligence has actively contributed in recent years to the intelligent automation of services in the tourism sector;

The paper uses an explanatory method to explain the theory and co-relationship with quantitative results. Second, quantitative data were collected through a questionnaire, and the research has adapted items from the previous empirical literature review. The self-administered questionnaire was distributed with the help of local language researchers to take reliable and valid data from the respondents.

2) The second working hypothesis is the predictability of tourist services by using models of structural equations;

The paper analyzes the predictive impact of artificial intelligence on intelligent automation in tourism with mediating influence of ESG, IoT, facilitating adoption, and creating a sustainable future with structural equation modeling (SEM), which is a gap in the literature. The initial model and model fit were measured and employed in the existing artificial intelligence automation tourism situation. The final decision was taken on the modified model fit, and its coefficient of determination was used for prediction.

3) The third hypothesis is related to the direct interdependent relationship between artificial intelligence and intelligent automation in tourism.

The paper developed a linear model to study the artificial intelligence relationship and its dependency on intelligent automation in tourism. Data were collected from five popular tourist places in China. Different researchers developed scales, and we adapted a scale from previously valid and reliable dimensions, factors, indicators, and elements, which were identified in the existing literature. The study nature was quantitative, and accurate and reliable items are always demanded. For instance, the study used seven (7) different types of scale, such as the internet of things (IoT, 8 items and the study just selected 4 items that have good Cronbach alpha value and we retained in our research) that Krishna and Verma (2016) and Vašíček et al. (2017) adapted, "artificial intelligence" (AI = 5 items), "creating a sustainable future" (CSF = 6 items), "intelligent automation tourism" (IAT = 6 items), and "facilitating adoption" (FA = 8 items) indicators by Tussyadiah (2020), "tourism impact scale" (T = 6 items) (Ap and Crompton, 1998), and "ESG measurement scale" (ESG = 8 items)" indicators adapted from Sultana et al. (2018). Reliability and validity are the essential measurements of the questionnaire, and this paper collected one hundred-two (102) pilot tests to ensure reliability and validity of the scale. The concepts were converted to the variables, and seven (7) indicators were chosen for the artificial intelligence automation in tourism in the tourist places of China. The study counters these indicators with a non-probability purposive sampling technique with $N = 411$ sample size through ("G*Power") "software", which is shown in **Figures 1**, **2** and **Eq. 1**. (Faul et al., 2007). In this regard, $N = 402$ have given the responses regarding artificial intelligence automation of tourism, which were proceeded for the data analysis phase. Similarly, the data were collected from the 402 tourists and their tourism department employees. **Equation 1** of the sample size is given:

$$\begin{aligned}
&\gamma = X\beta + \varepsilon \\
&\mathrm{X} = (1X_1,\ X_{2\ldots\ldots}X_m)\ and\ N \times (m+1,\ matrix\ = X_{\boldsymbol{i}}) \\
&\beta \text{ of length } = (m+1) \\
&\varepsilon \text{ of length N} = (\varepsilon\mathrm{i}\ \sim\ \mathrm{N}(0,\ \sigma)
\end{aligned} \tag{1}$$

Suppose that. . .

$$\mathrm{H0:}\ \ R^2 Y.B\ = 0$$

$$\mathrm{H1:}\ \ R^2 Y.B > 0.$$

The effect size and its equation for the sample size are given:

$$f^2 = \frac{R^2\, Y.B}{1 - R^2\, Y.B}$$

$$R^2\, Y.B = \frac{f^2}{2 + f^2}$$

The sample size has seven (7) predictors and a similar noncentrality parameter ($\lambda = 20.550$). The value of "Critical F" is important for measuring the sample, and it was 2.032 with numerator df (7). Denominator df was count 403, and effect size f square was 0.05. Similarly, power ($1 - \beta = 0.93$) is measured for the sample size, and actual power was 0.930. In conclusion, the study's sample size was derived ($N = 411$) and 402 respondents filled questionnaire.

The researchers took help from the formula of "F test linear multiple regression: fixed model, R^2 deviation of predictors" and followed the COVID-19 SOPs. Furthermore, Statistical Package for Social Sciences (version 21), AMOS and SEM, were used to measure the initial model and model fit for the paper conclusion. This empirical paper has tested two models to project the tourism and intelligence automation tourism among tourist and employees. For instance, the initial model has seven (7) constructs, and their values of RMSEA and SRMR were higher than cutoff points such as 0.19 and 0.47, whereas the GFI, CFI, and NNFI values were 0.694, 0.592, and 0.629, lower than the cutoff point, which indicated that there is no ideal fitness present. On the other hand, the χ^2/df value was 10.496, which is also higher than the cutoff point. As a result, the model needs modification, which suggested that SEM and added two covariate control factor, error terms, with the combination of nine (9) indicators for the causal and effect theoretical relationship for an inferential measure of the intelligent automation of tourism among Chinese tourist and tourism department employees. According to the modeling phase, data pre-processing activities are necessary to guarantee that inaccurate, blaring, redundant, and repetitive information are removed from the data. **Equation 2** describes the "sum of squared differences" between the line and the actual data point is minimized, and it is called Alpha squares in the multiple regressions and with several predictors.

$$\begin{aligned}
&Otcome\, i = \text{(model)} + \text{error}\, i \\
&Y = (b_0 + b_1\, X_{i1}\ + b_0 + b_2\, X_{i2}\ + \ldots\, b_0 + b_n\, X_n\,) + \ \varepsilon_i
\end{aligned} \tag{2}$$

Similarly, the SEM measures the level of dependency in the linear equation model, which leads to the structural modeling in applied statistics. **Equation 3** is the basic formula of the SEM.

$$\begin{aligned}
&C(\alpha.\alpha) = [N - r]\left[\sum_{g-1}^{G} \frac{(N)^{g\, f\left(\mu^g, \sum g, x^{(g)}, S^{(g)}\right)}}{N}\right] = [N - r]F(\alpha.\alpha) \\
&\mathrm{fkl}\left(\mu^g \sum (g) x^{(g)} S^{(g)}\right) \\
&\quad = \log\left[\sum g\right] + tr\left(S^{(g)} \sum{}^{(g-1)+\left(x^{(g)}-\mu^g\right)} \sum{}^{(g-1)\left(x^{(g)}-\mu^g\right)}\right) \\
&\quad c = (N^1 - 1)F^{(1)} = (N-1)F. \\
&\quad C = \sum_{g=1}^{(G)} N^{(g)} F^{(g)} = FN.
\end{aligned} \tag{3}$$

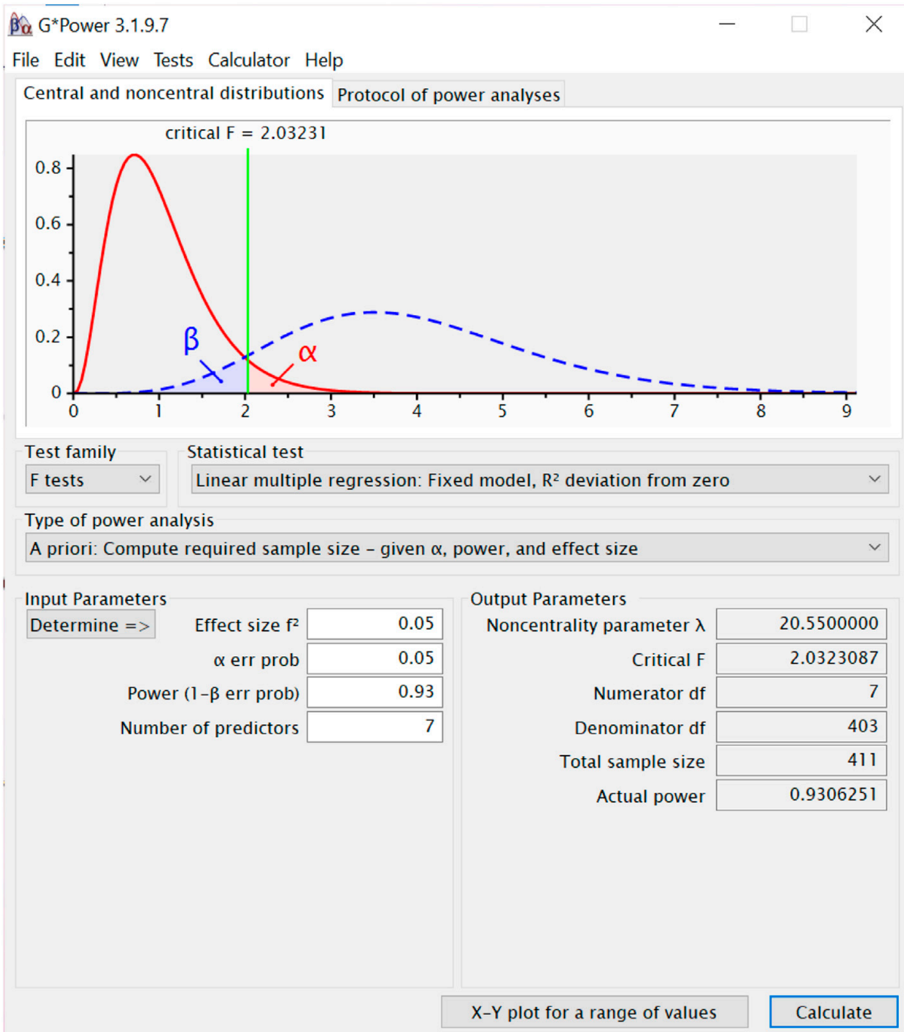

FIGURE 1 | Central and Noncentral Distribution.

Furthermore, data were ready for the normal distribution, and all the outliers were removed from the data, which is the basic assumption of a regression equation. The final training dataset was evaluated with the help of these aforementioned equations and further applied bootstrapping technique to the model fit (second model) for accurate results and future efficient prediction for intelligent automation in the tourism, which can be beneficial for the ESG criteria.

Data Analysis

This study empirically tests all the indicators with confirmatory measurement factor analysis and derives an equation for each item (statements). The measurement model suggested that construct validity and reliability are perfect, and the model is applicable for the further structural equation evaluation, which is portrayed in **Figure 3**. Moreover, the initial model (first model) and model fit (second model) were measured for the actual prediction of beneficial artificial intelligent automation in tourism department with ESG protocols. Likewise, the initial model was not found with satisfactory results, meaning not a good fit with the **Eq. 2** criteria, and the paper modified the proposed model and added two control variables (respondents' age and education) with covariate paths as well as error term (e1, e5, e6) as covariates to achieve desired results. These added factors evaluate the model statistically significant (**Figures 3**, **5**).

The primary goal of path analysis is to determine any causal relationships among the study variables. SEM is one of the most advanced approaches for determining whether or not a cause-and-effect connection exists between a set of variables (Hair et al., 2014). Notably, the paper differentiated a casual R^2 relationship between the initial model and model fit. It is to be noted that the actual logic of path analysis is to develop a diagram that is clearly connected with arrows, covariate, and show the real causal flow or the real direction of cause-and-effect for future prediction. The beauty of path analysis is that it measures association from the direct path to indirect causal effects, can be estimated simultaneously, and predicts a good model for future issues. So, the path diagram

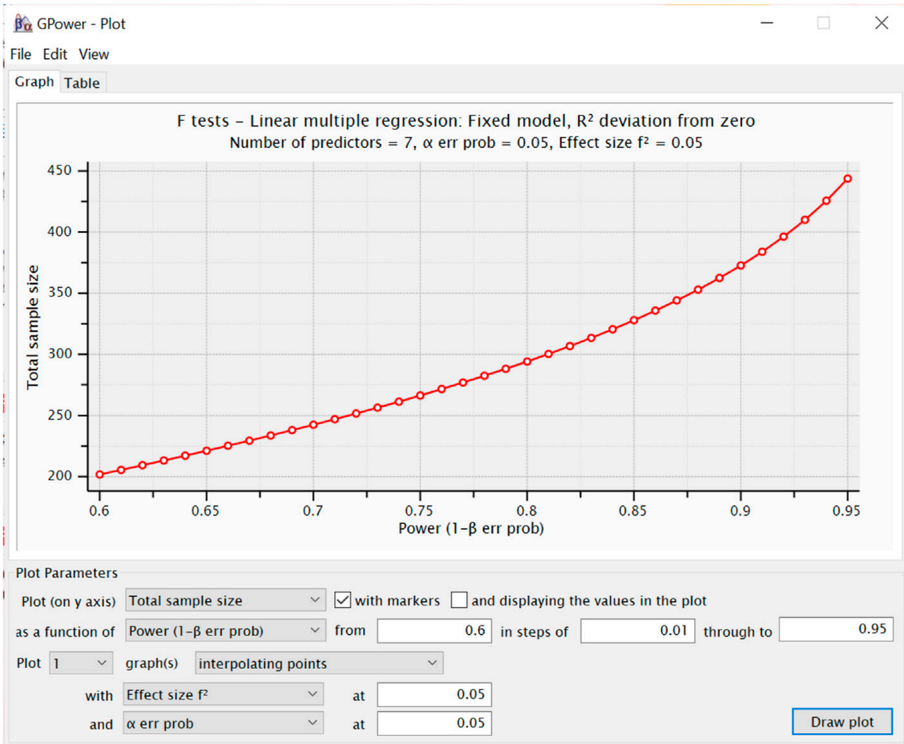

FIGURE 2 | F Tests.

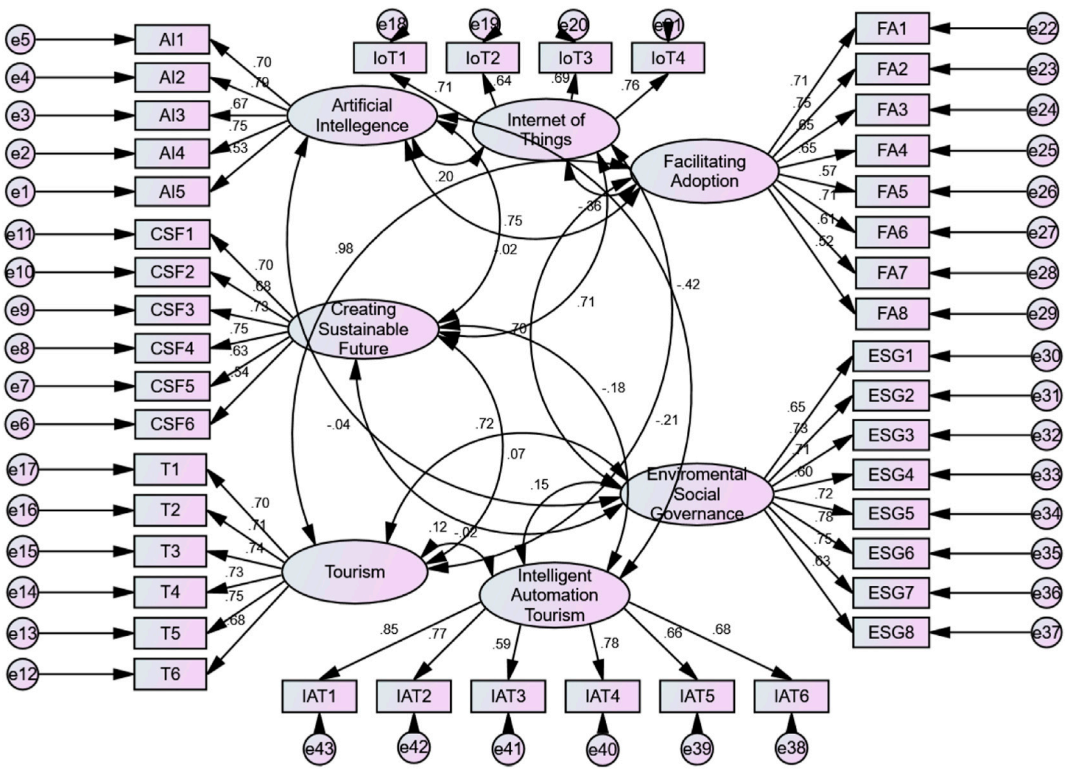

FIGURE 3 | Measurement of the artificial intelligence, intelligence automation tourism, and internet of things (N = 402).

TABLE 1 | Fit indices for artificial intelligence, facilitating adoption, sustainability, ESG investment, intelligent automation tourism, and internet of things among tourists (N = 402).

Model	$\chi^2 df$	χ^2/df	GFI	CFI	NNFI	RMSEA	SRMR
Initial model	10.496	1.785	694	0.592	0.692	0.476	0.195
Model fit	3.719	1.393	0.936	0.921	0.863	0.086	0.095
$\Delta\chi^2$	6.777	—	—	—	—	—	—

Note: N = *402, All the changes in χ^2 values are computed relative to model, χ^2 > 0.05, GFI = goodness of fit index, CFI = comparative fit index, NNFI (TLI) = non-normed fit index, RMSEA = root mean square error of approximation, SRMR = standardized root mean square, $\Delta\chi^2$ = chi-square change.*

shows a pictorial illustration of the theoretical explanation of cause-and-effect relationships among a set of variables up to numerical results (ratio and percentages). Agresti and Finlay (1997) concluded that the basic attribute of path analysis is to build direct and indirect causal effects among the set of outcomes and predictors. The use of indirect effects is very beneficial in the derivation of scientific knowledge. An indirect effect is when a variable affects an endogenous indicator over its effects on some other factors or indicators. It is called an indirect effect and is also known as intervening indicator in the subjective model. However, SEM was constructed and applied to evaluate the mediating role of creating sustainable future, facilitating adoption, ESG, and IoT, between artificial intelligence and intelligent automation in tourism. The exhibition of the initial model and model fit are shown in **Table 1**.

The statistical equation for the SEM in the context of intelligent automation in tourism was introduced and the equation derived the CMIN values, which is shown in the formula covariance-based model **Eq. 4**.

$$
\begin{aligned}
& C\,(\alpha.\alpha) = [N-r]\left[\sum_{g-1}^{G} \frac{(N)^{g} f\left(\mu^{g}, \sum g, x^{(g)}, S^{(g)}\right)}{N}\right] = [N-r]F(\alpha.\alpha) \\
& \mathrm{fkl}\left(\mu^{g} \sum (g) x^{(g)} S^{(g)}\right) = \log\left[\sum g\right] + tr\left(S^{(g)} \sum (g-1) + \left(x^{(g)} - \mu^{g}\right) \sum (g-1)\left(x^{(g)} - \mu^{g}\right)\right) \\
& c = (N^{1}-1)F^{(1)} = (N-1)F. \\
& \mathrm{C} = \sum_{g=1}^{(G)} N^{(g)} F^{(g)} = FN. \\
& (D1) CMIN\ Initial\ Model = 10.496 \\
& CMIN\ Model\ Fit = 3.719 \\
& \Delta\chi^{2} = 10.496 - 3.719 = 6.777 \\
& D2\ fml\left(\mu^{g} \sum (g) x^{(g)} S^{(g)}\right) = fkl\left(\mu^{g} \sum (g) x^{(g)} S^{(g)}\right) - fkl\left(\mu^{g} \sum (g) x^{(g)} S^{(g)}\right) \\
& = \log\left[\sum g\right] + tr\left(s^{g} \sum (g-1) + \left(x^{(g)} - \mu^{(g)}\right) \sum (g-1)\left(x^{(g)} - \mu^{(g)}\right)\right). \\
& CMIN\ Initial\ Model = \chi^{2}/df = 1.785 \\
& CMIN\ Model\ fit = \chi^{2}/df = 1.393
\end{aligned}
\tag{4}
$$

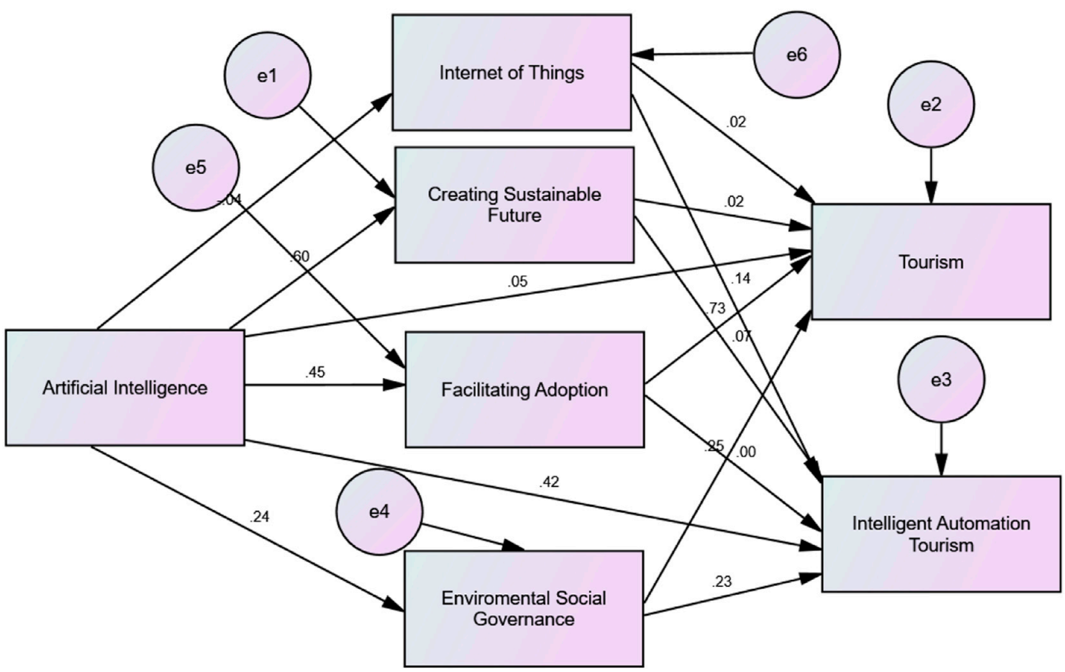

FIGURE 4 | Empirical results from a complex multivariate initial model representation standardized regression coefficient for intelligent automation in tourism (N = 402). Note: a complex multivariate model of five endogenous constructs and two exogenous indicators. Completely standardized maximum likelihood parameter estimate for intelligent automation in tourism among tourists and employees.

The fit indices indicated for designing beneficial artificial intelligence, intelligent automation tourism, sustainability, facilitating adoption IoT, and tourism are shown in **Table 1**. Absolute fit for model fit was χ^2 (12,402) = 3.719, $p < 0.001$. The fit indices were considered to indicate the good fit of the data with the tested model and the study analyzed the model fit in two key steps. In step 1 and step 2, the indices' absolute and relative fit (GFI, CFI, NNFI, RMSEA, SRMR) were compared. Because the χ^2 test of absolute model fit is sensitive to sample size and number of parameters, investigators often turn to various descriptive fit statistics to assess the model's overall fit in data. The following equation mathematically measures the absolute and relative fit (**Eq. 5**):

$$
\begin{aligned}
&GFI = 1 - \frac{\dot{\mathrm{F}}}{\dot{\mathrm{F}}_b}\\
&f\left(\left(\sum(g), s^{(g)}\right) = \frac{1}{2} tr\left[K^{(g-1)}\left(x^{(g)} - \sum(g-1)\right)\right]\right)2.\\
&Model\ fit\ value\ of\ GFI = .936\\
&CFI = 1 - \frac{\max\left(\hat{\mathrm{C}} - d, 0\right)}{\max\left(\hat{\mathrm{C}}_b - d_b, 0\right)} = 1 \frac{NCP}{NCP_b}\\
&RNI = 1 - \frac{\hat{\mathrm{C}} - d}{\hat{\mathrm{C}}_b - d_b}\\
&Model\ fit\ value\ of\ CFI = .921\\
&TLI = 1 - \frac{\frac{\hat{\mathrm{C}}_b}{d_b} - \frac{\hat{\mathrm{C}}}{d}}{\frac{\hat{\mathrm{C}}_b}{d_b} - 1}\\
&Model\ fit\ value\ of\ TLI = .863\\
&SRMR = \sqrt{\sum_{g-1}^{G}, \left\{ \sum_{\boldsymbol{i-1}}^{pR}, \sum_{\boldsymbol{j-1}}^{\boldsymbol{j\leq i}}, \left(\check{s}^{gij}-; \sigma^{(gij)}\right) \right\} / \sum_{\boldsymbol{g-1}}^{G} p*(g)}.\\
&Model\ fit\ value\ of\ SRMR = .095\\
&Population\ RMSEA = \sqrt{\frac{F}{\frac{0}{d}}}\\
&Estimated\ RMSEA = \sqrt{\frac{F}{\frac{0}{d}}}\\
&LO\,90 = \sqrt{\frac{\delta L/n}{d}}\\
&HI\,90 = \sqrt{\frac{\delta U/n}{d}}\\
&RMSEA = .086
\end{aligned}
\tag{5}
$$

Hu and Bentler (1999) measured that χ^2/df in between 1 and 3 RMSEA and SRMR values should be less than 0.08 and CFI, TLI, or NNFI and GFI values usually higher than 0.9 are considered as a good value when it becomes 0.9 ≤ 0.8 then allowable in some cases. Likewise, RMSEA and SRMR for the initial model were 0.47 and 0.19, whereas the GFI, CFI, and NNFI values were 0.69, 0.59, and 0.69, respectively, while the other side χ^2/df value was 1.785 in the above (**Table 1**). The fitted model of the study was fit according to the descriptive measure of fit because the p values were <0.05). Furthermore, the model modification process started as suggested by the modification indices for the intelligent automation tourism. Modification indices followed up some of the variance and covariances between errors in terms of artificial intelligent automation in tourism indicators because some of the elements were similar in content and context. According to Tomás et al. (1999), the covariance between error terms in survey-based research can legitimately draw the variance. The criteria of modification indices for error covariance should be at least 4.0 (Byrne, 2016). Moreover, the study drew the covariance, and the "chi-square Chang" was greater than 6.777 in the modification process. All the non-significant paths were removed in step 2 of the model and added some covariance paths. After that, the indices of absolute and relative fit (GFI, CFI, NNFI, and RMSEA) were again compared and calculated in that stage. The RMSEA and SRMR for the model fit after drawing covariance and removal of insignificant paths were discarded; the results of RMSEA and SRMR (0.08 and 0.09, respectively) were counted since the GFI, CFI, and NNFI values were 0.93, 0.92, and 0.86, respectively, while χ^2/df was 1.393. It means finding the difference between the proposed model and the saturated model. Now it was the perfect model for the projection of the intelligent automated feature in the tourism when mediation model was added. In conclusion, the model was fit, and the modification process does not allow the data to further modify the model (**Figure 4** and **Figure 5**).

Figure 5 also suggested that the path coefficient was significant because p values were <0.05. Now which path coefficient was considerably significant, and which one was not significant, the arrows of the path had explained in numbers. As a result, the mediation model measure that IoT, tourism sustainability, facilitating adoption, and ESG investment mediate the relationship between artificial intelligence designing and tourism, and intelligent automated tourism with beta values (CSF = β = 0.55, IoT = β = 0.03, FA = β = 0.40, ESG = β = 0.25). Likewise, artificial intelligence directly influences tourism with a positive path coefficient (AI = β = 0.04, $p > 0.05$), and artificial intelligence directly influences intelligent automated tourism with a positive path coefficient (IAT = β = 0.41, $p < 0.05$). The data concluded that creating sustainability was a strong coefficient between artificial intelligence when applied the intelligent automated tourism. Likewise, artificial intelligence brings positive change in the tourism with the help of IoT, ESG policy, sustainable factor, and different facilities in the tourism department. Artificial intelligence brings improvement in the tourism and intelligent automated tourism (**Figure 5**).

The study used bootstrapping technique for the sample enlargement in the model fit and estimates to be analyzed the direct and indirect effects on study variables. For example, artificial intelligence has a direct effect on IoT, sustainability, facilitating adoption, ESG policy as well as indirectly effect on

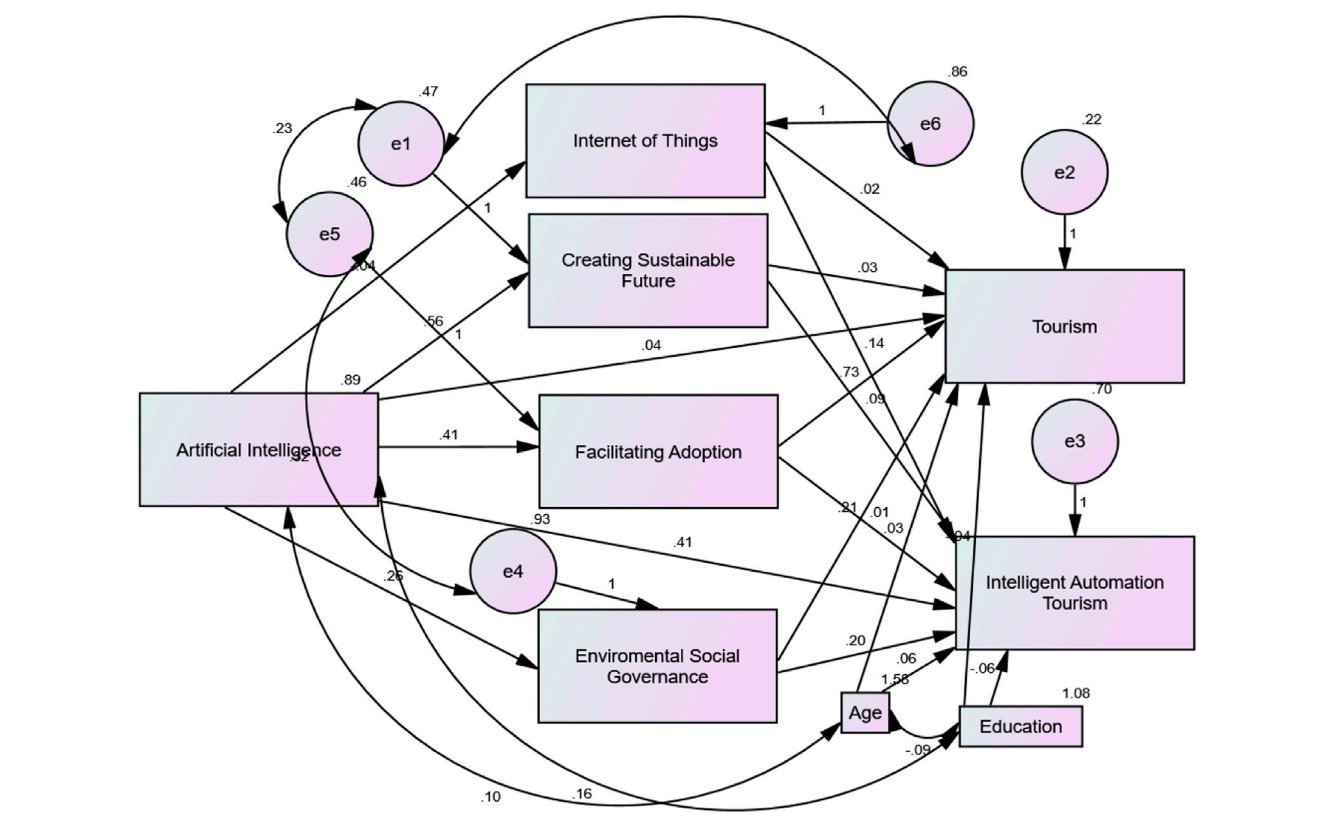

FIGURE 5 | Empirical results from a complex multivariate model representation standardized regression coefficient for intelligent automation in tourism among tourists (*N* = 402). Note: a complex multivariate model of five endogenous constructs and two exogenous indicators along with two control variables. Completely standardized maximum likelihood parameter estimate for the artificial intelligent automation in tourism among tourists and employees.

tourism and intelligent automation in tourism. Similarly, Valeri and VanderWeele (2013) suggested that five thousand (5,000) bootstrapped sample is reliable and valid in the linear multiple paths especially for the SEM analyzed data.

The research hypothesized that artificial intelligence design has beneficial influence on the tourism and intelligent automation tourism with mediating role of sustainability, IoT, adoption, and ESG policy. Likewise, the results of direct effects revealed that artificial intelligence design is a highly significant and positive predictor for tourism as well as a significant positive predictor for intelligent automation in tourism, whereas artificial intelligence design was a significantly positive predictor for IoT while on another side it was found to be a positive significant predictor for facilitating adoption. Furthermore, artificial intelligence was found to be a cause for ESG while also directly affecting the intelligent automation in tourism. The data concluded that artificial intelligence could increase intelligent automation in tourism with the help of ESG, IoT, sustainability, and facilities adoption (**Table 2**).

The aforementioned results in **Table 3** revealed indirect effects of internet of things between artificial intelligence and tourism; it was found to be a highly projective mediator for the overall model. Similarly, internet of things model was found to be a positive mediator for artificial intelligence and intelligent automation tourism. As a result, creating sustainability was found to be an insignificant indirect predictor between artificial intelligence, tourism, and intelligent automation tourism. Similarly, facilitating adoption was a positive indirect significant predictor between artificial intelligence and tourism as well as a positive predictor for intelligent automation tourism. Lastly, ESG was found to be a positive significant predictor for tourism and intelligent automation tourism.

The model fit equation revealed that seven hypotheses were rejected, and all the proposed hypotheses were accepted, as artificial intelligence design predicts tourism and artificial automation tourism. Furthermore, measurement and structural model is showing significant and insignificant paths in **Table 4**.

DISCUSSION

The techniques proposed can be generalized to any tourism sector and the current study found that artificial intelligence brings development in the tourism as well as intelligent automation is beneficial for it. In this context, Ivanov and Webster (2019) delineated that artificial intelligence automation predicts and influences the automated future of travel and tourism. Intelligent automation has begun to infiltrate the world tourist

TABLE 2 | Standardized estimates of direct effects for the paths of intelligent automation in tourism (*N* = 402).

Variables	IoT		CSF		FA		ESG		Tourism		IAT	
	β	S.E	β	S.E	β	S.E	β	S.E	β	S.E	β	S.E
Artificial Intelligence	0.03	0.04	0.55***	0.03	0.40***	0.03	0.25***	0.05	0.04	0.03	0.41***	0.06

*p< 0.05, **p< 0.01, ***p< 0.001. *Note: CSF = creating sustainability future; FA = facilitating adoption; ESG=environmental, social, governance; IoT= internet of things; IAT = intelligent automation in tourism.*

TABLE 3 | Standardized estimates of indirect effects of the paths for intelligent automation in tourism (*N* = 402).

Variables	Tourism			Intelligent automation in tourism		
	β	SE	CR	β	SE	CR
Artificial intelligence						
IoT	0.016	0.031	0.530	0.138***	0.054	2.539
CSF	0.028	0.050	0.550	0.086	0.089	0.965
FA	0.728***	0.052	14.117	0.010	0.091	0.114
ESG	0.208***	0.032	6.852	0.205***	0.054	3.822

*p < 0.05, **p < 0.01, ***p < 0.001. Note: *CSF = creating sustainability future; FA = facilitating adoption; ESG=environmental, social, governance, IoT= internet of things.*

TABLE 4 | Hypothetical paths for artificial intelligence and intelligent automation in tourism (*N* = 402).

Hypotheses	Direction	Paths	Estimate	SE	CR	*p*	Label
FA	←	AI	0.408	0.036	11.333	***	Sig
CSF	←	AI	0.559	0.036	15.426	***	Sig
IoT	←	AI	0.037	0.049	0.752	0.452	Insig
ESG	←	AI	0.257	0.051	5.044	***	Sig
IAT	←	AI	0.414	0.061	6.816	***	Sig
IAT	←	ESG	0.205	0.054	3.822	***	Sig
Tourism	←	CSF	0.028	0.05	0.55	0.582	Insig
Tourism	←	FA	0.728	0.052	14.117	***	Sig
IAT	←	FA	0.01	0.091	0.114	0.910	Insig
Tourism	←	AI	0.04	0.034	1.154	0.249	Insig
Tourism	←	IoT	0.016	0.031	0.53	0.596	Insig
Tourism	←	ESG	0.208	0.03	6.852	***	Sig
IAT	←	CSF	0.086	0.089	0.965	0.334	Insig
IAT	←	IoT	0.138	0.054	2.539	0.011	Sig

*p < 0.05, **p < 0.01, ***p < 0.001. *Note: CSF = creating sustainability future; FA = facilitating adoption; ESG=environmental, social, governance; IoT= internet of things; IAT = intelligent automation tourism.*

practices. The technical side of intelligent systems, meaning how to design better, more effective artificial intelligence for service delivery, has dominated research on intelligent automation, particularly automation applied to the services sectors (Pinillos et al., 2016; Jabeen et al., 2021). This is mainly due to the virtuous artificial intelligence exploration and innovation process. Given dynamic efficiency, artificial intelligence is projected to have a substantial beneficial influence on the economy, and it is quickly establishing one of the most critical sectors in the economic plan of the world's most industrialized countries (Rao, 2017; Dutton, 2018; Yigitcanlar et al., 2021). As a result, empirical research is committed to initiate what might help developed countries gain traction in the race to achieve the next major accomplishment in AI and intelligent robots. The more funding accessible to spend in technical innovation, the quicker artificial intelligence technology improves (Russell et al., 2015). Likewise, Formosa (2021) defined that artificial intelligence has a relationship with social and human robotics autonomy.

Artificial intelligence (AI) has permeated many organizational processes, raising concerns that clever robots could soon be able to make decisions instead of many individuals. This study analyzes how humans and AI might support each other to incorporate decision-making processes that are generally characterized by unpredictability, uncertainty, and ambiguity, to give a more proactive and realistic viewpoint (Jarrahi, 2018). The current study delineated that ESG was found to be a positive significant predictor for tourism and intelligent automation tourism, which is countering unpredictability, uncertainty, and ambiguity among individuals.

The potential applications of artificial intelligent automation have been widely described in literature. For instance, intelligent automation inquiry in the social sciences is underperforming, which is necessary given the significance of intelligent automation for the mechanisms underpinning social interactions and controlling the community. The majority of research has focused on the socially responsible (and legal) attributes of artificial intelligence and its application (Gurkaynak et al., 2016; Nawi et al., 2021). Furthermore, Huang and Rust (2018) have given prediction about possible future consequences for the social evolution of task and competencies. Intelligent automation design is the best facilitator in the adaptation process (Colby et al., 2016; Colby et al., 2016; Huang and Rust, 2018; Jarrahi, 2018). The social science components of intelligent automation and the technological ones must be prioritized in development of human beings (Russell et al., 2015). In this respect, the study concluded that artificial intelligence is a good predictor for bringing sustainability in the tourism sector and intelligent automation tourism is possible in the future.

The limitations of the study are that, for example, the research of intelligent automation in the social sciences is weak, which is necessary given the importance of intelligent automation for the mechanisms underlying social interactions and community control. Moreover, we intend to continue such research so that we can also contribute to intelligent automation in the social sciences, which would make it especially possible in the scientific field of tourism to be able to be automated through artificial intelligence.

CONCLUSION

In summary, scientific technique has demonstrated high-quality results for the intelligent automation tourism with sustainable environmental and social governance. The idea started from the broad research agenda and then systematically constructed knowledge in the area of artificial intelligence perspective, and its relationship with intelligent automation tourism, as well as conducting robust scientific research to advise policy measures and efforts from diverse stakeholder groups, such as governments and tourism organizations, to confirm the answerable adoption of intelligent automation in tourism. The scientific analysis proposes multiple survey preferences based on key scientific inquiries about artificial intelligence, associated automated technology, and their implementations in tourism. However, constructing beneficial artificial intelligence, facilitating adoption, examining the implications of intelligent automation, and establishing a sustainable vision with the help of ESG criteria could be a good framework for the tourism sector.

The outcome of predictive model leads to the conclusion that artificial intelligence design can improve tourism department if the intelligent automated framework was applied to it. This is because artificial intelligence, internet of things, facilitation adoption, and sustainable ESG had a predictive association found with intelligent automation in tourism.

Contributions

The main achievements, including contributions, may be summarized as follows:

- Artificial intelligence and intelligent automation framework provide an advancement of state-of-the-art for the tourism sector.
- As a social phenomenon and an economic activity, tourism has to be shaped in the future, and this study provides a framework for future research in the field of AI, robotics, IoT, ESG, and intelligent automation in tourism.
- Policymakers should follow artificial intelligence professionals and specialists for intelligent automation in tourism. Afterwards, ESG criteria framework for the future of intelligent automation in the tourism department can positively have an effect.
- It is recommended that artificial intelligence should improve the tourism sector, which positively influences the environment of intelligent automated tourism.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

Conceptualization: LT, WY, and OM. Methodology: LT, WY, and OM. Software: OM. Validation: LT and WY. Writing—original draft preparation: OM and WY. Writing—review and editing: LT and WY. Funding acquisition: OM.

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The Power of Civilization: The Role of Civilized Cities in Corporate ESG Performance

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Civilization usually has a societal impact that is created by well-integrated members of society. The present study argues that government-led construction of a national civilized city encourages enterprises to assume more ESG investments, including social and environmental practices. Based on panel data of Chinese listed firms, we found that if the firm's residence is rated as a national civilized city, the corporate ESG performance improves. This effect is only significant for environmental practices, which are easily quantified and of high concern for the government. In addition, this positive effect is only significant in state-owned firms with a close relationship with the government. We also found that the spotlight effect of the media is an essential guarantee for civilized city policies to improve corporate ESG performance. This study confirms the role of government-led civilized city construction as a soft restraint mechanism in enhancing corporate environmental practices, but also found that there is insufficient motivation for other social responsibilities. These findings expand research on the influencing factors of corporate ESG performance.

Keywords: civilized city, ESG performance, environmental practices, state ownership, media attention

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INTRODUCTION

The uncoordinated nature of urbanization and development patterns in China has promoted economic growth, but it has also led to a series of social issues such as environmental pollution and lack of public order (Lu et al., 2021; Yang et al., 2022a; Zhang et al., 2022). To improve the quality of citizens' lives and promote the sustainable development of cities, the Chinese government has undertaken the construction of civilized cities from top to bottom through national civilized city selection activities. Since firms are economic agents of urban development and should take responsibility for promoting sustainable urban development (He et al., 2019; Xiong et al., 2020; Chai et al., 2022), the present study investigates China's civilized city policy, which aims to improve corporate environmental, social and governance (ESG) performance, exploring the mechanism of this relationship.

ESG is an enterprise evaluation standard or investment concept that pays attention to the environmental, social, and governance performance of enterprises rather than financial performance. Corporate ESG performance can reflect the contribution of enterprises in promoting sustainable economic development and fulfilling social responsibility and is an important factor for investors in the capital market to consider when making investment decisions. CSR covers a wider range of contents, concerns more stakeholders, and applies to a wider range of fields. ESG and CSR have the same goal, that is, enterprises may achieve long-term and steady development and create value for both shareholders and society. How to improve corporate ESG performance has become a hot issue of academic interest. Previous literature has conducted a series of studies from micro perspectives, such as senior executives' moral cultivation (Campbell, 2007), education level (Manner, 2010), management confidence level (Tang et al., 2015), and corporate governance directors' network (Nandy et al., 2020). Some literature has explored the incentive and restraint mechanisms from a macro perspective, such as regional legal systems (Gainet, 2010) and institutional quality (Ucar and Staer, 2020). However, few studies have explored the impact of government-led soft restraint mechanisms on corporate ESG performance from the pilot policies of civilized cities. Zhang et al. (2021) investigated the impact of national civilized city selection on corporate environmental performance and found that the environmental performance of firms was better after their location was selected as a national civilized city. Chai et al. (2022) also found evidence that firms were more active in their social responsibility, especially for the environment, in similar conditions.

We extend the aforementioned literature by examining the impact of civilized cities on corporate ESG performance. Specifically, our original contributions are reflected in the following aspects: first, we conducted various robustness tests, including propensity-score matching with a difference-in-differences (PSM-DID) estimator, event study analysis, and alternative variables method. A series of modern quantitative analysis methods were used to make our findings more convincing. Second, we discovered the important links between politics and business, and the media spotlight effect on the impact of civilized cities on corporate ESG performance. Third, unlike the findings of Chai et al. (2022), we found that after being selected as a national civilized city, corporate ESG practices are characterized by on-the-spot performance, that is, firms are more active in environmental investments, which are more likely to be noticed by the government and more easily quantified. Yet despite this, they place less emphasis on social responsibility, which is not easily captured by external stakeholders.

RESEARCH BACKGROUND

The selection of national civilized cities is a top-down recognition policy implemented by the Chinese government. Its purpose is to praise and encourage cities to improve their civilization and achieve sustainable development (Fu et al., 2021; Li et al., 2021). As early as 1996, the Chinese government included the construction of spiritual civilization in national policy documents, calling for the improvement of citizenship and urban civilization. In 1999 and 2002, the Chinese central government honored progressive cities across the country for creating civilized cities, which was a precursor to the national civilized city policy. To further improve the effectiveness of the construction of urban civilization, the central government raised the national civilized city standards in 2003 and announced the evaluation indicators the following year. In 2005, China announced the first batch of national civilized cities, and since then, the central government has selected national civilized cities every 3 years.

The national civilized city is considered to be the highest honor for Chinese cities (Shi et al., 2019). The latest national selection of civilized cities contains nearly 200 indicators to construct a strict evaluation mechanism. Thus, being selected as a national civilized city has a long-term impact on the city's economy and society. In addition, the Chinese government has a high authority (Yang et al., 2022b). The top-down leadership of the Chinese government in constructing civilized cities can often be supported by local businesses and individuals (Liu et al., 2021a; Liu et al., 2021b; Zhang et al., 2021). Therefore, the national civilized city policy may encourage firms to take on more social and environmental responsibilities.

The goal of national civilized city construction and corporate ESG performance is consistent, which is to achieve sustainable economic and social development (Chai et al., 2022). Firms need to fulfill the social responsibility entrusted to them by the city government to obtain legitimacy from local governments (Xu et al., 2021). The environment is the core indicator of a civilized city (Shao et al., 2021; Yue et al., 2021). The construction of a national civilized city has put forward higher and stricter requirements for corporate environmental responsibility (Zhang et al., 2021). Therefore, in the process of constructing a civilized city, firms tend to invest more in ESG practices to meet government expectations (Chai et al., 2022).

METHODOLOGY

Sample and Data

Our initial sample consists of China's A-share listed firms in the Shanghai and Shenzhen stock exchanges from 2010 to 2017. We selected observations in the light of the following criteria: 1) excluding observations in the banking, insurance, and other financial industries; 2) excluding observations with transaction statuses of special treatment (ST), suspension from trading (*ST) or particular transfer (PT); 3) excluding observations with only one-year data; and 4) excluding observations with missing and unavailable data. Finally, we obtained the unbalanced panel data of 13,119 observations as the final sample.

The financial data related to the listed firms come from the China Stock Market and Accounting Research (CSMAR) database and Wind database. City-level data came from the China City Statistical Yearbook. Corporate social responsibility data is an evaluation index sourced from the Hexun Database[1]. This index started in 2010, and the civilized city pilot was implemented for two sessions before 2010. To eliminate the interference of the two civilized city selection activities on the empirical results, we excluded the sample of cities that were covered by the two selections mentioned above.

[1]The corporate social responsibility index is available at: http://stockdata.stock.hexun.com/zrbg/Plate.aspx?date=2021-12-31.

TABLE 1 | The impact of civilized cities on corporate ESG performance.

	(1)	(2)	(3)	(4)	(5)	(6)
Civ_City	0.049**		0.057**	0.045**	0.054**	0.049**
	(2.393)		(2.154)	(2.175)	(2.302)	(2.191)
Civ_City (−3)		0.009				
		(0.252)				
Civ_City (−2)		−0.018				
		(−0.522)				
Civ_City (−1)		0.046				
		(1.350)				
Civ_City (0)		0.055				
		(1.482)				
Civ_City (1+)		0.058*				
		(1.649)				
Civ_City (2+)		0.072*				
		(1.836)				
Civ_City (3+)		0.076*				
		(1.693)				
Control Variables	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Observations	13,199	13,199	7,507	13,199	11,587	13,199
Adj_R2	0.460	0.460	0.479	0.466	0.483	0.460

*Robust standard errors are in parentheses; ***, **, * are significant at the 10%, 5%, and 1% levels, respectively; control variables are included in the regressions.*

Estimation Models

Considering that the national civilized cities are selected in batches, we set the following progressive difference-in-difference (DID) model:

$$LnESG_{ict} = a_0 + a_1 Civ\_City_{ct} + \sum a_j Controls_{cit} + \delta_t + \theta_i + \varepsilon_{cit}$$

Among them, $LnESG_{ict}$ represents the ESG performance of enterprise i in year t. Civ_City_{ct} means whether city c was rated as a national civilized city in the year t. $Controls_{cit}$ is a set of control variables at the city and firm levels. The fixed effect of the firm (θ_i) and year fixed effect (δ_t) is added to the model, and ε_{cit} is a random disturbance term.

Variables

Corporate ESG performance is the dependent variable. We used the corporate social responsibility index evaluated by Hexun because this corporate social responsibility index includes the main content of ESG performance (Long and Zhang, 2021). In order to avoid the problem of heteroscedasticity caused by the absolute value, we used its logarithm value.

The national civilized city is the core explanatory variable, and we used a dummy variable to indicate whether the policy was implemented. The two civilized city selection times involved in the sample period were 21 December 2011, and 28 February 2015. Therefore, we set the corresponding city policy time to 2012 and 2015, respectively.

In addition, we also added the following control variables in the regression. At the regional level, we controlled GDP per capita (*LnPGDP*), measured by the logarithm value of GDP per capita, and population density (*Population*), measured by the ratio of urban population to the administrative area. At the firm level, we controlled firm size (*Size*), measured by the logarithm value of total assets, financial leverage (*Lev*), measured by the ratio of total liabilities to total assets, profitability (*Roa*), measured by the ratio of total profits to total assets, firm age (*Age*), measured by the logarithm value of the years since its establishment, and property right (*Soe*), measured by the dummy variable coded as 1 if the firm is a state-owned.

RESULTS

Benchmark Regression

Table 1 shows the results of the impact of the selection as the national civilized cities on corporate ESG performance. In Model 1, the coefficient of *Civ_City* is significantly positive at the level of 5%, indicating that national civilized cities enhance corporate ESG performance. This is consistent with the conclusion of Chai et al. (2022) that the construction of a national civilized city led by the Chinese government has effectively strengthened the sense of corporate social responsibility. Under the government pressure and soft restraint mechanism brought about by the national civilized city selection policy, firms often help create a national civilized city by assuming more social responsibilities. Therefore, local governments constructing national civilized cities make a top-down pressure transmission mechanism for local firms, forcing them to invest in ESG actively.

The basic premise for applying the DID model is that there is no systematic difference in the corporate ESG performance between the experimental group and the control group before implementing the policy. To test whether this premise is confirmed, we refer to the practice of Li et al. (2016) and try whether the parallel trend condition is satisfied based on the event study analysis. Specifically, we proposed the following estimation model:

$$LnESG_{ict} = a_0 + \sum_{k=-3}^{3+} \alpha_k Civ\_City_k + \sum a_j Controls_{cit} + \delta_t + \theta_i + \varepsilon_{cit}$$

Among them, Civ_City_k represents the dummy variable of the kth year of policy implementation, valuing 1 when the experimental group is in the kth year of policy implementation and 0 otherwise. Model 2 in **Table 1** shows the results estimated by the above estimation model. In each year before the policy was implemented, the coefficients of *Civ_City* are not significant, which satisfies the assumption of parallel trends, and the DID model is suitable for the evaluation of policy effects in this study.

To further test whether the above results are robust, we conducted the following tests: 1) to reduce the effect of selection bias on the empirical results, we provided the results of the estimation of samples based on the propensity score matching method after 1:1 proximity no-put back matching in Model 3; 2) to eliminate the interference of the development trend of different industries on the empirical results, we controlled the fixed effect of industry-year multiplication in Model 4; 3) to alleviate the problems caused by missing values

TABLE 2 | Heterogeneity analysis.

	(1)	(2)	(3)	(4)	(5)	(6)
	Different types of responsibilities		Nature of property rights		Media attention	
	Environmental responsibility	Shareholder responsibility	State-owned	Non-state-owned	High attention	Low attention
Civ_City	0.054**	0.023	0.082**	0.005	0.065**	0.042
	(2.507)	(1.482)	(2.517)	(0.195)	(1.991)	(1.283)
Control Variables	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Observations	13,199	12,994	5,727	7,432	5,344	5,330
Adj_R2	0.184	0.427	0.483	0.507	0.529	0.479

*Robust standard errors are in parentheses; ***, **, * are significant at the 10%, 5%, and 1% levels, respectively; control variables are included in the regressions.*

of data, we further increased the variables at the city level in Model 5, including the proportion of the added value of the tertiary industry to GDP, the size of the government (the ratio of fiscal expenditure to GDP), and the level of opening up (the ratio of foreign direct investment to GDP). At the firm level, we added the proportion of intangible assets to total assets, the proportion of tangible assets to total assets, and the proportion of shares held by the top ten shareholders; and 4) to alleviate the serial autocorrelation problem of residuals among firms, we clustered the standard errors of coefficients at the firm level in Model 6. The above results show that the coefficients of Civ_City are always positive at the 5% level of significance, indicating that national civilized cities will improve corporate ESG performance, which is consistent with our main findings.

Further Analysis of the Heterogeneity of Different Social Responsibilities

Our dependent variable, corporate ESG performance, is measured by the corporate social responsibility index evaluated by Hexun, which mainly consists of the environmental responsibility index and shareholder responsibility index. We separated the two indexes to estimate the regressions. Models 1 and 2 in **Table 2** show the results. It can be seen that after the city is selected as the national civilized city, corporate environmental responsibility has been significantly increased, but the impact on shareholder responsibilities is not significant. This finding is contrary to Chai et al. (2022) but is consistent with the logic of corporate behaviors under government regulation. Firms assuming social responsibility have the characteristics of acting on the spot. Specifically, when the city is selected as the national civilized city, the local government requires firms to assume more social responsibility, primarily environmental responsibility. Firms pursuing economic interests are more willing to take on environmental responsibilities that are highly quantifiable while ignoring shareholder responsibilities that the government is less concerned about and hard to supervise.

Further Analysis of the Heterogeneity of Property Rights

From the perspective of property rights, state-owned firms have more political connections and are more closely related to the government (Lou et al., 2021). Compared with non-state-owned ones, they are more likely to reach agreements with government goals (Kim and Sumner, 2021). The civilized city policy may be more able to increase the ESG performance of state-owned firms. We divided the sample into two sub-samples, one for state-owned firms and another for non-state-owned firms. We found that national civilized cities have improved the ESG performance of state-owned firms, but the impact on non-state-owned firms is not significant. Models 3 and 4 in **Table 2** report this heterogeneous impact. This result is consistent with our logical conjecture. It also confirmed the findings of Cheng et al. (2021) that state-owned firms play an essential role in implementing government policies, while non-state-owned ones have relatively little feedback and implementation.

Further Analysis of the Role of Media Attention

The media is an external supplement to the corporate governance mechanism (Xiong and Luo, 2021). The brand effect of civilized cities will attract more media attention. When the city is selected as the national civilized city, corporate behaviors, especially social responsibility behaviors, receive special attention from the media, and the firms are required to perform more social responsibility (Zhou et al., 2019). We used the number of times a firm was reported in the news as a proxy variable for its media attention. Based on the median value of the number of reporting times in one industry each year, we divided the sample into two sub-samples, one for high media attention and another for low media attention. We found that firms that have received more media attention will have a better ESG performance when their cities are selected as the national civilized cities. However, the ESG performance of firms with low media attention has not been affected by the national civilized cities, as shown in models 5 and 6 in **Table 2**. This is a unique discovery of this paper. It can be seen that the spotlight effect of the media is an essential guarantee for civilized city policy to enhance corporate ESG performance. This result is similar to the findings of Xiong and Luo (2021), that is, the media spotlight effect will increase the transparency of corporate behavior, inhibit corporate anomie behavior, and encourage firms to fulfill their social responsibilities.

CONCLUSION

To regulate the social order and promote the sustainable development of cities, China encourages the construction of civilized cities from top to bottom. Based on the panel data of China from 2010 to 2017, using the PSM-DID method, this paper explores the role of civilized cities in corporate ESG performance. The main findings of this paper are as follows. First, national civilized cities improve corporate ESG performance. Second, civilized city policy can more significantly improve the ESG performance of state-owned enterprises, but has no significant impact on that of non-state-owned enterprises, which is similar to the conclusions of existing literature (Chai et al., 2022). This result might be because state-owned enterprises are more inclined to cooperate with local governments in the construction of civilized cities due to close political connections. Third, the civilized city policy can significantly improve corporate environmental responsibilities, but its impact on shareholder responsibilities is not significant. This is probably because ecological civilization is the core of civilized city construction and the focus of government attention. Thus, the effect of national civilized cities is only reflected in the environmental responsibility that the government pays more attention to and is easy to quantify. The incentive effect on other social responsibilities is insufficient. This is a unique finding of this paper and an important supplement to existing literature. Fourth, the civilized city policy can significantly improve the ESG performance of enterprises that have received more media attention, but its impact on enterprises with less media attention is not significant. In other words, the spotlight effect of the media is an essential guarantee for civilized city policies to enhance corporate ESG performance. This is an original discovery of this paper, and also an important breakthrough in this research field.

Our study also has some shortcomings. Due to ESG performance data restrictions, we only focused on listed firms in China. However, the impact of national civilized cities on the ESG performance of non-listed small- and medium-sized firms lacks a systematic study. In future research, we will add ESG evaluation indicators and use data from multiple countries. In addition, we have not conducted an in-depth investigation on external institutional factors. When studying the impact of government actions on corporate ESG performance, the institutional mechanism of external policies such as environmental regulations, cannot be ignored, which needs further research in the future.

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

Conceptualization, ZQ and WL; methodology, EZ and CW; data analysis, ZQ and EZ; validation, WL; investigation, ZQ; resources, WL; writing—original draft preparation, ZQ and EZ; writing—review and editing, CW and WL; visualization, ZQ; supervision, WL and CW; project administration, WL. All authors have read and agreed to the published version of the manuscript.

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Does ESG Disclosure Help Improve Intangible Capital? Evidence From A-Share Listed Companies

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With the disclosure of ESG, the investment related to ESG disclosure has increased, and the trend of changes in intangible capital has shown an "inverted S-shaped" curve. The research shows that, in the initial stage of investment in ESG construction, new ESG investments increase intangible capital. With the increase in ESG investment and the advancement of time, the positive effect of the increase in ESG scores on intangible capital begins to appear and gradually offsets the cost of ESG investment. However, when the ESG score of a company is raised to a certain level, the marginal effect of continuing to increase ESG investment will reduce the increase in intangible capital.

Keywords: ESG, business performance, corporate profits, net profit, marginal effect

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INTRODUCTION

Climate change has become a real and urgent crisis facing mankind, and a serious and long-term challenge. To address global climate change, the United Nations calls on countries to take practical action to reduce carbon emissions and to achieve harmony between humans and nature. Balancing the environment and economic development to achieve a harmonious coexistence between humans and nature, the issue of environmental sustainability has become one of the top priorities of current concerns. The Party Central Committee attaches great importance to the sustainable development of the environment and economy, and green and low-carbon strategies are gradually emerging. The 18th Party Central Committee, with Comrade Xi Jinping at the core, has put forward the climate action goals of "ecological civilization construction" and "carbon neutral, carbon peak". According to the "Carbon Summit Action Plan by 2030" issued by the State Council in 2021, during the period of the "14th Five-Year Plan", a green and low-carbon approach has become the way to promote high-quality development and ecological civilization construction. The United Nations continues to promote the ESG (environmental, social, governance) regulation as the main body for carbon reduction. Since ESG first appeared in the UN's *Who Cares Wins* report in 2004 and the United Nations Global Compact (UNGC) and the United Nations Environment Programme Sustainable Finance Initiative (UNEPFI) jointly released the Principles for Responsible Investment (PRI) in 2006, ESG regulation and disclosure policies worldwide have been gradually improved. For example, the European Union has a centralized department for the development of ESG regulatory policy, and has established a complete "regulation–guidance–training–disclosure" system for the regulation of ESG disclosure and mandatory legislation on information disclosure. In the US, the disclosure of ESG information is guided by the market; for example, a large number of passive ESG fund products are issued by mutual fund companies, which broaden the financial financing channels of listed companies with high ESG performance and motivate listed companies to disclose ESG voluntarily. In Japan, pension fund investment is used as a capital guide to invest in listed companies with high ESG performance and motivate listed companies to actively disclose their ESG information.

In order to implement the goals of the Paris Agreement, the Chinese government has proposed the goal and initiatives of "carbon neutrality and carbon peaking" in 2020. As a public enterprise, listed companies should play the role of capital market and be the main force to achieve carbon neutrality and the carbon peak strategy. In order to urge Chinese listed companies to improve the quality of information disclosure, the relevant Chinese authorities started to improve the relevant system as early as 2016. In 2016, the People's Bank and seven other ministries and commissions issued the *Guidance on Building a Green Financial System*, proposing to establish and improve the mandatory environmental information disclosure system for listed companies. In the same year, the CSRC revised the provisions on the content and format of annual and semi-annual reports in *The Guidelines on the Content and Format of Information Disclosure by Companies Issuing Public Securities*. Companies and their subsidiaries that are key emission units announced by the environmental protection authorities should disclose relevant environmental information. In December 2017, the CSRC promulgated *The Guidelines on the Content and Format of Information Disclosure by Companies Issuing Public Securities No. 2: Content and Format of Annual Reports (Revised 2017),* which stipulates that if the content of environmental information is disclosed in the form of interim reports during the reporting period, the subsequent progress or changes shall be explained. Companies other than key emission units may disclose their environmental information with reference to the above requirements, and if not, the reasons shall be fully explained. Companies are encouraged to voluntarily disclose relevant information that is conducive to protecting ecology, preventing pollution and fulfilling environmental responsibilities. In September 2018, the SEC issued the revised Code of Governance for Listed Companies, which states that "listed companies should pay attention to the welfare of the communities in which they are located, environmental protection, public welfare and other issues while maintaining the company's sustainable development and maximizing shareholders' interests, and attach importance to the company's social responsibility." Under the urging of relevant authorities, the amount of voluntary ESG information disclosures by listed companies has increased significantly. According to data from the Shanghai Stock Exchange, of the 1,420 listed companies that released their annual reports in 2017, 855 made disclosures of environmental information, an increase of 235% from the previous year. Among them, 386 companies were key emission units and 439 were voluntary disclosures. In addition, 666 listed companies disclosed environmental information in their semi-annual reports in 2018, up 40% from the previous year, according to Shenzhen Stock Exchange data. A total of 215 companies voluntarily disclosed more environmental information, including the establishment and implementation of the environmental responsibility system, the amount of environmental investment, the acquisition of environmental management system certification and the development of cleaner production audits. More than 1,500 listed companies disclosed

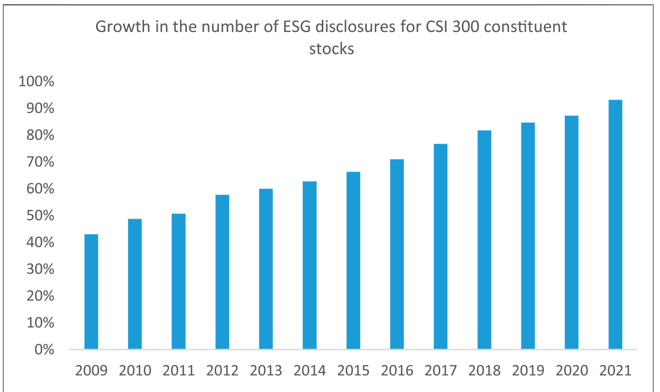

FIGURE 1 | Growth in the number of ESG disclosures for CSI 300 constituent stocks. Source: Shang Dao Rong Green, Wind Information.

environmental information in their semi-annual reports in 2021, making it the year in which listed companies disclosed the most ESG-related information. While listed companies are disclosing ESG-related information, Chinese public funds are launching ESG products on an increasingly large scale. According to the data of the *China Responsible Investment Annual Report 2020*, the scale of China's pan-ESG public securities funds per month was 120.972 billion yuan in 2020, and the number of pan-ESG indices released reached 52, including 15 in the ESG preferred category, 6 in the corporate governance preferred category, 2 in the starting low-carbon preferred category, and 27 in the energy-saving and environmental protection industry category.

The voluntary disclosure of ESG by listed companies has increased significantly, as shown in **Figure 1**. As shown in **Figure 1**, the number of ESG information disclosures of CSI 300 constituents, for example, increased by 43% in 2009 and reached 81.8% in 2018. In the process of the voluntary disclosure of ESG information, how do listed companies implement the content of ESG information? Does investing working capital in ESG-related disclosures lead to corporate operating performance, and what is the mechanism by which ESG information disclosure is causing changes in intangible capital ? The traditional view is that managers have a special responsibility to maximize shareholder value under the constraints of relevant laws and regulations, whereas some argue that management has a more important responsibility not only to shareholders but also to a wider range of stakeholders. When management is biased toward social responsibility, it invests more in ESG disclosure and reports implementing higher cost socially responsible investments, which can increase intangible capital even if financial incentives exist. Firms perform better financially when management's preference for CSR investments is higher than when managers have a strong preference for wealth (Martin, 2021). It has also been shown that there is a non-negative relationship between ESG disclosure and corporate financial performance (Li et al., 2017; Wang and Sarkis, 2017; Kuo et al., 2021), and it will cause changes in intangible capital.

Overall, existing studies have not analyzed the impact of ESG disclosure on the intangible capital of firms in terms of changes in ESG scores due to ESG disclosure by micro firms. The possible marginal contributions of this study include: first, introducing the square of log ESG scores, exploring the dynamic process of the changes in voluntary ESG disclosure on intangible capital, and revealing the "inverted U" type relationship between ESG disclosure and intangible capital; second, exploring the impact of the change in ESG score on intangible capital from the perspective of micro-corporate ESG change, and further elucidating the impact of ESG disclosure on intangible capital. Finally, the impact of ESG disclosure on intangible capital is discussed from the perspective of developing countries, which enriches the relevant research results at the level of ESG disclosure. Generally, there is a transition period after listed companies receive regulatory requirements, but the process of ESG information disclosure by Chinese companies shows that listed companies are responsive to disclosure (as seen in **Figure 1**), reflecting their sense of social responsibility as public companies.

LITERATURE REVIEW AND RESEARCH HYPOTHESIS

ESG Disclosure and Intangible Capital

Intangible capital is usually defined as the intangible resources that enter the production process (Yang and Shi, 2018), mainly including software, intellectual property, brand and innovative business process (Crouzet and Eberly, 2018), and is highly correlated with tangible capital (McGrattan Ellen and Prescott, 2014), is one of the important driving forces of enterprise business activities. In the early stage of enterprise digital transformation, except for equipment related to digital equipment, enterprises need to invest intangible resources such as human resources, technical know-how, information network and enterprise culture in business process transformation, management and operation training, software maintenance and other fields.

In the context of advocating for the green economy, sustainable investment is increasingly becoming one of the important issues of concern for all aspects of society. In response to the carbon neutrality and carbon peaking strategies advocated by the government, listed companies are increasingly focusing on disclosing information about ESG, and investors are increasingly concerned about corporate ESG disclosure (Khan et al., 2016). ESG disclosure is valuable to shareholders and can have an impact on corporate value, but ESG can amplify the true value of overvalued companies and reduce the true value of undervalued firms (Bofinger et al., 2022). What is the contribution of voluntary ESG disclosure for listed companies to the listed companies themselves? To this end, studies have been conducted on the relationship between ESG disclosure and corporate financial performance, but the findings are mixed. A total of 90% of the studies suggest that there is a non-negative relationship between ESG disclosure and corporate financial performance, such as Wang and Sarkis (2017) and Li et al. (2017). The main studies can be divided into two types. The "social impact hypothesis" believes that the better a company fulfills its social responsibility, the better its financial performance will be. Its logic has two points: 1) improving social influence and attracting more customers through corporate social responsibility initiatives can build a positive, upbeat social image, and increase intangible capital, which in turn can widely attract potential customers and expand the market share. 2) Improving employees' sense of belonging and identity can enhance productivity. By attaching importance to the working environment of employees and establishing a comprehensive talent training mechanism, companies can bring a sense of belonging to their employees and promote their initiative, thus improving the overall productivity of the company. Therefore, ESG investment can lead to higher financial performance through the above two social impact mechanisms. The optimal social responsibility hypothesis proposes that the relationship between CSR and corporate financial performance is not a simple linear relationship, but rather a relationship similar to an inverted U-shape; if a company invests too much in ESG, it will correspondingly reduce its financial profit (Bowman and Haire, 1975), but can increase intangible capital. Based on this, hypothesis 1:

Hypothesis 1: ESG information disclosure promotes the increase of intangible capital.

Transmission Mechanism of ESG Information Disclosure to Intangible Capital

In terms of the drivers of the impact of intangible capital at ESG disclosure sites, there are studies to enhance ESG performance by decomposing corporate value into profitability and the cost of equity capital (Zhang et al., 2021), and by increasing Tobin's Q (Wong et al., 2021), improving corporate cash flow (Gregory, 2021) and reducing the cost of debt (Eliwa et al., 2021) to enhance intangible capital. Furthermore, Kuo et al. (2021) tracking study of ESG performance indicators and the short-term financial performance of 30 airlines worldwide showed that in the initial stage of ESG implementation, airlines' return on assets tended to decrease; in the long-term implementation process, ESG implementation helped airlines' return on assets increase.

It has also been shown that ESG disclosure shows a weak correlation with intangible capital (Friede et al., 2015). In non-linear models, ESG disclosure has a U-shaped relationship with financial performance, whereas in linear models, ESG disclosure has no linear relationship with financial performance (Nollet et al., 2016). For emerging market countries, ESG disclosure is not related to firm profitability (Garcia et al., 2017).

Although studies on ESG information disclosure and corporate value have reached different conclusions, under the carbon neutral and carbon peak strategy, the voluntary disclosure of ESG information by listed companies helps to achieve communication with suppliers and consumers and realize the improvement of intangible capital. ESG information disclosure and improvement of intangible capitalis a nonlinear relationship. The early stage of ESG information disclosure leads to a significant increase in costs and a decline in corporate business performance; when ESG inputs reach a certain level, ESG information disclosure will promote the improvement of intangible capital.

Intangible capital, such as software and information system, is becoming more and more important to corporate profitability, and the expansibility of intangible capital makes it easier for enterprises to obtain competitive advantages (Autor et al., 2020; Akcigit and Ates, 2021). The influence of intangible capital on enterprise performance can be summarized from two aspects. On the one hand, enterprise productivity can be improved by improving industry concentration and market power (Crouzet Nicolas Eberly, 2019; Crouzet Nicolas Eberly, 2019); On the other hand, enterprises adopt more intangible capital and scale-biased technology brought about by the progress of information technology to form the "superstar" effect (Autor et al., 2020) and achieve stable profit growth. Intangible capital not only has an impact on business performance, but also affects the quality of macro-economy. Intangible capital is an important source of productivity and economic growth (Yang and Shi, 2018). Crouzet and Eberly (2021) research shows that intangible capital affects the accuracy of TOTAL factor productivity in The United States, especially when the mismeasurement of intangible capital and the increase of the addition rate will lead to one-third to two-thirds of the downward deviation of total factor productivity growth in the United States.

Studies have shown that there is a certain promoting relationship between firm performance and intangible capital. Based on this, hypothesis 2 are proposed:

Hypothesis 2: ESG disclosure and intangible capital have an inverted U shape.

Since the mandatory disclosure of ESG information by listed companies started in 2017, some companies may fail to comprehend the role of ESG in the early stage of ESG disclosure, resulting in ESG scores that may not reflect the true value of the company. However, ESG disclosure enables communication with investors, and it plays a key moderating role, which mitigates the negative impact of disadvantaged firms and weakens the positive impact of advantaged firms (Fatemi et al., 2018). There are significant changes in corporate ESG ratings as firms continue to increase their investment in ESG. Changes in ESG rating affect stock price performance. Shanaev and Ghimire (2021) investigate the impact of changes in 748 ESG ratings on the stock returns of U.S. companies from 2016 to 2021 by using a calendar time portfolio approach. Their study then showed that ESG rating upgrades result in a 0.5% increase in monthly returns, whereas ESG rating downgrades are detrimental to stock performance. Of course, ESG disclosure helps to mitigate uncertainty (Gregory, 2022), and the voluntariness of firms to increase ESG disclosure to mitigate uncertainty increases. Because enterprise performance and intangible capital have promotion relationship, hypothesis 3 is proposed:

Hypothesis:3: Changes in ESG scores affect intangible capital.

MODEL AND DATA

1) Model

To measure the relationship between ESG disclosure and intangible capital, the following model is introduced:

TABLE 1 | Statistical description of the main variables.

Variable	Obs	Mean	Std. Dev	Min	Max
lnesg	5,471	6.29	0.96	2.15	9.68
lnesg^2	5,471	3.36	0.56	0.59	5.15
fs_esg	1,427	1.29	0.56	0.3	3.9
lnprofit	14,872	0.55	1.54	–4.61	8.06
lncash	16,153	1.59	1.66	–4.61	9.79
lndebt	16,161	3.61	0.58	–0.17	7.54
lnroe	14,843	2.14	0.97	–3.91	6.89
lnxrd	14,319	-0.58	1.57	–9.21	5.68
lncaptial	16,025	0.13	1.80	–4.61	8.09
lnint_cap	16,126	1.32	1.38	–3.22	8.59
lnshare_holder	14,195	4.07	0.29	2.11	4.61

$$\ln \text{int\_}cap_{it} = \alpha + \beta_1 \ln esg_{it} + \beta_2 \ln esg_{it}^2 + \beta_3 X_{it} + \varepsilon_{it} \quad (1)$$

esg_{it} in **Equation 1** denotes the logarithm of the ESG score of company i in period t, represents the result of ESG "output". $\ln int\_cap_{it}$ denotes the logarithm of intangible capital i in period t. X_{it} denotes the set of control variables, mainly the log of the net cash flow at the end of the period (ln*cash*), the log of net profit that is attributable to the parent company of company (ln*profit*), the log of the assets and liabilities (ln*debt*), the log of capital expenditure (ln*capital*), the log of the return on net assets (ln*roe*), the log of R&D spending (ln*xrd*), the log of the top ten shareholders' shareholding ratio (ln*share_holder*). To further characterize the relationship between ESG disclosure and the intangible capital of listed companies, this study controls for time and firm fixed effects.

Intangible capital has been considered to be particularly elusive, and its depreciation rate is unknown, so it is difficult to adopt the methods traditionally used to evaluate the capital stock (Tambe et al., 2020). How to measure intangible capital is one of the core issues concerned by academia. Throughout the existing studies, the main methods for measuring intangible capital are as follows: Enterprises' intellectual capital and organizational capital (Peters & Taylor, 2017), Tobin Q (Brynjolfsson et al., 2021), IT investment measurement (Tambe et al., 2020), input-output measurement (McGrattan Ellen and Prescott, 2014). Intangible capital input mainly includes intellectual capital and organizational capital (Eisfeldt and Papanikolaou, 2014; Peters and Taylor, 2017), intellectual capital is measured by R&D input expenditure, and the sum of selling, General, and Administrative (SG&A) expenditure and intellectual capital and organizational capital are counted as intangible capital by perpetual inventory method. The intangible capital accounting method in this study is based on Peters and Taylor (2017).

2) Description of data and key indicators

ESG disclosure data for A-shares started in 2017, and the data collection period for the equity study is from 2017 to 2020 for non-ST stocks in A-shares. ESG indicators refer to CSR scores, and this study mainly uses A-share Wind scoring criteria and FTSE Russell scoring criteria.

TABLE 2 | Baseline regression results.

	ln*int_cap*	ln*int_cap*	Lnsg
	(1)	(2)	(3)
lnesg	1.28*** (0.16)	1.35*** (0.16)	1.25** (0.49)
lnesg^2	−2.43*** (0.28)	−2.54*** (0.27)	−2.18** (0.85)
lncash	0.07*** (0.01)	0.03** (0.01)	−0.11*** (0.04)
lndebt	0.16*** (0.03)	0.05 (0.03)	0.17* (0.10)
lnroe	−0.21*** (0.03)	0.03 (0.04)	−0.31** (0.14)
lnprofit	0.27*** (0.03)	0.05 (0.04)	0.24* (0.14)
lnshare_holder	0.28*** (0.06)	0.30*** (0.06)	0.17 (0.19)
lncapital	0.02*** (0.009)	0.01 (0.009)	−0.008 (0.03)
lnxrd	0.17*** (0.01)	0.16*** (0.01)	0.04 (0.04)
sa	—	−0.92*** (0.10)	−3.55*** (0.38)
Corporate fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Adj-R^2	0.96	0.96	0.92
Observations	4,593	4,593	3,066

*Note: ***, ** and * denote 1, 5 and 10% significance levels, respectively; values in parentheses are standard errors.*

TABLE 3 | Robustness tests.

	ln*int_cap*	ln*int_cap*	ln*int_cap*
	GMM	2SLS	OLS
	(1)	(2)	(3)
lnesg	0.45** (0.19)	0.60*** (0.17)	0.76*** (0.19)
lnesg^2	−0.77** (0.32)	−1.01*** (0.29)	−1.47*** (0.33)
lncash	0.21*** (0.01)	0.22*** (0.02)	-0.00 (0.02)
lndebt	0.22*** (0.02)	0.22*** (0.02)	0.08* (0.05)
lnroe	−0.26*** (0.02)	−0.25*** (0.02)	-0.07 (0.05)
lnprofit	0.39*** (0.02)	0.38*** (0.02)	0.11** (0.05)
lnshare_holder	0.22*** (0.04)	0.20*** (0.03)	0.15** (0.08)
lncapital	0.01 (0.009)	0.05 (0.08)	0.03*** (0.01)
lnxrd	0.25*** (0.01)	0.25*** (0.01)	0.16*** (0.01)
sa	0.005** (0.002)	0.005 (0.04)	−1.15*** (0.15)
Corporate fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Adj-R^2	—	0.72	0.97
Observations	4,593	4,593	2096

*Note: ***, ** and * denote 1, 5 and 10% significance levels, respectively; values in parentheses are standard errors.*

The main variables involved in this study are shown in **Table 1**. As shown in **Table 1**, the mean value of the ESG score of the listed companies is 6.29, and the minimum and maximum values are 2.15 and 9.68, respectively, indicating that under the policy initiative, listed companies all start to disclose the relevant ESG indicators, but the funds invested in the governance of ESG by different companies show large differences, which can be seen mainly from the ESG score. The differences in the capital invested in ESG governance can be seen from the relevant financial indicators, such as the fact that the mean value of the logarithm of the cash flow of the listed companies is 1.59, and the minimum and maximum values are −4.61 and 9.79, respectively, indicating that there is significant heterogeneity in the cash flow of the listed companies. This leads to significant differences in the effect of enterprises in ESG governance due to financial constraints.

The sample size of FTS Russell ESG scores data is less, only about 1,400. Although there are fewer observations of FTSE Russell ESG scores, it also shows heterogeneity in ESG scores across companies.

EMPIRICAL RESULTS

1) Basic regression results

The results of the benchmark regressions of this study are presented in **Table 2**. Column (1) of **Table 2** indicates that ESG disclosure helps to increase intangible capital, as shown by the significantly positive coefficient of ln*esg*. However, the improvement of intangible capital by ESG disclosure is not instantaneous, and the growth rate of the listed companies' intangible capital slows down as companies increase their investment in the ESG field. This shows that the coefficient of $(\ln esg)^2$ is significantly negative, indicating that the investment in the ESG field and the intangible capital of the listed companies show a typical "inverted U" trend. After further controlling for financing constraints (sa), the results in column (2) of **Table 2** remain robust, and the conclusion that ESG disclosure helps improve intangible capital still holds. To test the robustness of this result, the ESG disclosure data is replaced with the business reputation indicator, and the results are presented in column 3) of **Table 2**. The results in column (3) of **Table 2** remain robust. The above findings suggest that ESG disclosure helps to improve intangible capital, but the investment in the area of ESG shows a non-linear relationship with the intangible capital of the listed companies.

The main reasons for the non-linear relationship between the ESG information disclosure of listed companies and intangible capital are as follows: firstly, ESG information disclosure requires relevant information in the fields of environment, social responsibility and governance, etc. According to the framework of the Securities and Futures Commission on ESG disclosure, listed companies collate and collect relevant information or data in the fields of environment, social responsibility and governance, and then they need to increase certain equipment and labor in the first phase. This will undoubtedly cause an increase in the short-term costs of enterprises, which will lead to increase in their short-term intangible capital level. Secondly, ESG disclosure helps to improve performance. When a company takes the initiative to undertake social responsibility, it can announce to the public that it has established a positive image, which in turn attracts potential customers, improves the market share and increases net profit, it can also increase intangible capital. Finally, ESG disclosure helps retain talents. By attaching importance to the working environment of employees and establishing a comprehensive talent training mechanism, companies bring a sense of belonging and humanistic care to their employees, promoting their initiative and, thus, improving the overall productivity of the company, which in turn improves intangible capital.

However, with the increase of ESG investment, the improvement effect of ESG score on intangible capital weakens. When the ESG score of an enterprise is raised to a certain extent, the enterprise has established a good image among the public, and it may be "uneconomical" to maintain a better image through ESG investment.

2) Robustness tests

As we all know, in accounting indicators, some indicators are directly related to each other. In order to overcome the endogeneity problem caused by the connection between indicators, we need to use other tools to test. In this paper, the improvement of ESG score of explanatory variables may be related to R&D investment, net profit, asset-liability ratio and other indicators.

Due to the possible endogeneity problem in OLS regression, GMM, 2SLS and partial sample deletion methods are introduced to test the robustness of the benchmark regression results, which are shown in **Table 3**. Column (1) of **Table 3** uses the GMM method, and its findings are consistent with column (2) of **Table 2**, i.e., ESG disclosure helps increase intangible capital, as shown by the significantly positive coefficient of ln*esg*. However, the improvement of ESG disclosure on intangible capital is not instantaneous, and the growth rate of the listed companies' intangible capital slows down as the companies' investment in the ESG field increases, which shows that the coefficient of $(\ln esg)^2$ is significantly negative. This indicates that the investment in the ESG field and the intangible capital of listed companies show a typical "inverted U" type trend. Column (2) of **Table 3** adopts the 2SLS method, and its results are consistent with column (1) of **Table 3**. Since some public enterprises are relatively more active after the Chinese government authorities advocated ESG information disclosure, and public enterprises in China are mainly state-owned enterprises, the data sample of state-owned enterprises is retained on the basis of column (2) of **Table 2**, and its regression results are consistent with column (2) of **Table 2**. The above result shows that the disclosure of ESG information by public companies helps intangible capital, but the positive relationship between ESG disclosure and intangible capital is not linear; ESG disclosure increases inputs and decreases cash flow, leading to a decrease in operating performance. However, as ESG information disclosure reaches a certain level, the average ESG inputs begin to decline, and intangible capital appears to improve. Similarly, the accuracy of the benchmark regression results was verified again by different methods.

3) Further Discussion

According to the Wind ESG indicator system, it involves 3 major dimensions, 27 topics and more than 300 indicators. For example, in the environmental indicators, indicators such as waste water, waste gas, and green buildings are covered, so that enterprises need to increase investment in environmental governance in order to reduce the "three wastes". Among the social indicators, it mainly involves indicators such as R&D and innovation, occupational health and safety production, product quality, employment, etc. These indicators involve maintaining customer relationships, and it is necessary to increase R&D investment to improve product quality. Governance indicators include auditing, ESG governance, equity and shareholders, corruption and other indicators. Improving governance also requires investment.

Based on the analysis of the above three dimensional indicators, in order to obtain a higher ESG score, it is necessary to continuously increase investment. Therefore, changes in ESG scores can reflect changes in a company's social, environmental, and governance investments.

The above findings explain the relationship between ESG disclosure and the intangible capital of listed companies, but the interaction between changes in ESG scores due to ESG inputs and intangible capital has not been addressed. How does ESG disclosure reflect ESG inputs? The existing data cannot portray the ESG input of listed companies at all. In order to further portray the relationship between the ESG inputs of listed companies and intangible capital, another indicator needs to be found. This study uses the change in ESG score (*esg_diff*) to portray the impact of corporate ESG input. The reasons for choosing the change in ESG score to reflect the change in ESG input are as follows: firstly, a third-party evaluation organization by investigating the EGS score of listed companies is relatively objective. Secondly, since the change in ESG score itself can reflect the indicator of corporate ESG improvement or lack thereof, when the ESG score improves, it is reasonable to believe that the ESG input of listed companies increases, and when the ESG score decreases, then the listed companies' ESG input has not been increased.

Table 4 shows the relationship between changes in the ESG scores of listed companies and intangible capital. Column (1) of **Table 4** considers the influence of DYNAMIC changes of ESG on intangible capital of listed companies, and the results show that change in ESG score helps to increase intangible capital, as shown by the significantly positive coefficient of ln*esg_diff*. However, the improvement of intangible capital by change in ESG score is not instantaneous, and the growth rate of the listed companies' intangible capital slows down as companies increase their investment in the ESG field. This shows that the coefficient of $(\ln esg\_diff)^2$ is significantly negative, indicating that the investment in the ESG field and the intangible capital of the listed companies show a typical "inverted U" trend.

Column (2) of **Table 4** introduces the lagged period variable (*l_profit*) of net profit attributable to the parent company of listed companies, and the results show that the increase in ESG input will reduce the current net profit of enterprises, but will have a boosting effect on the net profit of the latter period, which shows that the coefficient of ln*profit* is significantly negative, whereas *l_profit* (lagged period net profit) is significantly positive.

Column (3) of **Table 4** introduces the two-period lagged variable (*l2_profit*) of net profit attributable to the parent company of the listed companies, and its results show that the increase in ESG input will reduce the current net profit of enterprises, but have a boosting effect on the net profit of the latter two periods, which shows that the coefficient of ln*profit* is significantly negative, whereas *l2_profit* (two-period lagged net profit) is significantly positive, and the two-period lagged net profit significance level and coefficient are greater than

TABLE 4 | The relationship between changes in ESG disclosure and intangible capital.

	ln*int_cap*	ln*int_cap*	ln*int_cap*	ln*int_cap*
	(1)	(2)	(3)	(4)
lnesg_diff	0.16*** (0.03)	0.01*** (0.003)	0.014*** (0.003)	0.014*** (0.003)
$lnesg\_diff^2$	−0.05*** (0.008)	−0.04*** (0.01)	−0.04*** (0.01)	−0.04*** (0.01)
l_profit	—	0.02*** (0.004)	—	—
l2_profit	—	—	0.01*** (0.004)	—
l3_profit	—	—	—	0.03*** (0.01)
lncash	0.023** (0.01)	0.017 (0.011)	0.02** (0.011)	0.02** (0.011)
lndebt	−0.24*** (0.023)	−0.33*** (0.03)	−0.30*** (0.03)	−0.30*** (0.03)
lnroe	0.44*** (0.03)	0.62*** (0.04)	0.48*** (0.03)	0.48*** (0.03)
lnprofit	−0.36*** (0.03)	−0.53*** (0.04)	−0.40*** (0.03)	−0.40*** (0.03)
lnshare_holder	0.49*** (0.05)	0.58*** (0.06)	0.53*** (0.06)	0.53*** (0.06)
lncapital	−0.02*** (0.007)	−0.03*** (0.01)	−0.02*** (0.01)	−0.02*** (0.01)
lnxrd	0.19*** (0.012)	0.18*** (0.01)	0.18*** (0.01)	0.18*** (0.01)
sa	−1.22*** (0.07)	−1.62*** (0.08)	−1.38*** (0.08)	−1.38*** (0.08)
Corporate fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Adj-R^2	0.91	0.91	0.91	0.91
Observations	10,118	9,293	9,279	9,279

*Note: ***, ** and * denote 1, 5 and 10% significance levels, respectively; values in parentheses are standard errors.*

that of the lagged one period. This indicates that the current net profit decreases little with the increase in ESG investment, but has an increasing marginal impact on the future net profit.

Column (4) of **Table 4** introduces the lagged three period variable (*l3_profit*) of net profit attributable to the parent company of the listed companies. The results show that the increase in ESG investment will reduce the net profit of enterprises in the current period, but will have a boosting effect on the net profit in the next three periods, as shown by the significantly negative coefficient of lnprofit and the significantly positive coefficient of *l3_profit* (lagged three period net profit). The results indicate that the increase in ESG investment will reduce the net profit of the company in the current period, but will have a significant contribution to the net profit in the next three periods.

The relationship between changes in ESG scores and intangible capital verifies that the changes in ESG disclosure on intangible capital are not linear as traditionally believed, but rather show a non-linear relationship. The reasons for the non-linear relationship between the change in ESG disclosure and intangible capital are as follows: first, the increase in ESG investment in the short term and increase intangible capital, but in the future years, the increase in ESG investment and intangible capital increase will present “uneconomic” conditions. Secondly, the marginal improvement in future performance is better than the decline in short-term business performance, indicating that the future benefits that the companies can obtain can compensate for the short-term decline in performance, which is one of the motivations for companies to be willing to actively disclose ESG information.

4) Heterogeneity Analysis

The data description in **Table 1** already shows that heterogeneity characteristics exist among different listed companies. Moreover, the heterogeneity is evident in different types of companies. In order to study the relationship between ESG and intangible capital, this study examines the heterogeneity from the business level and the region where the companies are located, and the results are shown in **Table 5**.

Columns (1) to (4) of **Table 5** show the geographic regions in which the companies are located, which can generally be divided into four regions, namely, East, Central, West and Northeast. For listed companies in the East, Central and West, the results in column (1), (2) and (3) of **Table 5** show that the ESG disclosure of the listed companies promotes intangible capital, and with the increase in ESG disclosure investment, ESG disclosure and intangible capital show an “inverted U” shape, which shows that the coefficient of ln*esg* is significantly positive, whereas the coefficient of $(\ln esg)^2$ is significantly negative. For listed companies in Northeastern regions, the results in columns (4) of **Table 5** indicate that ESG information disclosure by listed companies does not contribute to the improvement of intangible capital, and there is no “inverted U” type relationship between ESG information disclosure and intangible capital. The reasons for the above differences may be as follows: firstly, for the East, Central and West, the listed companies are located in a region with better economic vitality, the communication between enterprises and investors is more adequate, and the listed companies are more willing to disclose information. Secondly, for the regions with relatively weak economic vitality, the exposure of the listed companies may not be too high, and they also face certain financial constraints. Thirdly, the transformation and upgrading of the old industrial base in northeast China is slow.

Columns (5) and (6) of **Table 5** measure the impact of ESG disclosure on intangible capital in terms of good and bad corporate performance. The classification of good and bad corporate performance is based on the mean value of the logarithm of the return on net assets of the listed companies,

TABLE 5 | Heterogeneity analysis results.

	ln*int_cap*				ln*int_cap*		ln*int_cap*	
	East	Central	West	Northeast	Good Performance	Poor Performance	High per Capita Income Generation	Low per Capita Income Generation
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
lnesg	1.23*** (0.20)	1.41*** (0.38)	1.72*** (0.44)	0.54 (0.63)	2.09*** (0.24)	0.28 (0.22)	1.15*** (0.18)	1.67*** (0.33)
lnesg^2	−2.38*** (0.34)	−2.56*** (0.66)	−3.11*** (0.75)	−0.91 (1.10)	−3.88*** (0.41)	−0.57 (0.37)	−2.20*** (0.32)	−3.09*** (0.57)
lncash	0.05*** (0.02)	−0.01 (0.03)	−0.05 (0.03)	0.02 (0.05)	0.04** (0.02)	0.01 (0.02)	0.034** (0.016)	0.01 (0.02)
lndebt	0.001 (0.04)	0.11 (0.08)	0.09 (0.08)	0.12 (0.13)	−0.04 (0.04)	0.05 (0.05)	0.16*** (0.05)	−0.03 (0.04)
lnroe	0.09** (0.05)	−0.14 (0.10)	−0.3*** (0.11)	−0.002 (0.08)	0.08 (0.05)	−0.18*** (0.05)	−0.10* (0.06)	0.10* (0.06)
lnprofit	−0.05 (0.05)	0.20** (0.01)	0.39*** (0.11)	0.05 (0.10)	0.05 (0.06)	0.19*** (0.05)	0.16*** (0.06)	−0.07 (0.06)
lnshare_holder	0.17** (0.07)	0.42** (0.16)	0.39** (0.18)	0.38 (0.34)	0.33*** (0.10)	0.07 (0.08)	0.33*** (0.08)	0.20*** (0.01)
lncapital	0.004 (0.01)	0.04* (0.025)	0.01 (0.02)	−0.09** (0.04)	−0.007 (0.01)	0.02* (0.01)	0.005 (0.01)	0.001 (0.02)
lnxrd	0.19*** (0.01)	0.19*** (0.03)	0.09*** (0.02)	0.12*** (0.04)	0.16*** (0.02)	0.13*** (0.01)	0.13*** (0.01)	0.31*** (0.03)
sa	−0.98*** (0.13)	−0.75*** (0.28)	0.41 (0.31)	−1.67*** (0.48)	−0.66*** (0.15)	−1.07*** (0.17)	−0.57*** (0.15)	−1.04*** (0.16)
Corporate fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj−R^2	0.96	0.95	0.96	0.97	0.95	0.98	0.97	0.94
Observations	3,225	641	576	151	2,808	1785	2,518	2075

*Note: ***, ** and * denote 1, 5 and 10% significance levels, respectively; values in parentheses are standard errors.*

and those greater than the mean value are included in the group of good performance, whereas those less than the mean value are included in the group of poor performance. Column (5) of the table shows that the ESG disclosure of the listed companies promotes the improvement of intangible capital, and the ESG disclosure and intangible capital show an "inverted U" type relationship. Column (6) of the table shows that the ESG disclosure of the listed companies with poor intangible capital does not promote the increase in current net profit, but there is also an "inverted U" type relationship between ESG disclosure and intangible capital. The possible reasons for this situation for the poor performers are as follows: first, they face financial constraints to increase ESG investment in the short term and may not have the funds or may not invest in ESG disclosure at the expense of current operating cash flow, which may affect their business performance. Second, in terms of improving the public image of the company, it is less likely that the company's management will improve its public image from ESG investment because the poor performance of the company already has a negative impact on the public.

To further portray the heterogeneity of different firms, an indicator reflecting firms' revenue per capita is introduced, and the mean value of the logarithm of revenue per capita is used as the benchmark; firms with a logarithm of revenue per capita greater than this mean value are included in the group with high revenue per capita, and vice versa in the group with low revenue per capita. Columns (7) and (8) of **Table 5** analyze the results of the impact of ESG disclosure on intangible capital in terms of revenue per capita. Column (7) shows the group with high revenue per capita, ESG disclosure promotes the improvement of intangible capital, and ESG disclosure has an inverted U-shaped relationship with intangible capital. Column (8) shows the group with low revenue per capita, and for this group, ESG disclosure does not promote an increase in current net profit, but there is also an "inverted U" relationship between ESG disclosure and intangible capital. The possible reasons for this situation for the group with low revenue per capita are as follows: first, for listed companies with low revenue per capita, their own operating performance may be less than satisfactory, and the management faces a difficult choice between ESG investment and maintaining the existing operation due to the financial constraints on corporate ESG investment. Secondly, for listed companies with low revenue per capita, ESG investment can hardly improve revenue per capita in the short term, resulting in the weak willingness to participate in corporate ESG investment.

The above heterogeneity analysis shows that ESG information disclosure and intangible capital present large differences across companies. For developing regions in the Central and Western, listed companies are significantly more willing to disclose ESG than those in the East regions; for listed companies with good performance, listed companies are also significantly more willing to disclose ESG information. For listed companies with good revenue per capita, listed companies are significantly more willing to disclose ESG information than those with poor revenue per capita.

MAIN CONCLUSION

The report of the 19th Party Congress pointed out that China's economy has shifted from the stage of high-speed growth to the stage of high-quality development. Social responsibility and corporate green innovation both contribute to China's high-quality development, but it is difficult to balance social and economic benefits at the same time, and it is a question of whether both can bring economic benefits to the enterprises themselves while bringing social benefits. In response to global climate change, China has made a solemn commitment to the world to achieve carbon neutrality and carbon peaking, and in order to achieve this goal, the relevant Chinese authorities have formulated relevant policies and measures to promote enterprises to steadily promote carbon reduction plans. Listed companies are the public enterprises in China's manufacturing industry, and their voluntary ESG disclosure has become a key concern for social monitoring. Under pressure from various aspects, by 2017, more and more companies have voluntarily disclosed ESG by listed companies, and the quality of ESG disclosure has become better and better, which is shown by the slow process of improvement in companies' ESG scores.

Is there a relationship between ESG score improvement and intangible capital? To unravel this mystery, this study introduces the square of intangible capital and explores the dynamic process of the change in voluntary ESG disclosure on intangible capital, showing that ESG disclosure significantly contributes to the performance of listed companies, but ESG disclosure and intangible capital show an "inverted U" shape. The relationship between ESG disclosure and intangible capital is further analyzed by using ESG score change (*esg_diff*) to characterize the impact of corporate ESG input. The study shows that the increase in ESG input reduces the current net profit of the company, but significantly contributes to the net profit of the next period, the next two periods and the next three periods.

However, there is significant heterogeneity in the effect of ESG disclosure on intangible capital. The heterogeneity of ESG disclosure in east, central, west and northeast regions shows that ESG disclosure promotes intangible capital only in the eastern region and has an "inverted U" shape, whereas there is no such relationship in the other regions. In terms of good or bad intangible capital, ESG disclosure promotes intangible capital in the group with good performance, and ESG disclosure has an "inverted U" relationship with intangible capital, whereas there is no significant relationship between ESG disclosure and intangible capital in the group with poor performance. From the perspective of revenue per capita, ESG disclosure promotes intangible capital in the group with high revenue per capita, and ESG disclosure has an "inverted U" relationship with intangible capital, although there is no significant relationship between ESG disclosure and intangible capital in the group with high revenue per capita. However, there is an "inverted U" relationship between ESG disclosure and intangible capital in the group with low revenue per capita.

The above study shows that the ESG information disclosure of listed companies has shown a large differentiation, and this differentiation is likely to further expand. Some listed companies that have completed the first phase of climate target commitment through product transformation and business transformation have gradually started to pursue more stringent and comprehensive environmental and climate targets in order to further reduce the indirect impact of their products and business on the climate. A common goal is the "carbon footprint neutrality" goal, which calculates the total carbon emissions generated during the production process, from raw material processing to final product production, and helps upstream producers use alternative raw materials and renewable energy to build a carbon footprint for each link of the entire industry chain as part of the "carbon neutral" development goal. In order to balance the ESG disclosure of listed companies and help relatively backward enterprises enhance and improve ESG information disclosure, the following levels of improvement are needed, and the following policy insights are derived:

First, improve ESG disclosure scoring standards to achieve comparability among indicators. Compared with foreign countries, domestic ESG-related research is still in the initial stage. Not only are there relatively few studies dedicated to the evaluation of ESG indicators for listed companies, and the definition and connotation of ESG have not yet reached a consensus, but there are also limitations in the research on the individual evaluation of listed companies' fulfillment of social responsibility and green development by relevant rating research institutions. Moreover, ESG research institutions have formed their own schools of thought, lacking absolutely convincing index systems and evaluation methods, and some studies only publish the evaluation results without disclosing the evaluation indexes and evaluation methods, and the evaluation itself lacks transparency.

As shown in **Table 1**, as corporate heterogeneity leads to large differences in ESG information disclosure input by listed companies, whether it is the Wind ESG score or FTSE Russell's ESG score, these two indicators only have total scores without further differentiating each score item of E, S and G. The comparability of ESG scores among different industries needs to be further improved.

Second, tax incentives are given in the field of ESG information input to prompt enterprises to establish and improve detailed indicator systems. For ESG rating agencies, the database of ESG ratings of domestic listed companies is weak, and the data source of ESG-related indicators is a difficult problem. The main data sources of existing research include the public disclosure of listed companies' financial reports and social responsibility reports as well as data from media, data provided by third-party organizations, questionnaires, data information obtained from field research, etc. Therefore, there exists the phenomenon that some evaluation institutions backwardly deduce the evaluation system based on experience and internal data, which lacks certain scientificity and operability.

Listed companies need to disclose ESG information, and the ESG implementation of all aspects of governance requires investment from all aspects of ESG one by one, such as the purchase of environmental protection equipment, etc., all of which reduce corporate operating cash and is an extremely difficult choice for companies with poor operating performance. In order to help company improve ESG information disclosure, the government can consider giving companies certain tax incentives in the area of ESG investment to increase their motivation.

Third, form a socialized guidance enterprise ESG disclosure mechanism. Drawing on the experience of the United States and Japan in socially guiding enterprises to voluntarily disclose ESG information. Policy makers should formulate relevant policies which can promote public funds and pension funds to establish ESG fund products. The ESG fund products can expand financial financing channels for listed companies.

Fourth, for the listed companies in Northeastern regions, the relevant departments appropriately give policy inclination to listed enterprises in these regions to help them quickly establish and improve ESG information disclosure to increase their enthusiasm toward disclosing ESG information.

DATA AVAILABILITY STATEMENT

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

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WJ is responsible for article writing and model building, ZS for building research ideas and models, TY for literature translation.

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El Niño and Commodity Prices: New Findings From Partial Wavelet Coherence Analysis

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This study investigates whether the El Niño Southern Oscillation (ENSO) affects primary commodity prices over time. We employ a wavelet approach that allows us to disentangle the time and frequency domains and to uncover time-varying nonlinear relationships at different frequency levels. Moreover, we adopt partial wavelet coherence (PWC) and eliminate macroeconomic effects on commodity prices. We observe that ENSO is associated with agricultural, food, and raw material commodity prices at lower frequencies of 32–64 and 64–128 months. These results are stronger from 2000 onward, which are not observed using a conventional wavelet method. Our results suggest a recent strong relationship between ENSO and commodity prices, which has important implications for policymakers regarding climate change risk.

Keywords: climate risk, commodity prices, partial wavelet coherence, El Niño, ENSO

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INTRODUCTION

In 2018, the National Climate Assessment (NCA) reported that climate change created new risks.[1] Global warming, sea level rise, abnormal temperatures, and extreme weather affect human health and economic growth. Recently, climate risk, regarded as an important risk factor, has received attention from financial investors.[2] For instance, abnormal temperatures affect economic activities and investors' decisions. An increase in summer temperature is negatively related to gross state product in the United States (Colacito et al., 2019). Global high abnormal temperatures cause an increase of drought and result in a decrease of stock prices in the food industry (Hong et al., 2019). Retail investors tend to sell shares of carbon-intensive firms during abnormally high temperatures (Choi et al., 2020). Investors who invest in high-carbon-dioxide-emission firms demand compensation for carbon dioxide emission risk (Bolton and Kacperczyk, 2021).[3] In contrast, Addoum et al. (2020) find a weak relationship between temperature shocks and establishment sales in the United States, and conclude that temperature shocks are more important in emerging countries.

We focus on the impact of climate risk on real commodity prices. Real commodity prices provide important information to both policymakers and financial investors. Commodity prices are

[1]Fourth National Climate Assessment (globalchange.gov).
[2]Giglio et al. (2021) consider climate risk as disaster risk and construct a model that contains feedback loops between economic growth and climate disaster risk. Similarly, Engle et al. (2020) propose a dynamic hedging strategy for climate risk using textual analysis. Yuan and Yang (2020) explore how market uncertainty influences the carbon market.
[3]Pedersen et al., 2021 report that low carbon emission firms earn positive alphas.

associated with business cycles and their shocks are driving forces for output fluctuations in emerging economies; see Fernández et al. (2017), Fernández et al. (2018). Commodities have been used as investment assets because of their low correlations with stock market returns (Erb and Harvey, 2006; Gorton and Rouwenhorst, 2006; Tang and Xiong, 2012; Buyuksahin and Robe, 2014; Singleton, 2014). Basak and Pavlova (2016) propose a theoretical model in which the financialization of commodities leads to an increase in stock and commodity return correlations. Fernandez-Perez et al. (2017) show that commodity markets entail future investment opportunity state information that is not revealed by dividend yields or term spreads. Real exchange rates in advanced economies are also affected by commodity price shocks (Ayres et al., 2020).

We investigate how the El Niño Southern Oscillation (ENSO)—a type of climate risk—impacts primary commodity prices over time. ENSO is a climate pattern that is associated with changes in the temperatures of waters in the central and eastern tropical Pacific Ocean and influences weather, and rainfall. El Niño and La Niña are extreme phases of this cycle and El Niño is linked to crop production (Handler and Handler, 1983; Iizumi et al., 2014; Hsiang and Meng, 2015). Moreover, ENSO plays an important role in real commodity price fluctuations and influences not only certain geographical areas, but also the world economy. ENSO shocks create droughts in one region and influence commodity supply in the world market, because commodity production is limited to specific regions (Ubilava, 2018). It accounts for approximately 20% of global commodity price fluctuations (Brunner, 2002). Channels of ENSO shocks are complex, and Cashin et al. (2017) construct multicountry models and extract indirect ENSO shocks through third-markets. Moreover, Ubilava (2018) and Nam (2021) provide evidence that ENSO shocks have heterogeneous and nonlinear effects on individual agricultural commodities.

In this study, we employ a wavelet approach and investigate the relationship between commodity prices and ENSO. This approach allows us to disentangle the time and frequency domains and to uncover time-varying relationships at different frequency levels. Ortu et al. (2013) and Dew-Becker and Giglio (2016) highlight the importance of the frequency domain since long-run shocks play a key role in asset prices. It is advantageous for financial time series data that includes different behaviors in short -and long-run intervals. The previous literature investigates stock market risk-return relationships, market integration across international stock markets, and market microstructure at different frequency levels (Gençay et al., 2005; Rua and Nunes, 2009; Hasbrouck, 2018; Sakemoto, 2020).

Some studies propose adopting the frequency domain in portfolio constructions; for instance, In and Kim (2006), Cai et al. (2017), and Conlon et al. (2018). ENSO data have a cyclical component, and deploying stationary-type autoregressive models are difficult, as reported by Campbell and Diebold (2005) and Nam (2021); hence, our wavelet approach is a strong tool for modeling ENSO data. Therefore, the first contribution of this study is that it explores the time-varying nonlinear relationships between real commodity prices and ENSO shocks using the wavelet approach.

Commodity prices are not only driven by ENSO shocks; macroeconomic fundamentals are also important factors in determining prices. In particular, short-term interest rate in the United States is a fundamental factor in determining global commodity prices. Frankel (2008) points out that a high interest rate leads to a decline in commodity storage demand. Furthermore, speculators shift money from commodity markets to the U.S. Treasury bills with changes in interest rates. We need to eliminate the effects generated by short-term changes in interest rates and examine the commodity prices and ENSO shock nexus in the time and frequency domains.

Our second contribution is that we adopt partial wavelet coherence (PWC), which allows us to explore how ENSO shocks impact commodity prices after eliminating interest rate effects. PWC is proposed by Mihanović et al. (2009) and Ng and Chan (2012) and has been widely used in geophysics.[4] Both interest rate and ENSO shocks entail time-varying impacts on commodity prices (Ubilava, 2018; Byrne et al., 2020); therefore, PWC is a powerful method of capturing time-varying relationships. More importantly, our approach extends the work of Ubilava (2018), Byrne et al. (2020), and Nam (2021), and captures the frequency-domain relationships.

Our third contribution is that we focus on commodity price co-movement, which is more informative in capturing economic states. Previous studies have revealed that common factors exist across commodity prices (see Pindyck and Rotemberg, 1990; Byrne et al., 2013; West and Wong, 2014). Some studies observe that co-movement is linked to other macroeconomic fundamentals. For instance, Gospodinov and Ng (2013) find that common factors in commodity convenience yields predict inflation. Alquist et al. (2020) uncover that a common shock in primary commodity markets is negatively associated with global economic activities. Focusing on commodity price co-movement is an important difference from Ubilava (2018), who examines individual commodity prices since the information of commodity price co-movement information reveals economic states.[5]

To preview our results, we find strong correlations between commodity prices and ENSO at lower frequencies and in two periods: from 1968 to 1990, and 2000 onward. Moreover, we adopt the PWC approach and provide evidence that the strong correlations from 1968 to 1990 became weaker, whereas they were stronger from 2000 onward. These are not observed without controlling for the interest rate effects. The strong correlations during the early period were associated with high inflation rates and the active monetary policy by the U.S. Federal Reserve Board (Clarida et al., 2000). Our results also demonstrate that interest rates play an important role in determining commodity prices, as proposed by Frankel (2008); therefore, it is important to control for their effects and to evaluate commodity price fluctuations. The reason for the strong link between ENSO and commodity prices

[4]Recently, PWC is employed in the economics and finance literature (Aloui, et al., 2018; Wu et al., 2020).

[5]Some studies investigate ENSO impacts on prices of specific commodities: vegetable oil (Ubilava and Holt, 2013) and coffee (Ubilava, 2012; Bastianin et al., 2018).

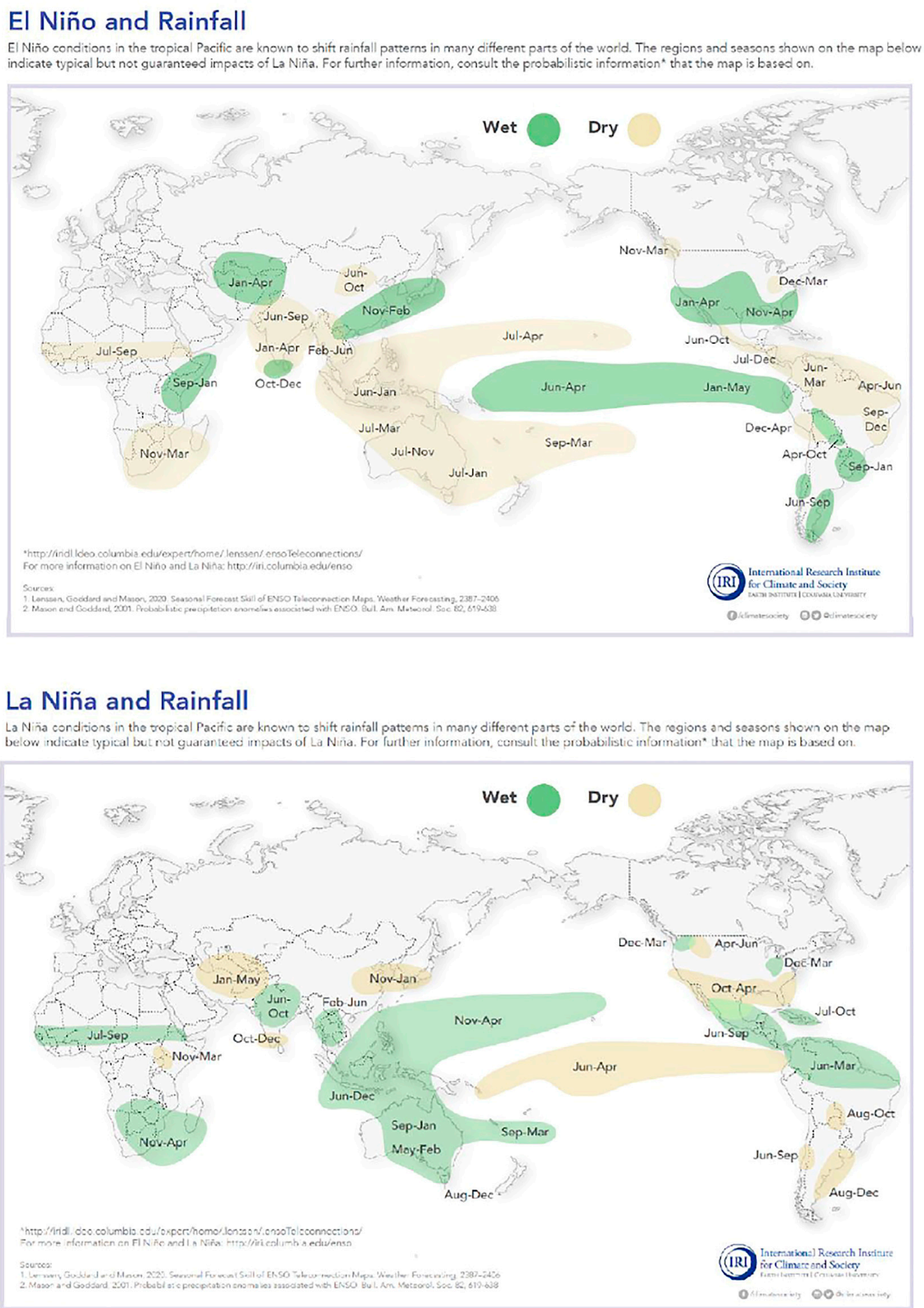

FIGURE 1 | EL Niño and La Niña effects. Notes: This figure indicates the weather patterns during El Niño and La Niña events. Source: International Research Institute for Climate and Society at Columbia University, based on Lenssen et al. (2020) and Mason and Goddard (2001).

after 2000 stems from the financialization of the commodity market (Tang and Xiong, 2012; Singleton, 2014). Investors consider commodities as one of asset classes and focus on a common risk across assets (Asness et al., 2013; Koijen, et al., 2018). Recently, investors regard climate risk as an important risk factor in the financial market. In particular, carbon intensity receives attention as an important risk factor both in traditional assets (Choi et al., 2020; Bolton and Kacperczyk, 2021; Pedersen et al., 2021) and in new assets (Yang and Hamori, 2021; Yang and Xu, 2021; Yang 2022). The financialization in the commodity market and the growing awareness of the carbon intensity lead to the strong relationship between ENSO and commodity prices after 2000.

The remainder of this article is organized as follows. In *Data*, the data are briefly described. *Methodology* describes the methodology of the wavelet coherence and PWC. *Empirical results* presents our empirical results. *Robustness checks* contains and examination of the robustness of the results. Finally, we conclude the article in *Conclusion*.

DATA

ENSO

ENSO is a climate cycle of sea surface temperature and air pressure of the overlying atmosphere in the tropical Pacific region. El Niño and La Niña are extreme events in this cycle. During the normal phase, air pressure in Northern Australia and Indonesia is lower than that on the west coast of equatorial South America, which causes trade winds to move from east to west over the Pacific Ocean and draws warm surface water westward. This circulation of winds brings precipitation to Australia and the Western Pacific.

During an El Niño event, the air pressure difference between the west and east weakens, and allows warmer water to move into the central and eastern Pacific Ocean. This leads to warmer sea surface temperatures in the central and eastern tropical Pacific Ocean, to severe droughts in Australia and the western Pacific Ocean, and to heavy precipitation on the west coast of equatorial South America. In contrast, during a La Niña event, trade winds strengthen, and the area of warmer water is constrained to the western Pacific Ocean, which causes an increase in rainfall over northern and western Australia. **Figure 1** shows the patterns of temperature and rainfall during El Niño and La Niña events.

We follow Brunner (2002) and Cashin et al. (2017), and employ the Southern Oscillation Index (SOI) to capture El Niño intensities. The SOI is calculated using the observed sea level pressure differences between Tahiti and Darwin in Australia. A negative (positive) SOI value indicates that air pressure is below (above) average in Tahiti and above (below) that at Darwin. The negative value of the SOI coincides with abnormal warm (cold) ocean waters across the eastern tropical Pacific and El Niño (La Niña) events. We obtain the SOI data from the National Centers for Environmental Information.[6]

Commodity Prices and Interest Rates

To examine how climate risk affects commodity prices, we collect a commodity price index for agriculture that is most influenced by climate risk. Moreover, we obtain three agricultural sub-indices: beverages, food, and raw materials. These data are downloaded from the World Bank (pink sheet). Previous studies, such as Byrne et al. (2013), West and Wong (2014), and Alquist et al. (2020), highlight the importance of commodity common factors. Motivated by their findings, our main analysis focuses on commodity indices, rather than on individual commodities. Real commodity prices are associated with the business cycle and inflation (Fernández et al., 2017; Alquist et al., 2020), and following Fernández et al. (2017), we calculate the real commodity price return as $log\frac{p_t}{p_{t-1}} - log\frac{CPI_t}{CPI_{t-1}}$, where p_t is the commodity price at time t and CPI_t is the U.S. consumer price index at time t.

Real commodity prices are negatively associated with real interest rates (Frankel, 2008). In this study, we employ a real interest rate and control for the interest rate effects on commodity prices. Following Frankel (2008) and Byrne et al. (2013), we calculate the real interest rate as $i_t - log\frac{CPI_t}{CPI_{t-1}}$, where i_t is the U.S. three-month Treasury bill rate. Our data cover the period from January 1960 to February 2021, and the total number of observations is 732.

The descriptive statistics for SOI, real commodity price returns, and real interest rates are summarized in **Table 1**. The results of the Augmented Diceky-Fuller (ADF) test show that all the data series are stationary. The upper part of **Figure 2** demonstrates the time-series plot of the SOI. The persistence of negative values below -2 indicates that El Niño events were severe in 1978, 1983, 1992, 1998, 2005, and 2016, whereas the values above two indicate that La Niña events corresponded to 1971, 1974, 1975, 2008, and 2011. In **Supplementary Figure SA2**, the top and middle rows represent the time-series prices and real returns of the four commodity indices and real interest rates, respectively. Commodity prices have risen from 1970 to 1986 and have also increased since year 2000.

METHODOLOGY

Wavelet Coherence Analysis

This section describes wavelet coherence analysis that allows us to assess the frequency components of nonlinear relationships without losing time-specific information. We begin by mapping an original series into two directions of frequency and time *via* a mother wavelet function. Following Torrence and Compo (1998), Torrence and Webster (1999), and Grinsted et al. (2004), a continuous wavelet function of time series x_t can be defined as

$$W_x(\tau, s) = \int_{-\infty}^{\infty} x_t \frac{1}{\sqrt{|s|}}\psi^*\left(\frac{t-\tau}{s}\right)dt \tag{1}$$

where ψ is a wavelet function with two variables τ and s. The translation parameter τ determines the location of the wavelet and s is a scaling parameter that controls the width of the wavelet.[7] The term $|s|$ denotes the absolute value of s, and the superscript * indicates complex conjugation. A continuous

[6]https://www.ncdc.noaa.gov/teleconnections/enso/soi.

[7]We use the Morlet wavelet function. For more details, see Grinsted et al. (2004).

TABLE 1 | Descriptive statistics.

	Mean	Median	SD	Skewness	Kurtosis	ADF	Observations
Commodity prices							
Agriculture	−0.001	−0.003	0.026	0.057	6.600	−7.513***	732
Beverages	−0.001	−0.003	0.044	0.899	7.793	−7.126***	732
Food	−0.001	−0.002	0.033	0.097	6.701	−7.677***	732
Raw materials	−0.001	−0.002	0.024	0.375	6.699	−7.641***	732
SOI	0.120	0.100	0.955	−0.196	3.570	−6.832***	732
ONI	−0.013	0.000	0.843	−0.373	3.191	−6.069***	732
Δi	−0.006	0.005	0.449	−1.643	19.539	−7.448***	732

*SOI is the Southern Oscillation Index. ONI is the value of the Oceanic Niño Index multiplied by (-1). Δi is the first difference in U.S. 3-month Treasury Bill real prices. SD denotes standard deviation. ADF is the Augmented Dickey-Fuller test. *** indicates significance level at the 1%.*

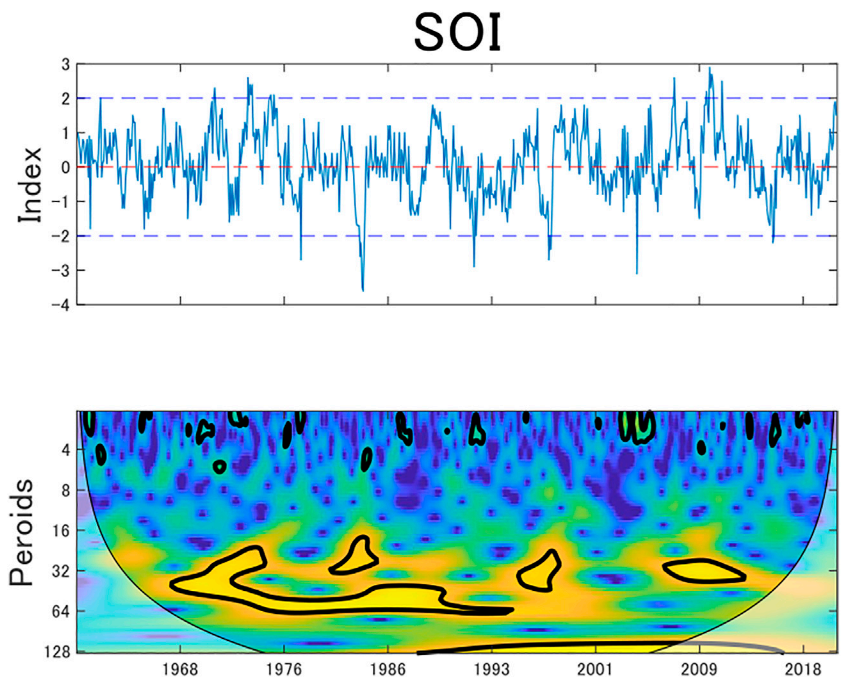

FIGURE 2 | SOI figure from top to bottom are the time series of the Southern Oscillation Index at the top and its wavelet power spectrum at the bottom. Notes: The black contour in the wavelet power spectrum shows a 5% significance level estimated from the Monte Carlo simulations. The color code in the wavelet power spectrum shows the degree of local variance, ranging from blue (low variance) to yellow (high variance). The bold line in the wavelet power spectrum shows the edge effects.

wavelet function can decompose an original time series into both time and frequency.

The continuous wavelet power is defined as $|W_x|^2$, which indicates the local variance of x_t. According to Grinsted et al. (2004), we set the cone of influence to present the edge effects, and we assess the statistical significance of the wavelet power by using the null hypothesis of an autoregressive (AR) process of order one.[8]

Given two time series, x_t and y_t, their (squared) wavelet coherence function can be defined as follows:

$$R^2_{xy} = \frac{|S(W_{xy})|^2}{S(|W_x|^2)S(|W_y|^2)} \tag{2}$$

where W_{xy} is the cross-wavelet transform function of x_t and y_t[9]. S is the smoothing operator that smoothens the time series by varying the wavelet scales. The squared wavelet coherence $(0 \le R^2_{xy} \le 1)$ interprets the correlation between x_t and y_t in a time-frequency space. According to Torrence and Compo (1998) and Grinsted et al. (2004), the Monte Carlo simulation method is employed to estimate the statistical significance level of wavelet coherence.

[8]See details in Grinsted et al. (2004).

[9]$W_{xy} = W_x W^*_y$, where * is the complex conjugate operator.

TABLE 2 | Estimated results of regression analysis.

Panel A	—	Constant	SOI	Δi	Adjusted R^2 (%)	*p*-Value of F Statistics
Agriculture	Monthly	−0.001 (0.344)	0.001 (0.541)	0.008*** (0.000)	1.8	0.001
	Quarterly	−0.003 (0.004)	0.003 (0.004)	0.009** (0.004)	1.5	0.064
	Annually	−0.010 (0.016)	0.005 (0.015)	0.028*** (0.010)	8.4	0.032
Panel B						
Beverages	Monthly	−0.001 (0.002)	0.000 (0.002)	0.004 (0.003)	0.0	0.570
	Quarterly	−0.004 (0.006)	−0.000 (0.006)	0.002 (0.007)	-0.8	0.969
	Annually	−0.014 (0.611)	−0.020 (0.430)	0.004 (0.795)	-2.3	0.698
Panel C						
Food	Monthly	−0.001 (0.001)	0.000 (0.001)	0.010*** (0.003)	1.8	0.001
	Quarterly	−0.003 (0.004)	0.004 (0.005)	0.012** (0.005)	1.9	0.038
	Annually	−0.009 (0.019)	0.006 (0.018)	0.038*** (0.012)	11.4	0.013
Panel D						
Raw materials	Monthly	−0.001 (0.001)	0.001 (0.001)	0.002 (0.002)	-0.0	0.396
	Quarterly	−0.004 (0.003)	0.004 (0.004)	0.003 (0.004)	0.0	0.347
	Annually	−0.014 (0.017)	0.021 (0.016)	0.017 (0.011)	2.8	0.167

*SOI is the Southern Oscillation Index. Δi is the first difference in U.S. 3-month Treasury Bill real prices. The numbers in parentheses are the standard deviations. *, **, and *** indicate significance level at the 10, 5, and 1%, respectively.*

Partial Wavelet Coherence Analysis

Next, we describe PWC analysis, which is an extension of bivariate wavelet coherence analysis. Mihanović et al. (2009) propose the PWC approach that represents a nonlinear relationship between x_t and y_t. This allows us to assess a "pure" correlation by excluding the influence of the other variables, since the correlation (coherence) may be misleading if it is dependent on the third variable. Ng and Chan (2012) employ the PWC approach for geophysical applications, and Hu and Si (2021) develop the PWC method that is not limited to one excluding variable.

Following Mihanović et al. (2009), Ng and Chan (2012), and Hu and Si (2021), a (squared) partial wavelet coherence function is defined as

$$\rho^2_{xy,z} = \frac{\left|\gamma_{xy} - \gamma_{xz}\gamma^*_{yz}\right|^2}{\left(1 - R^2_{xz}\right)\left(1 - R^2_{xz}\right)} \tag{3}$$

where $\gamma_{xy} = \frac{S(W_{xy})}{\sqrt{S(W_x)S(W_y)}}$. The PWC in **Eq. 3** represents the bivariate relationship between x_t and y_t after excluding the effects of variable z_t. Similar to the normal wavelet coherence method, the Monte Carlo simulation method used to calculate the statistical significance level of PWC.[10]

EMPIRICAL RESULTS

In this section, we first estimate an impact of ENSO shocks on real commodity price returns using a regression model. Then, we use the wavelet coherence method to measure the nonlinear relationships between commodity price returns and ENSO shocks in the time-frequency domains. Finally, we use the PWC and examine how ENSO shocks affect commodity price returns after excluding the effects of interest rates.

Linear Regression Results

We begin with the regression results and regress the commodity returns onto the SOI and the interest rate in three time domains: monthly, quarterly, and annually. **Table 2** presents that SOI has a positive impact on commodity returns of agriculture, food, and raw material,[11] but the estimates are not statistically significant, which suggests that the SOI effects are nonlinear, as reported by Ubilava (2018) and Nam (2021). Panels A and C of **Table 2** show that the real interest rate is an important determinant of agricultural and food returns, which is in line with Frankel (2008) and Byrne et al. (2013). The real interest rate effects are positive, which contrast with the results of the previous literature. We use a change in the interest rate and it causes the positive relationships.[12]

Empirical Results Based on Wavelet Coherence

Having found a weak relationship between SOI and commodity returns, we use wavelet analysis to explore nonlinear relationships in the time-frequency space. First, we decompose our data series

[10]See more details in Hu and Si (2021).

[11]For example, Bennetton et al. (1998) argue that hot and dry summer droughts increase the frequency and severity of wildfires, which in turn reduce the crop yields and the next wheat exports. Thus, it leads to higher world wheat prices.

[12]We employ a change in the interest rate due to obtain the stationary series and we observe a negative relationship with the raw data series.

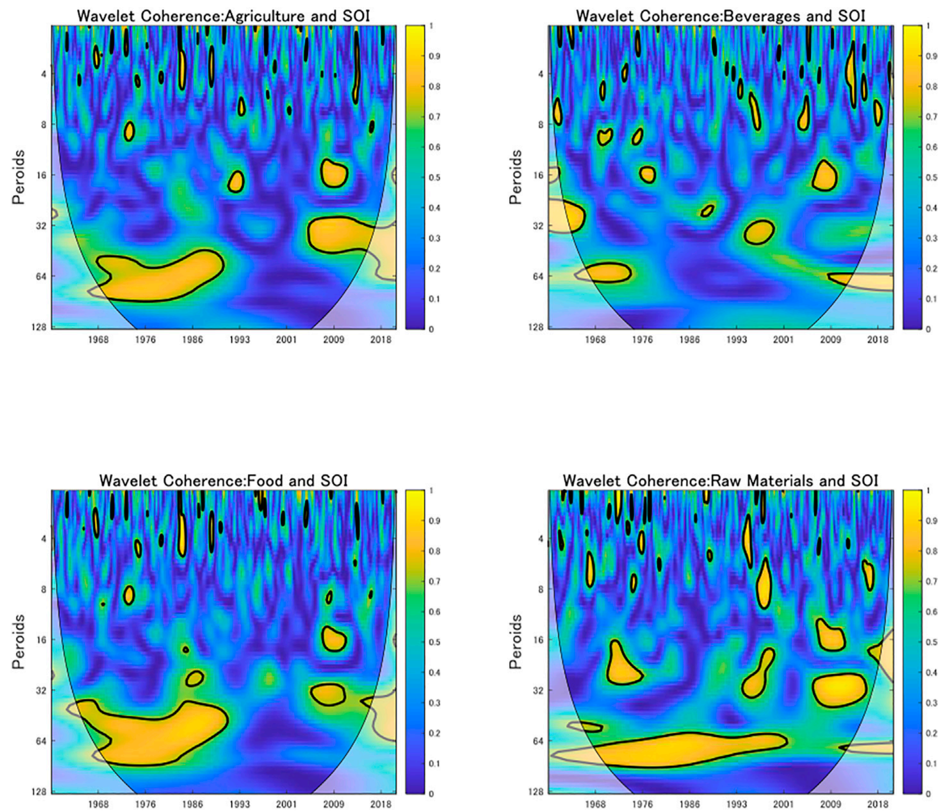

FIGURE 3 | Wavelet coherences between commodity prices and SOI. Notes: The black contour shows a 5% significance level estimated from the Monte Carlo simulations. The color code shows the degree of coherence strength, ranging from blue (low coherence) to yellow (high coherence). The bold lines indicate the edge effects.

individually based on **Eq. 1** and search for their local variance. According to the length of our data series, they are decomposed into seven levels: level one (1–2 months), level two (2–4 months), level three (4–8 months), level four (8–16 months), level five (16–32 months), level six (32–64 months), and level seven (64–128 months), covering the short-term (less than 1 year), mid-term (1–2 years), and long-term horizons (over 2 years).

The bottom sections of **Figure 2**; **Supplementary Figure SA2** demonstrate the wavelet power spectrum plots of the SOI, four commodity price returns, and the interest rate. From Grinsted et al. (2004), colors ranging from blue to yellow indicate a low or high degree of local variance and the black contour indicates a 5% significance level using the Monte Carlo simulation method. The bold line in the influence cone indicates the area affected by edge effects. The dark contours on the 32- to 64-month scales in the wavelet power spectrum plot of **Figure 2** indicate that high local variance of the SOI appeared in the long-term range during the periods 1968–1995 and 2006–2011. The frequency of the ENSO is consistent with the findings reported by Ray and Giese (2012) who observe that the mean frequency distribution of the ENSO is 3.9 years (46.6 months), with the standard deviation of 1.9 years (22.8 months). Bunde et al. (2005) document that there is long-term memory in the climate record that leads to a pronounced clustering of extreme events.

For the commodity markets in **Supplementary Figure SA2**, we find high volatility periods on the 4 to 8- and 32- to 64-month scales from 1970 to 1986 and on the 8- to 16- month scales from 2008 to 2010. The periods of high volatility in the SOI and commodity markets overlap. We also observe significant high interest rate volatility in the long run period of 1976–1986, which corresponded with the high inflation period in the United States.

Second, we investigate the nonlinear interdependence of commodity price returns and SOI by estimating their wavelet coherence, as shown in **Figure 3**. Similar to **Figure 2**; **Supplementary Figure SA2**, the color codes from blue to yellow show coherence values from zero to one and the black contour lines indicate a 5% significance level using the Monte Carlo simulation method. We note that agricultural, food, and raw material commodity returns had high correlations with the SOI on the 32 to 64- and 64- to 128-month scales for the two periods of 1968–1990 and from 2000 onward. The correlation between beverage price return and SOI was weak. These results confirm the findings of Ubilava (2018) and Nam (2021) that ENSO shocks have heterogeneous and nonlinear effects on agricultural commodities. Whereas they focus only on the effect of climate on individual commodity prices, we employ agricultural price indices, which are much more informative in terms of capturing the economic state

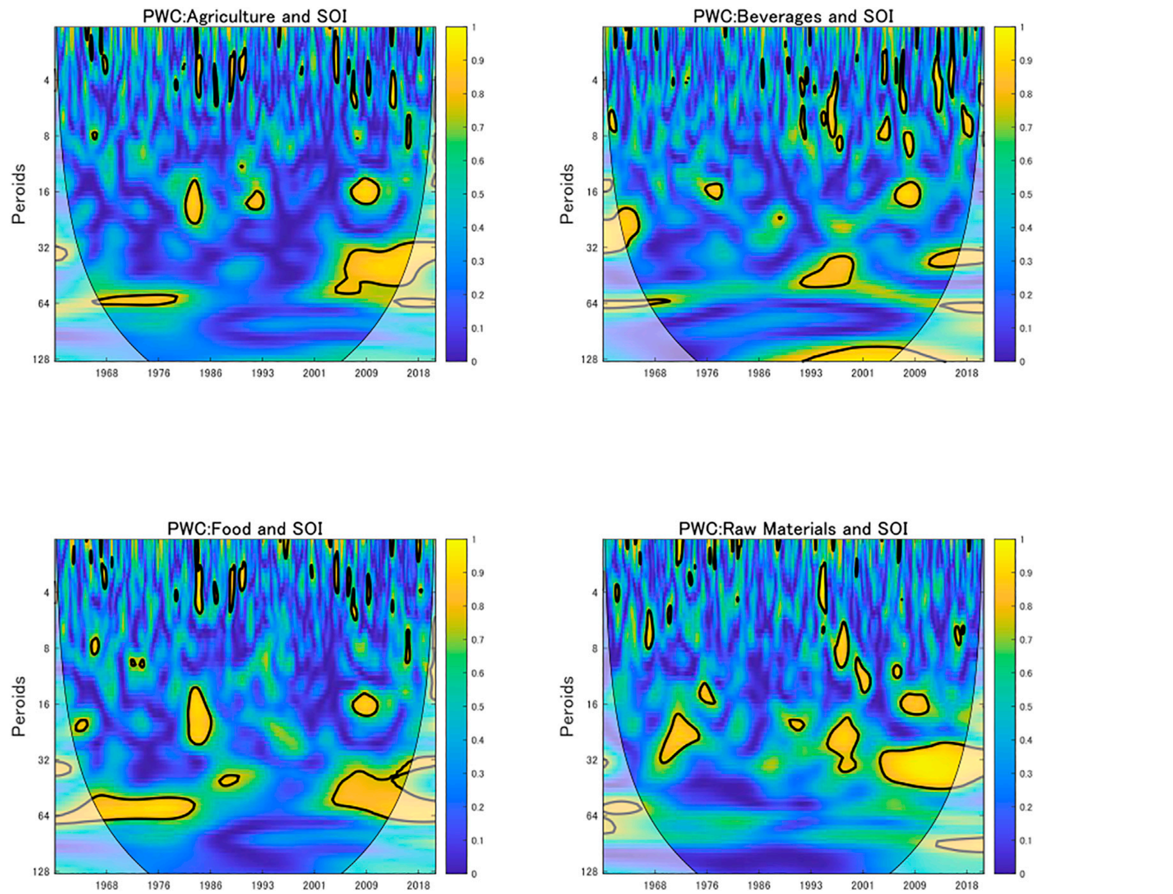

FIGURE 4 | Partial wavelet coherences between commodity prices and SOI. Notes: The black contour shows a 5% significance level estimated from the Monte Carlo simulations. The color code shows the degree of partial wavelet coherence strength, ranging from blue (low coherence) to yellow (high coherence). The bold lines indicate the edge effects.

(Byrne et al., 2013; West and Wong, 2014; Alquist et al., 2020). In addition, the vector autoregressive (VAR)-type models adopted in previous studies do not assess time and frequency information simultaneously.

Empirical Results Based on PWC

Finally, we use PWC to investigate the partial correlations between commodity prices and SOI, since PWC allows us to find wavelet coherence after eliminating the effect of the other variables (Mihanović et al., 2009; Ng and Chan, 2012). Frankel (2008) reports that high interest rates reduce demand for commodity storage, which in turn affects commodity prices. Interest rates are an important determinant for commodity prices and we investigate "pure" relationships between the commodity price returns and the SOI after eliminating the interest rate effects in this section.

Figure 4 presents estimated results using PWC and the color code and black contour lines have the same meaning as those in **Figure 3**. The results indicate that the strong correlations from 1968 to 1990 estimated in **Figure 3** were weaker as shown in **Figure 4**, suggesting that agricultural, food, and raw material commodity price returns during this period are mainly driven by a change in the interest rate, and not by ENSO shocks. This is related to the high inflation period triggered by oil price shocks and the proactive monetary policy implemented by Paul Volcker (e.g., Clarida et al., 2000). The correlations were stronger from year 2000 onward, controlling for interest rate effects, which implies that climate risk became a greater determinant of commodity prices. These are related to recent global warming that enhances ENSO variability (Cai et al., 2018; Power et al., 2021).[13] Ubilava (2017) also investigates ENSO-induced asymmetric price transmissions in the international wheat market and reports that the ENSO indeed affects international wheat prices. Disasters related to extreme weather are linked to agricultural prices in both domestic and international markets (Chatzopoulos et al., 2020) and impact the stock prices of food firms (Hong et al., 2019).

For a more intuitive understanding, we plot the results of a more detailed analysis of time-varying coherence (top) and

[13]A rise in temperatures is linked to more frequent and severe disasters, which leads to unstable financial systems (Giuzio et al., 2019; Flori et al., 2021).

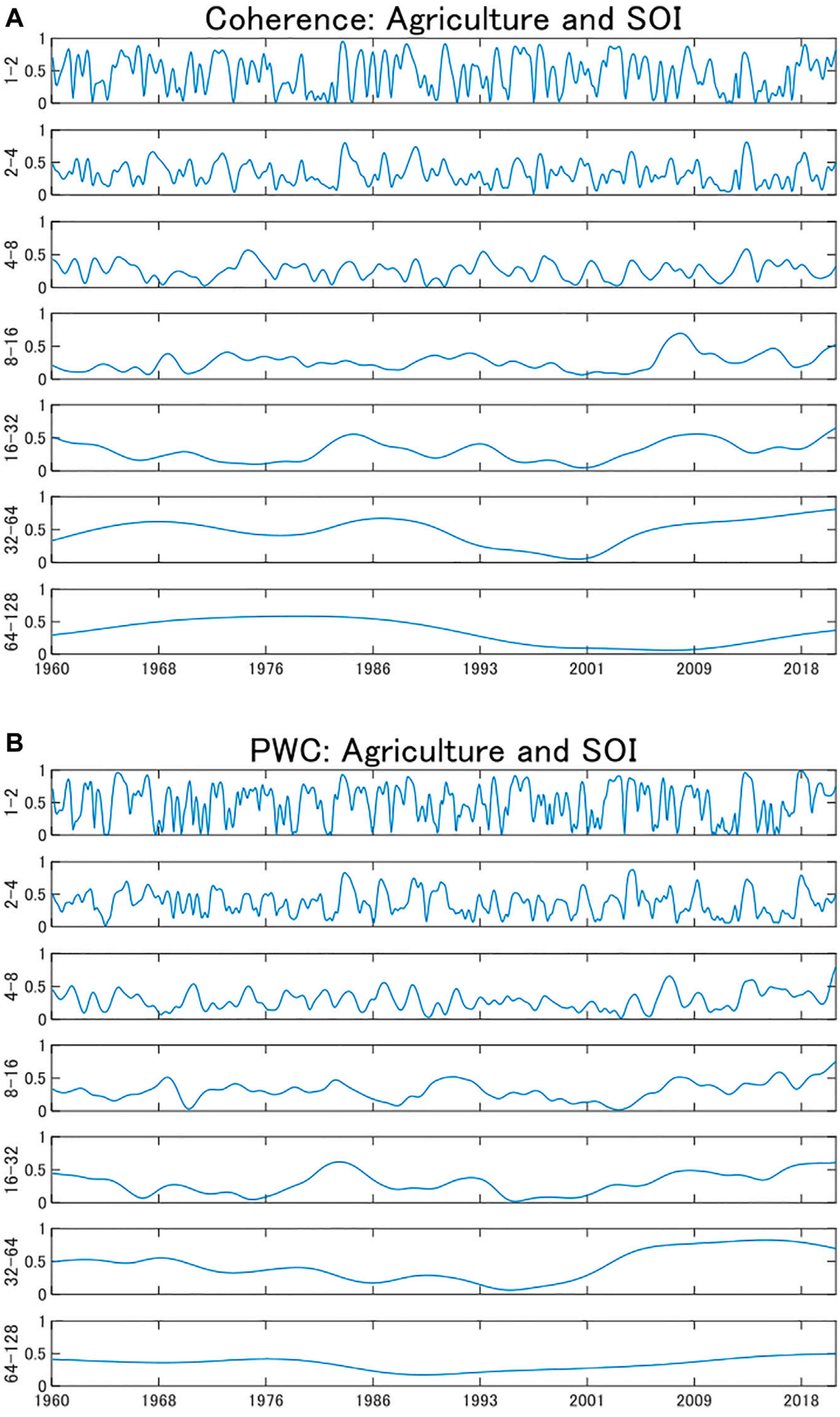

FIGURE 5 | Time-varying wavelet coherences **(A)** and partial wavelet coherences **(B)** between agriculture and SOI across different frequencies.

PWC (bottom) in **Figure 5**; **Supplementary Figure SA3**. The vertical axis shows the values of the wavelet coherence and PWC. A coherence value close to one indicates a high correlation and a value close to zero indicates a weak correlation. We find that the results of wavelet coherence and PWC are heterogeneous across different time scales. Specifically, they are more variable in short-term horizons and more stable in long-term horizons. However, the correlations of PWC became weaker than those of wavelet coherence in the mid- and long-term (16- to 32-, 32- to 64-, and 64- to 128-month scales) from 1968 to 1990, and became stronger from year 2000 onward. This implies that ENSO events became severe and climate risk had a greater impact on commodity markets after removing the interest rate effects, which is consistent with **Figures 3**, **4**.

ROBUSTNESS CHECKS

Ocean Niño Index (ONI)

Having found time- and frequency-specific relationships between commodity prices and the SOI, we investigate whether our results are robust when we adopt a different ENSO measure. We follow Brunner (2002) and Ubilava (2018) and use another monthly series of the ENSO index named the Ocean Niño Index (ONI), which is the rolling index of 3-month average anomalies in the equatorial Pacific sea surface temperature (SST). The value of +0.5 or higher indicates El Niño, whereas the value of –0.5 or lower indicates La Niña.[14] **Supplementary Figure SA1** shows the time series and wavelet power spectrum of the ONI. We can see that most high variance of the ONI occurs on the 16 to 32- and 32- to 64-month scales.

Commodity Prices and ONI

Next, we investigate the impact of ONI on commodity prices. The results estimated by linear regressions are presented in **Supplementary Table SA1**, and we find that the estimates of ONI are not significant. We also compare the results of wavelet coherence and PWC, adopting ONI as shown in **Supplementary Figures SA4–A6**. Similar to the results estimated by the SOI, strong correlations between commodity prices and the ONI were observed on the 32 to 64- and 64- to 128-month scales and during two periods of 1968–1990 and from year 2000 onward. These results are related to previous studies that deploy data on SST anomalies (Brunner, 2002; Ubilava, 2018).

Supplementary Figures SA4–A5 demonstrate that the correlation between the beverage and ONI is weaker than that of the other three pairs. In contrast to the wavelet coherence results, the PWC provides evidence that the medium- and long-term correlations weakened in 1986–1990 and strengthened after 2000 after removing the effects of interest rates, which is consistent with the results when we adopt the SOI.

CONCLUSION

This study examines how ENSO shocks affect four primary commodity index prices: agriculture, beverages, food, and raw materials. Commodity price co-movement is strongly linked to business cycles and provides important information for policymakers (Byrne et al., 2013; Gospodinov and Ng, 2013; Alquist et al., 2020). ENSO shocks influence commodity prices, but their impacts are nonlinear (Brunner, 2002; Ubilava, 2018; Nam, 2021). Moreover, it is difficult to investigate them using time-series models that assume stationary data series (Campbell and Diebold, 2005; Nam, 2021). Thus, we employ the wavelet coherence analysis approach to measure nonlinear relationships in the time and frequency domains, allowing inclusion of non-stationary data, such as ENSO shocks. More importantly, we apply the PWC approach proposed by Mihanović et al. (2009) and detect a "pure" relationship by removing the effects of the interest rate, which is an important variable in commodity prices (Frankel, 2008).

We find that the correlations between ENSO shocks and commodity price returns, such as agriculture, food, and raw materials, are almost homogenous, while ENSO shocks have a weaker correlation with the return of beverages than with the other commodities. We observe that the high correlations were at lower frequencies (32–64 and 64–128 months) and occurred in two periods, 1968–1990 and from year 2000 onward. Furthermore, comparing the results of wavelet coherence and PWC, we see that the high correlations between 1968 and 1990 became weak and the high correlations from year 2000 onward became strong by eliminating the effects of the interest rate, suggesting a recent strong relationship between commodity prices and ENSO. This indicates that controlling for interest rate effects is substantial for capturing the relationships between commodity prices and ENSO shocks.

Our findings have important implications for policymakers regarding climate change risks. The high correlations occurred at low frequencies, indicating that policies and institutions need to counter the adverse effects of ENSO shocks in the long run. The recent strong correlation between primary commodity prices and climate risk suggests that governments must consider the impacts of climate risk more carefully.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

AUTHOR CONTRIBUTIONS

XC: methodology, analysis of results, and writing. RS: conceptualization, writing, data collection, and review.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.893879/full#supplementary-material

[14]ONI is multiplied by (-1) to ensure consistency with the SOI (a negative value of the SOI indicates El Niño events).

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Can ESG-Responsible Investing Attract Sovereign Wealth Funds' Investments? Evidence From Chinese Listed Firms

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Global sustainable development focuses on environmental, social, and corporate governance (ESG) responsible investment as a leading-edge topic in global asset management. Because of the long-term financial returns and positive social benefits of ESG-responsible investment, ESG factors have been introduced into the investment decision-making and risk management of Sovereign Wealth Funds (SWFs). Therefore, this study examines the effect of firms' ESG-responsible investments on the investment scale of SWFs. We also examine the different influences of ESG factors in attracting SWFs' investment, which is of some significance in discussing the investment preferences of SWFs. We find that ESG performance attracts SWFs' investment by increasing ROA and reducing risk. The relationship between ESG and SWFs' investments may help managers adopt appropriate strategies to attract SWFs investments and achieve coordinated development.

Keywords: ESG, sovereign wealth funds, corporate finance, panel data, IV-2SLS, China

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INTRODUCTION

After the international crude oil price increases in 2007 and the subprime mortgage crisis in 2008, several Sovereign Wealth Funds (SWFs) have gradually emerged in developing countries. According to the statistics of the SWF Institute (SWFI), Norway Government Pension Fund Global (Norway GPFG), the world's largest SWF, controlled more than $1.4 trillion by 2021, whereas the total assets of the China Investment Corporation (CIC), the second-largest SWF, had exceeded $1.2 trillion (SWF Institute, 2022). The growth of SWFs is also noteworthy. In 2014, the assets under management (AUM) of SWFs had reached 5.5 trillion (Fotak et al., 2016), whereas this figure had exceeded 8 trillion US dollars in 2020 (Megginson et al., 2021).

Considering the scale of these investors, it is natural to focus on their investment strategies. Similar to other investment institutions, SWFs pursue short-term financial returns and strive to reduce risks. According to the 2020 annual report of the CIC, 17% of its assets are fixed-income products, whereas, for the Korea Investment Corporation (KIC), this proportion is as high as 35%. SWFs also consider sustainable corporate development in their investment decision-making. Norway's GPFG emphasizes that its fund management aims to obtain the highest possible return with medium risk while protecting and creating wealth for future generations. CIC also systematically considers the environment, social responsibility, and corporate governance (ESG) factors in all aspects of investment. Mubarak, Chief Executive of the Mubadala Development

Company in the United Arab Emirates, which takes oil revenue as the main source of its funds, said, “oil is not a resource for sustainable production. We need to make a strategic investment for the next generation after oil depletion” (Maeda, 2010). Therefore, in the large and rapidly growing Chinese market, we must question whether SWFs consider ESG factors when investing.

SWFs’ investment in mainland China began in 1995. Investment in China’s financial sector came from Singapore. In June 1995, the Singapore Government Investment Co., Ltd. (GIC) participated in establishing the China International Finance Co., Ltd. (CICC), with an investment of 7.5 million US dollars. Since 2009, the inflow of SWF investment into China has increased significantly, but there has been a significant difference in the value of SWFs. Before 2009, the SWF investment flowing into China was small, and the growth rate was slow. From 1995 to 2008, the cumulative investment attracted by SWFs reached US $8.9 billion. However, from 2009 to 2020, the average annual added value exceeded US $10 billion, and the cumulative investment reached US $264.6 billion. The main reason is the establishment of China’s SWF, which makes China have a stable source of SWF investment. After 2009, China became the main investor of SWFs, accounting for 56.53% of the total cumulative investment, reaching US $149.521 billion. In addition, Singapore is the country that likes to invest in China among the countries with SWFs, accounting for 19.3% of the total cumulative investment during the period, reaching US $51.047 billion. Canada and Norway have significantly increased their investment in China, Accounting for the third and fourth place in the proportion of cumulative investment from 2009 to 2020, accounting for 8.13 and 5.03%, respectively, with an investment of US $21.503 billion and US $13.313 billion, respectively. According to the INVESCO sovereign wealth fund report of 2021, 98% of SWFs will continue to invest in China. The primary driving force of investment is short-term, high returns. Insufficient ESG information disclosure hinders SWF investment, aligning with SWF’s trade-off between short-term returns and sustainable capital growth. With the transformation of China’s economic growth and the deepening of sustainable development strategies, Chinese firms’ social responsibility investment (SRI) has received increasing attention (Hofman et al., 2017). Improvements in ESG report disclosure also make it possible to evaluate Chinese firms’ ESG performance. However, because SWFs have no obligation to disclose information, their investment strategies and capital sources are often opaque (Alhashel, 2015). Therefore, the research on SWFs is challenging.

Based on this background, this study takes Chinese listed firms from 2008 to 2020 as the research object to explore whether their ESG performance positively affects SWF investments. First, we integrate the China Stock Market and Accounting Research Database (CSMAR), using principal component analysis to calculate the ESG performance scores of sample firms, and reduce the effect of sample selection errors through Heckman correction. The regression results show that overall ESG performance and ESG factors significantly help attract SWF investments. We then take the mean ESG score of the industry to which the firm belongs as an instrumental variable and use two-stage least squares to test the robustness of the results. We find that the SWF investment process may pay more attention to corporate governance factors. Finally, we introduce a mechanistic analysis to test the theoretical path through which ESG attracts SWF investment by improving ROA and beta.

LITERATURE REVIEW

What Is SWF?

Investment institutions owned and controlled by the government are considered SWFs. However, there are differences in the more specific definitions of SWFs because of the massive diversity of funding sources, governance structures, and investment objectives (Amar et al., 2018). According to the International Monetary Fund (IMF), SWFs should meet the following five conditions: (I) ease the volatility of commodities, (II) accumulate wealth for future generations, and (III) strives to reduce the opportunity cost of holding excess foreign exchange reserves and seek a higher rate of return, and (IV) support the development of the domestic economy (IMF, 2008). This shows the difference between SWFs and other investment institutions. Some studies have regarded SWFs as passive investors. For example, the Abu Dhabi Investment Company insists on not owning more than 5% of the same stock and does not pursue voting rights (Maeda, 2010). However, Dewenter et al. (2010) found the opposite. Most SWFs monitor or interfere with the target company, indicating that they may be active investors.

Although the term “Sovereign Wealth Fund” was first proposed by Rozanov (2005), the earliest SWF in the world can be traced back to the Kuwait Investment Corporation (KIA), established in 1953 (Boubakri et al., 2017). Since the 1950s, export-oriented strategies have achieved varying degrees of success (Bruton, 1998), and some countries have considered using public policy tools to manage foreign exchange reserves. However, the development of the SWF was slow during this period. With the rise in international oil and commodity prices in the early 21st century, SWFs established by countries that rely on natural resource income, such as Norway, Kuwait, and the United Arab Emirates, have developed rapidly (Eldredge, 2019). In addition, the funds for the China Investment Corporation come from the current account surplus caused by the sharp growth in exports, whereas the Government of Singapore Investment Corporation uses fiscal surplus directly (Maeda, 2010). The Australian Future Fund replenished its basic capital by selling 51% of Telstra, the largest telecommunications company in Australia (Eldredge, 2019). We list the top ten SWFs, according to the SWFI ranking, with their total assets and major funding sources in **Supplementary Appendix S1**, showing that SWF capital comes mainly from resource income and foreign exchange reserves (Curzio and Miceli, 2011). Governments may establish SWFs to pursue long-term returns and economic development (Lenihan, 2014) or treat macroeconomic policies with caution, especially in Asian countries and emerging economies (Castelli and Scacciavillani, 2012). Other motives for establishing SWFs, such as achieving geopolitical goals (Gilson and Milhaupt, 2009).

Investment Strategies of SWFs

The SWF investment strategy is similar to other private investment institutions. Although it is difficult to obtain financial indicators for target firms from the annual reports of major SWFs. There is still evidence that SWFs invest in companies with certain profitability (Fernandes, 2009; Bernstein et al., 2013), and investment behavior is related to a higher rate of return (Karolyi and Liao, 2017). Another portion of the literature shows that the principle of income maximization is not the only consideration for SWF investment. Chhaochharia and Laeve, 2009 found that SWF investment considers ethnic, religious, and cultural differences between the home country and the country where the target firm is located and political factors (Bernstein et al., 2013). For example, firms engaged in US campaign financing are more attractive to SWFs (Calluzzo et al., 2017). Gnabo et al. (2017) find that Temasek prefers to increase the scale of foreign investment when foreign exchange reserves grow rapidly. The factors considered in SWF decision-making are very complex.

SWF and Corporate ESG Performance

As large government-led investment institutions, SWFs are less constrained by short-term liabilities and liquidity; therefore, they are more capable of promoting sustainable investments and pursuing long-term returns (Wurster and Schlosser, 2021). As investors that accumulate wealth for future generations, SWFs have sufficient motivation for sustainable investments (Liang and Renneboog, 2020). From the perspective of financial performance, ESG can improve firms' operating performance (Peiris and Evans, 2010; Brogi and Lagasio, 2019) and competitiveness (Frooman, 1997), thus helping attract SWF investments. However, the high cost of improving and maintaining ESG performance may damage a company's financial performance (Garcia and Orsato, 2020). Some literature believes that there is no significant relationship between corporate SRI, returns, and corporate value (Atan et al., 2018). In addition, Nollet et al. (2016) believe a threshold effect on the impact of ESG performance on firm value. Positive returns can only be obtained when ESG performance reaches a certain level. There are differences between the effects of ESG factors on corporate financial performance in the existing literature. Thus, this study examines whether there is a theoretical mechanism through which ESG factors attract SWF investments by affecting firms' financial performance.

As an emerging market, Chinese firms may have a large gap with developed economies in corporate governance and market norms (Tanjung, 2021). The disclosure quality of ESG information may also be lower (Patel et al., 2002), reducing SWF's evaluation of Chinese firms' ESG performance. We also focus on the change in the ESG performance of Chinese firms in recent years. According to the Bloomberg database, we describe the trend of ESG disclosure average scores of firms in China, Japan, Russia, India, the United Kingdom, and the United States; the results are shown in **Figure 1**. **Figure 1** shows that the ESG disclosure score of Chinese firms has increased rapidly, but there is still a large gap with some developed economies (such as the United Kiingdom).

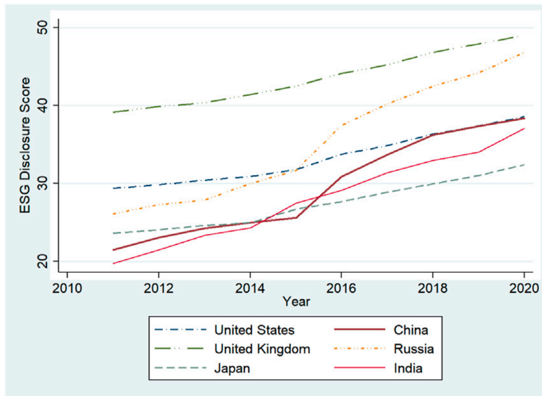

FIGURE 1 | ESG disclosure score by countries.

The progress of Chinese firms' ESG performance has benefitted from the implementation of a series of ESG-related laws. This study also considers whether the promulgation of the Environmental Protection Tax Law impacts the process of SWF evaluating the quality of ESG disclosure.

MODEL, DATA SOURCE, AND DESCRIPTIVE STATISTICS

Model Setting

In line with some empirical analyses of the relationship between SWF investment and corporate financial performance (Gangi et al., 2019; Liang and Renneboog, 2020), this study introduces ordinary least squares models with fixed effects, including province, industry, and year, as shown in **Eqs 1**, **2**. We lag all independent variables by 1 year to deal with endogenous problems.

$$\begin{aligned}\boldsymbol{Ownership}_{i,t} = \boldsymbol{\beta_0} + \boldsymbol{\beta_1 Score}_{E_{i,t-1}} + \boldsymbol{\beta_2 Score}_{S_{i,t-1}} + \boldsymbol{\beta_3 Score}_{G_{i,t-1}} \\ + \boldsymbol{\delta}^T \sum \boldsymbol{X}_{it-1} + \boldsymbol{\mu}_j + \boldsymbol{\varepsilon}_k + \boldsymbol{\theta}_t + \boldsymbol{\varepsilon}_{i,t}\end{aligned} \tag{1}$$

$$\begin{aligned}\boldsymbol{Ownership}_{i,t} = \boldsymbol{\beta_0} + \boldsymbol{\beta_1 Score}_{ESG_{i,t-1}} + \boldsymbol{\delta}^T \sum \boldsymbol{X}_{it-1} + \boldsymbol{\mu}_j + \boldsymbol{\varepsilon}_k + \boldsymbol{\theta}_t \\ + \boldsymbol{\varepsilon}_{i,t}\end{aligned} \tag{2}$$

$\boldsymbol{Ownership}_{i,t}$ represents the sum of shares held by SWFs in firm i in year t[1]; $\boldsymbol{Score\_E}_{i,t-1}$, $\boldsymbol{Score\_S}_{i,t-1}$, $\boldsymbol{Score\_G}_{i,t-1}$ and

[1]SWFI only counts the specific amount and shares invested by each SWF in a certain year, but does not include the changes in equity held by SWF. Therefore, we add up the shares invested by SWF during the sample period and accumulate them year by year to avoid the impact of the decline in the number of SWF transactions included in SWFI (for example, the number of SWF investments recorded in the database decreased significantly in 2019 and 2020). If this treatment is not carried out, the econometric regression may produce serious errors. In addition, because the first-order difference of explanatory variables will lose a lot of information, we will not consider it.

TABLE 1 | First principal component of each component.

• Environment	• Social Responsibility	• Corporate Governance
• Whether to disclose the concept of environmental protection	• Social donation amount (logarithm)	• Whether the share capital structure has changed
• Whether to disclose the completion of environmental protection objectives	• Whether to disclose the protection of the safety of employees	• Whether the top ten shareholders are related
• Whether to disclose the environmental management system	• Whether to disclose the protection of rights and interests of employees	• Whether the chairman of the board and the general manager serve concurrently
• Whether to disclose the environmental protection related to education and training	• Whether to disclose the protection of the rights and interests of shareholders	• The proportion of independent directors
• Whether to disclose the special environmental protection activities	• Whether to disclose the protection of the rights and interests of consumers	• Frequency of strategic committee meetings
• Whether to disclose the emergency mechanism of environmental emergencies		• Frequency of audit committee meetings
• Whether to disclose honors related to environmental protection		• Frequency of meetings of salary and assessment committee
• Whether to disclose the implementation of the "Three Simultaneities" system		• Frequency of meetings of the nomination committee
• Whether to be a key monitoring unit of environmental protection		
• Whether environmental violations have occurred		
• Whether environmental petition events occur		
• Whether it has passed the ISO14001 certification		

$\boldsymbol{Score\_ESG_{i,t-1}}$ represent the scores of environment, social responsibility, corporate governance, and the overall ESG score calculated by principal component analysis (PCA), respectively. All the first principal components are listed in **Table 1**. Referring to Gangi et al.'s (2019) variable selection, we use the control variables ($\boldsymbol{X_{it}}$), including the firms' return on assets (ROA), cash ratio (Cash_Ratio), the growth rate of sales (Growthrate_Sales), and intangible asset ratio (Intangible_Ratio), which can be proxy variables of corporate knowledge and technology level. In addition, we introduce the price-earnings ratio (PE) according to Bernstein et al. (2013). The leverage ratio (Lev) is also a key variable affecting SWF investments (Ciarlone and Miceli, 2014). Finally, we control for non-systematic risk (beta) and firms' market value (market value). μ_j、$\boldsymbol{\varepsilon_k}$、and $\boldsymbol{\theta_t}$ are province, industry, and year fixed effects, whereas $\boldsymbol{\varepsilon_{i,t}}$ represents the random error term.

Data Source

This study's sample comprises A-share listed companies in China from 2008 to 2020. Except for the dependent variable data from the SWFI, the data of the other variables are from the CSMAR database, and all nominal variables are converted to real ones based on 2008. In addition, we winsorize the continuous variables at the 1% level to reduce the influence of extreme values. We merged these two databases based on the company's English names. Among the 4,844 enterprises in our sample, 474 had SWF investors. As key independent variables, we refer to Qiu and Yin's (2019) method and calculate the ESG performance score of each firm using the PCA method. The first principal component of each component score is presented in **Table 1**. The total ESG score was calculated by summarizing the first principal component of each component. **Table 2** provides the descriptive statistics. We use the data imputation method for the price-earnings ratio (PE), beta, and leverage ratio (Lev), including more missing values.

TABLE 2 | Descriptive statistics.

Variable	Obs	Mean	Std. Dev	Min	Max
Ownership	5,926	0.019	0.061	0	1
Score_ESG	29,313	0	2.189	−2.93	8.255
Score_E	33,284	0	1.812	−1.322	10.331
Score_S	36,427	0	1.664	−2.065	4.444
Score_G	32,005	−0.063	1.48	−1.412	5.048
ROA	45,005	0.042	0.054	−0.12	0.273
Cash_Ratio	45,002	0.146	0.119	0.007	0.644
Intangible_Ratio	45,466	0.033	0.033	0	0.217
Growthrate_Sales	35,566	0.322	1.093	−0.323	15.611
Beta	46,040	1.162	0.218	0.457	1.919
PE	46,040	88.813	118.298	5.995	1,225.902
Lev	46,047	1.838	1.843	0.293	19.625
Marketvalue (Log)	35,876	22.52	1.29	19.439	30.834

EMPIRICAL RESULTS

Basic Empirical Results

First, we conducted a panel OLS regression, which considered heteroscedasticity and controlled for the fixed effects of provinces, industries, and years. As shown in **Table 3**, the first two columns of the regression do not include the control variables. The results showed that improving the ESG total score and each component score significantly attracted sovereign fund investment. However, after adding the control variables, only the coefficient of corporate governance score remains significant. In **Table 4**, we introduce the method of the dynamic panel system GMM, that is, $Ownership_{i,t-1}$ is added to the explanatory variable. In **Table 4**, in the two groups of GMM

TABLE 3 | Results of OLS regression (dependent variable: equity ownership held by SWFs).

Variables	(1)	(2)	(3)	(4)
ESG_Score(t-1)	0.0025*** (7.68)		0.0035 (1.08)	
E_Score(t-1)		0.0018*** (3.95)		0.0030 (0.60)
S_Score(t-1)		0.0012** (2.16)		−0.0017 (-0.32)
G_Score(t-1)		0.0040*** (6.26)		0.0038*** (6.00)
Control Variable	N	N	Y	Y
Year FE	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y
Province FE	Y	Y	Y	Y
R Square	0.2452	0.2052	0.2812	0.2349
N	4,487	4,069	3,936	3,772

Notes: Numbers in parentheses are t*-ratios. ***,**, and * indicate statistical significance at 1, 5, and 10% levels, respectively.*

TABLE 4 | Results of dynamic panel system GMM regression (dependent variable: equity ownership held by SWFs).

	(1)			(2)		
	OLS	FE	GMM	OLS	FE	GMM
Ownership(t-1)	1.0170*** (76.45)	0.8418*** (46.09)	1.0121*** (20.16)	1.0150*** (81.63)	0.8441*** (53.09)	0.9753*** (52.49)
ESG_Score(t-1)	−0.0001 (−1.12)	−0.0001 (−1.00)	−0.0001 (−0.48)			
E_Score(t-1)				−0.0003 (−1.40)	0.0002 (1.58)	−0.0002 (−1.19)
S_Score(t-1)				0.0001 (0.66)	−0.0003 (−1.61) 0.0000	0.0001 (0.51)
G_Score(t-1)				0.0003* (1.84)	0.0000 (0.16)	0.0004* (1.74)
Control Variable	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Industry FE	N	Y	Y	N	Y	Y
Province FE	N	Y	Y	N	Y	Y
F Value	823.07	478.21	6,846.83	697.89	437.27	1,245.02
Hansen test			10.02			7.77
N	3,772	3,772	3,772	3,772	3,772	3,772

Notes: Numbers in parentheses are t*-ratios. ***, **, and * indicate statistical significance at 1, 5, and 10% levels, respectively.*

regression, the coefficient value $Ownership_{i,t-1}$ is between the OLS and fixed effect (FE) model, and the p-value corresponding to the Hansen test is larger than 5%, which indicates that the null hypothesis of overidentification should be rejected. **Table 4** shows that the total ESG score has no significant impact on attracting SWF investment, while in each component, only the corporate governance factor is significantly positive. However, the sample used in this study may have serious sample selection errors; therefore, it is necessary to consider other empirical strategies.

Table 5 shows the results of firms' overall ESG and component scores under the Heckman two-stage regression. In this model, the probit model is used in the first stage. The dependent variable is a dummy variable that takes the value of 1 if it has an SWF investor; otherwise, it is 0. The difference from the general probit model is that the missing values are included in Heckman's one-stage regression, and all missing values are regarded as indicating that the company does not have an SWF investor, taking a value of zero. After the one-stage regression, we calculate the inverse Mills ratio (IMR), a variable calculated based on the predicted value of the firms' investment probability, and use it as the control variable of the two-stage regression to correct the sample selection error issue. The first two columns in **Table 5** represent the regression results of the ESG total score, and the last two columns represent the regression results of the component score. We first note that the IMR regression coefficients in the two models are significant, at least at the 10% level, indicating that there is indeed a sample selection error. Thus, the Heckman correction was more efficient. **Table 5** shows that ESG performance helps increase the probability of SWFs investment and has a positive relationship with the proportion of SWF investment shares. Similar to the results in **Table 4**, the effect of corporate governance is more significant than those of environmental and social responsibility. This result is similar to Liang and Rennebog (2020). They found that the ESG factor positively affected attracting SWF investment. However, we found that environmental, social responsibility and corporate governance factors had different effects on attracting SWF investment.

We must consider whether our model may have endogeneity problems; in particular, some large SWFs may affect or even interfere with the corporate governance of invested firms or promote the target firms to increase investment in environmental and social responsibility to improve their ESG performance (Al Ayoubi and Enjolras, 2021). This indicates that we did not overcome the endogeneity problem caused by reverse causality in our previous study. Previous empirical studies on the factors affecting SWF investment at the micro-level rarely consider the endogeneity problem (Boubakri et al., 2016;

TABLE 5 | Heckman two-step regression results.

	(1)		(2)	
	Heckman stage I	Heckman stage II	Heckman stage I	Heckman stage II
ESG_Score(t-1)	0.0477*** (8.72)	0.0198*** (2.68)		
E_Score(t-1)			0.0192** (2.65)	0.0072* (1.67)
S_Score(t-1)			0.0458*** (5.92)	0.0161* (2.28)
G_Score(t-1)			0.0275*** (3.78)	0.0126** (2.56)
IMR		0.5224*** (2.91)		0.4503** (2.74)
Control Variable	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y
Province FE	Y	Y	Y	Y
Wald chi2	2,345.33		2,199.48	
N	24,896	3,936	24,334	3,772

*Notes: Numbers in parentheses are z statistics. ***, **, and * indicate statistical significance at 1, 5, and 10% levels, respectively.*

TABLE 6 | IV Regression results (ESG overall score).

	Probit	IV stage I	IV stage II
IV_ESG_Score	0.0638*** (4.62)	0.3367*** (7.11)	
ESG_Score			0.0630*** (4.31)
IMR			0.7478*** (4.91)
F Value		50.61	
Wald chi2	3,033.46		
Control Variable	Y	Y	Y
Year FE	Y	Y	Y
Industry FE	Y	Y	Y
Province FE	Y	Y	Y
N	33,712	4,326	4,326

*Notes: Numbers in parentheses are z statistics. ***, **, and * indicate statistical significance at 1, 5, and 10% levels, respectively.*

Gangi et al., 2019). Liang and Rennebog (2020) chose the difference-in-difference method to overcome the endogeneity problem. One way to deal with endogeneity problems is to use the two-stage least squares of instrumental variables (IVs). We use the average ESG score of the industry to which the firm belongs as an IV. To use IVs in the Heckman two-step regression, we should replace endogenous variables with IVs for one-stage probit regression, calculate the IMR, and then introduce the IMR as a control variable for the IV two-stage regression. As we plan to use IVs to overcome the endogeneity problem, all variables are regressed with the current data during the regression to reduce the loss of sample size. The second column in **Table 6** shows that the F-value of the one-stage regression is 50.61, indicating that IV is effective. In contrast, the third column shows that the Heckman two-step method effectively corrects the sample selection error. After overcoming the endogeneity problem through the IV and Heckman two-step methods, we found that the enterprise's ESG performance attracted SWF investment, further verifying the robustness of our hypothesis. We also conducted an IV regression for each ESG component (**Table 7**). The first-stage regression results show that each IV has a strong correlation with its corresponding endogenous variables, and the F-values indicate the effectiveness of the IVs. After introducing IVs, we find that corporate governance and environmental factors attract significant SWF investments.

Mechanism Analysis

Many studies have discussed how ESG performance promotes corporate financial performance and market competitiveness (Frooman, 1997; Deng and Cheng, 2019). In the background, we consider whether ESG attracts SWF investment indirectly by improving firm performance. The method used to identify this theoretical mechanism was to test the mediating effect using the stepwise regression method, as shown in **Table 8**. We exclude the ROA lag term in columns (1) and (2) and the beta lag term in columns (3) and (4), and then add all variable regressions in columns (5) and (6). By comparing the results of the second stage of the Heckman regression, we find that the coefficient value of the ESG score in column (2) is larger than that in column (6), and the coefficient of ROA is significant at a 5% level, indicating partial mediation and no complete mediation. In addition, we used another return rate[2] to replace ROA. This conclusion remains unchanged, thus proving its robustness. In contrast, comparing the ESG score coefficients in columns (4) and (6) shows that ESG performance has a partial mediation effect on risk.

On 25 December 2016, the Environmental Protection Tax Law of the People's Republic of China was adopted by the 25th meeting of the Standing Committee of the 12th National People's Congress of the People's Republic of China. The law was first made public for comments in the second half of 2015, passed at the end of 2016, and came into effect on 1 January 2018. The promulgation of this law may help improve the performance of firms and the quality of ESG information disclosure, thus making it more attractive for SWF investing. We analyze this by setting up a dummy variable, Law_2016. Law_2016 equals 1 if the year is greater than 2016; otherwise, it equals 0. As the law was implemented in early 2018, Law_{2018} was set in the same way. We included Law_2016 and Law_2018 and their interactions with corporate ESG scores into the regression equation. **Table 9** presents the results of the Heckman two-step regression. We

[2]Return rate equals (total profit + financial expenses)/average total assets, where average total assets equals (total assets ending balance + total assets ending balance of last year)/2.

TABLE 7 | IV Regression results (each component of ESG).

	Probit	IV stage I			IV stage II
		E_Score	S_Score	G_Score	
IV_E_Score	0.0766*** (3.67)	0.6285*** (7.49)	−0.2695*** (−4.98)	0.2263*** (3.95)	
IV_S_Score	−0.0521 (−1.46)	−0.1462 (−1.38)	0.7163*** (8.86)	−0.4189*** (−4.89)	
IV_G_Score	0.0737* (2.53)	−0.4470*** (−5.40)	−0.3037*** (−4.83)	0.9990*** (16.39)	
E_Score					0.0207*** (3.11)
S_Score					0.0070 (0.94)
G_Score					0.0356*** (4.28)
IMR					0.4493*** (4.18)
F Value		50.43	28.87	91.41	
Wald chi2	3,023.96				
Control Variable	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y	Y
Province FE	Y	Y	Y	Y	Y
N	33,712	4,240	4,240	4,240	4,240

*Notes: Numbers in parentheses are z statistics. ***, **, and * indicate statistical significance at 1, 5, and 10% levels, respectively.*

TABLE 8 | Mechanism analysis.

	(1)	(2)	(3)	(4)	(5)	(6)
	Heckman stage I	Heckman stage II	Heckman stage I	Heckman stage II	Heckman stage I	Heckman stage II
ESG_Score(t-1)	0.0488*** (8.93)	0.0203*** (2.66)	0.0473*** (8.65)	0.0200** (2.57)	0.0477*** (8.74)	0.0198*** (2.68)
ROA(t-1)			2.5353*** (6.50)	1.0788** (2.43)	2.2219*** (5.66)	0.9801** (2.39)
Beta(t-1)	−0.4070*** (−8.32)	−0.1655*** (−2.68)			−0.3820*** (−7.69)	−0.1533*** (−2.64)
IMR		0.5265*** (2.88)		0.5342*** (2.78)		0.5224*** (2.91)
Control Variable	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y	Y	Y
Province FE	Y	Y	Y	Y	Y	Y
Wald chi2	2,359.55		2,330.92		2,345.33	
N	24,896	3,936	24,896	3,936	24,896	3,936

*Notes: Numbers in parentheses are z statistics. ***, **, and * indicate statistical significance at 1, 5, and 10% levels, respectively.*

TABLE 9 | Effect of the environmental protection tax law.

	(1)	(2)	(3)	(4)
	Heckman stage I	Heckman stage II	Heckman stage I	Heckman stage II
ESG_Score(t-1)	0.0142** (1.96)	0.0370*** (2.66)	0.0188** (2.43)	0.0453*** (7.04)
ESG_Score(t-1)×Law_2016	0.0133** (2.00)	0.0195*** (2.05)		
ESG_Score(t-1)×Law_2018			0.0065 (1.11)	0.0070 (0.71)
Law_2016	−0.0169 (−2.33)	−0.4331*** (−7.83)		
Law_2018			−0.1619*** (−2.33)	−0.4359 (−7.85)
IMR		0.5677*** (2.89)		0.5404*** (2.90)
Control Variable	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y
Province FE	Y	Y	Y	Y
Wald chi2	2,331.06		2,329.83	
N	24,896	3,936	24,896	3,936

*Notes: Numbers in parentheses are z statistics. ***, **, and * indicate statistical significance at 1, 5, and 10% levels, respectively.*

found that the coefficient and significance level of the ESG performance score are similar to those in our previous study, whereas the coefficients of Law_2016 and Law_2018 are significantly negative. One explanation is that firms may pay higher costs to maintain ESG performance (Garcia and Orsato, 2020). The coefficients of the enterprise ESG performance score and the interaction of Law_2016 are significantly positive in both regression stages, but the coefficient of the interaction with

*Law*_2018 is not significant. These results show that the Environmental Protection Tax Law may improve the quality of ESG disclosure before it is officially implemented. Firms and SWFs may be more sensitive to capturing, predicting, and adjusting the impact of the implementation of the law.

CONCLUSION AND DISCUSSION

To explore whether enterprises' ESG performance positively affects SWF investment, we first constructed scoring rules to evaluate enterprises' ESG performance. Using the samples of Chinese listed enterprises from 2008 to 2020 and the data on SWF investment, we conducted regression analysis through OLS, the Heckman two-step method, and IV-2sls. We find that better ESG performance can attract SWF investment. Specifically, the significance of corporate governance factors is less sensitive to our study's variable selection and research methods, indicating that corporate governance factors may be more attractive than environmental and social responsibility factors. We overcome the endogeneity problem by consolidating the existing conclusions using the IV method. Finally, we also find that ESG can indirectly win the favor of SWF by improving the return on assets and risk level of enterprises to improve their financial performance and estimate the effect of the Environmental Protection Tax Law, which may improve the quality of ESG disclosure.

The contribution of this study is that, based on Boubakri et al. (2016) and Gangi et al. (2019), we studied how ESG performance attracts SWF investment, enriching micro-level research on the relationship between SWFs and ESG. We consider endogeneity and overcome this problem using instrumental variables. In addition, we attempt to explain the ESG factors that affect the financial performance of enterprises to attract SWF investment through a mechanism test. We explain the investment strategy and asset allocation concept of SWFs. This conclusion also highlights the need for enterprises to improve ESG performance. However, this study's SWF data has some limitations. It is difficult to identify the stock changes in invested enterprises; therefore, our model has a certain estimation error. In addition, there is room for improvement in our rules when matching across the databases. Finally, it was difficult to analyze the heterogeneity because of the sample size. Specifically, it is of research value to distinguish between the industries of the target enterprises and conduct separate research on each large-scale SWF.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

GC conceived and designed the research method; LD conceived and designed the research method with GC and supplied the data; BW analyzed the data, wrote, and finalized the manuscript. All the authors have read and agreed to the published version of the manuscript.

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SUPPLEMENTARY MATERIAL

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Do Corporate Social Responsibility Practices and Green Finance Dimensions Determine Environmental Performance? An Empirical Study on Bangladeshi Banking Institutions

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This study aims to examine the effects of Corporate Social Responsibility (CSR) and green finance dimensions on the environmental performance of banking institutions in a developing economy like Bangladesh. In order to identify the relationship between the study variables, primary data were collected from 388 employees of Private Commercial Banks (PCBs) in Bangladesh using a non-probabilistic convenience sampling method and analyzed using the Structural Equation Modeling (SEM) approach. The results suggested that CSR practices have a positive influence on the environmental performance. Furthermore, the results indicated that the social, economic and environmental aspects of green financing significantly influence the environmental performance of banking institutions. Overall, the paper concludes that CSR practices and financing of various eco-friendly projects play a crucial role in improving the environmental performance of organizations and ultimately promote a sustainable development in the country. Finally, the study's findings can help managers of banking institutions in emerging economies like Bangladesh strengthen internal resources such as CSR activities and green finance to improve environmental performance. Therefore, the major policy implications are further discussed.

Keywords: CSR, green finance, environmental perfomance, banks, SEM, Bangladesh

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1 INTRODUCTION

Recently, most countries, especially the emerging ones, have prioritized economic advancement over environmental growth. As a result, they are facing several environmental issues, such as climate change, biodiversity loss, environmental degradation, soil erosion, air pollution, deforestation, land loss, etc. (Zheng et al., 2021a). Bangladesh is considered to be one of the next emerging countries in the world (Nawaz et al., 2020), with huge investment, growth and economic potential to become a market leader in the 21st century (Akter et al., 2018; Zheng et al., 2021a). However, like most developing nations, Bangladesh is also grappling with the problem of climate change and its associated environmental implications (Zheng et al., 2021a). To alleviate these threats and promote a sustainable development, they have developed several initiatives, including the adoption of green financing (Hossain, 2019; Zheng et al., 2021a). In this regard, banking institutions play a critical role by supporting socially responsible initiatives and financing a variety of eco-friendly projects, such as clean energy, alternative energy, energy efficiency, renewable energy, green industry development and waste management, among others (Akter et al., 2018; Zhixia et al., 2018), all of which greatly contribute to an organization's sustainability performance (Teixeira and Canciglieri Junior, 2019) and the country's sustainable economic development (Zheng et al., 2021a). Green finance (GF) is a growing concept (Liu et al., 2020) and can be defined as a new monetary tool that integrates economic benefits with environmental preservation (Wang and Zhi, 2016). Corporate social responsibility (CSR), on the other hand, is seen as another activity that assists organizations in improving their business for long-term sustainability (Kolk, 2016). Any organization's environmental performance can be measured by a number of metrics including low environmental emissions, pollution control, waste reduction and recycling (Lober, 1996). As a result, CSR and GF can be viewed as important approaches to increasing an organization's environmental sustainability (Kala et al., 2020; Suganthi, 2020).

For several decades, scholars have used CSR to assess an organization's performance (Ali et al., 2020; Kraus et al., 2020). However, there has been little emphasis dedicated to investigating green finance dimensions and CSR practices in the sphere of environmental performance. Moreover, a few studies have found that green finance significantly improves the environmental performance (Chen et al., 2022; X. Zhang et al., 2022), sustainability performance (Indriastuti and Chariri, 2021; G. Zheng et al., 2021a), and financial performance (Indriastuti and Chariri, 2021). Despite this, Wang et al. (2022) recently investigated the effect of green financing dimensions in accomplishing, excelling, and improving CSR in the banking sector. The study discovered that green finance and its corresponding dimensions (social, economic, and environmental) play a role in increasing the various facets of CSR such as employees, consumers, communities, legal and ethical issues, and stakeholders. Furthermore, literature has confirmed that CSR practices significantly improves organizational performance (Abbas, 2020; Famiyeh, 2017; Galant and Cadez, 2017; Javed et al., 2020; Laskar, 2018; Ri'os-Manrquez et al., 2021; Saeidi et al., 2021; Ying et al., 2021; G. Zhou et al., 2021), environmental performance (Ghisetti and Rennings, 2014; Bamgbade et al., 2018; Kraus et al., 2020; Suganthi, 2020; Ajibike et al., 2021; Sinha et al., 2021), and sustainability performance (Abbas et al., 2019; Ajibike et al., 2021; Indriastuti and Chariri, 2021; Pham et al., 2021; Sadiq et al., 2021). Despite the fact that numerous studies have evaluated a company's environmental and financial performance through CSR, academics continue to focus on this link due to inconclusive findings (Kraus et al., 2020). Besides, a couple of studies have been conducted to measure the impact of green banking practices on banks' environmental performance in Sri Lanka (Shaumya and Arulrajah, 2017), India (Kala et al., 2020), Nepal (Risal and Joshi, 2018) and Pakistan (Rehman et al., 2021). In the context of Bangladesh, a few studies have attempted to explore GF and sustainability performance of financial institution (G. Zheng et al., 2021a), as well as CSR and corporate performance (Alamgir and Uddin, 2017). However, the effect of CSR and GF dimensions (social, economic, and environmental) on the environmental performance of banking institutions remain largely unexplored. In addition, there exist limited studies in the direction of CSR, GF and environmental performance based on the primary data. To the best of the author's knowledge, no research has been conducted on the influence of CSR and GF dimensions on bank environmental performance.

In filling the aforementioned research gap, this study aims to answer the following two research questions: Do CSR practices have a positive influence on the environmental performance of PCBs in Bangladesh? Do GF dimensions such as social, economic and environmental have a positive effect on the environmental performance of PCBs in Bangladesh? In this study, we build on CSR and GF concepts to better understand how banks engage in green financing and social responsibility to improve their overall organizational sustainability. To construct our argument, we deploy the legitimacy theory to understand how corporations might legitimize their social responsibility actions (Suchman, 1995), and extend the concept of GF (Dörry and Schulz, 2018) to improve organizational sustainability performance. Furthermore, this is an empirical study based on survey data collected from the banking industry of an emerging economy such as Bangladesh. In order to examine the relationship between the study variables such as CSR practices, green finance dimensions (social, economic, and environmental), and environmental performance, the study used a structured questionnaire to collect the primary data from 388 bankers of private commercial banks (PCBs) using a non-probabilistic convenience sampling method. Subsequently, the structural equation modeling (SEM) approach was employed to analyze the obtained primary data. Empirical findings indicate that CSR practices have a positive influence on the environmental performance of banking institutions. In addition, the results show that the social, economic, and environmental aspects of green financing have a significant influence on environmental performance.

Moreover, in light of the existing literature on CSR, GF and environmental performance in the context of banking institutions in emerging economies, the empirical findings of the study offer a number of theoretical and practical contributions. First, this study is one of the first to empirically examine the positive association between the various components of GF (social, economic, and environmental) on the environmental performance of banking institutions in Bangladesh, which was overlooked by previous studies (Chen et al., 2022; X. Zhang et al., 2022; G. Zheng et al., 2021a). Second, the significant positive link between CSR and environmental performance in the context of banking sector represents a novel contribution to the existing literature on CSR and organizational sustainability. As a result, the study's empirical findings are consistent with the concepts of GF and legitimacy theory, which illustrate that GF and CSR practices improve firms' environmental performance by highlighting the need of societal consent in attaining long-term sustainable growth (Indriastuti and Chariri, 2021). Finally, the empirical findings can help managers of banking institutions in emerging economies like Bangladesh strengthen internal resources such as CSR activities and green finance to improve environmental performance.

The reminder of the paper is organized as follows: **Section 2** presents related literature and relevant hypotheses. **Section 3** advances the research methodology, followed by the results and discussions in **Section 4**. **Section 5** provides study conclusion and directions for future research.

2 LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

2.1 Legitimacy Theory

According to the legitimacy theory, societal consent is crucial to the promotion of an organization's environmental sustainability. Besides, legitimacy theory asserts that firms actively seek and maintain legitimacy by integrating corporate ideals, policies, and strategies with community values (Dowling and Pfeffer, 1975). As a result, organizations must choose activities that are appropriate and consistent with social perspectives, beliefs, and norms. Furthermore, green finance can be viewed as a company's strategy to gain and maintain legitimacy (Chariri, Anis et al., 2018) because it helps businesses to control the environmental implications of their operations by minimizing energy use and decreasing carbon emissions and other adverse consequences (Minatti Ferreira et al., 2014; Chen et al., 2022). According to the legitimacy theory, the substance and extent of CSR activities are determined by the link between societal expectations (e.g., in the form of prevailing social ideologies), managers' attitudes toward what they believe to be legitimate societal expectations, and company behavior (Gray et al., 1988). As a result, in accordance with the legitimacy idea, businesses should use green finance, social, and environmental initiatives to gain, maintain, or restore their legitimacy. Therefore, the current study developed a comprehensive research model based on the notion of legitimacy theory to evaluate the relationship between GF dimensions, CSR activities, and EP in the setting of banking institutions in an emerging country like Bangladesh.

2.2 Corporate Social Responsibility

The concept of CSR have a long and complicated history (Saeidi et al., 2021). However, it rose to prominence in the 20th century, particularly the early 1950s and has attracted the attention of academics and businesses in recent years (Carrington et al., 2019). The theories, concepts and ideas of CSR are frequently regarded as a western phenomenon due to the region's solid organizational frameworks as well as efficient and fair legislation (Ansong, 2017). Despite the popularity of CSR concept in the academia and businesses, it lacks a clear and unified definition (Bussmann et al., 2021). The absence of diverse theoretical limits and conceptualization has led to the proliferation of CSR definitions. However, the unified CSR standard definitions advocate that companies must design their strategies in accordance with the society's ethical expectations (Vuković et al., 2020). According to Carroll (1979), CSR is defined as a firm's social responsibility, which includes society's regulatory, economic, moral and discretionary demands of enterprises at any particular time. Furthermore, CSR is defined as a firm's sense of responsibility to the society and community (both ecological and social) in which it exists (Kaschny and Nolden, 2018). CSR refers to strategies that organizations or firms use to conduct business in a way that is ethical, socially responsible, and developmentally useful to the community (Mocan et al., 2015). Reducing carbon footprints, volunteering, and investing in environmentally conscious business are among the most important CSR activities undertaken by banking institutions (Mocan et al., 2015). Therefore, CSR initiatives can be understood as initiatives that organizations undertake for the benefit of society and the environment in order to achieve overall organizational performance and sustainability.

2.3 Green Finance and its Dimensions

Since its inception, GF has acquired a substantial traction in the economic conversation among international organizations and state governments (D. Zhang et al., 2019). GF has also gained popularity among academics, scholars, researchers and practitioners (D. Zhang, 2018; G. W. Zheng et al., 2021a), and it now represents a new financial model that stresses green investment to safeguard the environment while also promoting economic success (Wang et al., 2019). GF is seen as a vital component of sustainable banking, with a significant influence on the expansion of a balanced economy and markets in general (Akter et al., 2018; Hoque et al., 2019; G. W. Zheng et al., 2021a). GF is a holistic approach that combines numerous initiatives to enhance the monetary system's economic, social and environmental performance, as measured by Environmental, Social and Governance (ESG) criteria, i.e., factors that are critical components of long-term economic growth and finance (G. Zheng et al., 2021a). The main operations of GF include green bonds, microfinance, sustainable funds, impact investments, active ownership, credits for environmental sustainability and enhancement of entire financial systems. As defined by the EU high-level expert group on sustainable finance, GF is a financial system that addresses challenges such as environmental sustainability, sustainable housing, pension, infrastructural facilities, technological advancement, reducing carbon emissions, as well as other long-term academic and societal issues (G. Zheng et al., 2021a).

Furthermore, several previous studies have described GF as the development of economic, social and environmental implications of financial services (X. Zhou et al., 2020), with a broad influence on the expansion of a sustainable economy and company (Akter et al., 2018). The term "GF" refers to a set of three dimensions known as the "Triple Bottom Line," which includes social, economic, and environmental aspects (Malsha et al., 2020; G. W. Zheng et al., 2021a)· Most research, in particular, identify GF parameters in a unique way. Only a few studies, however, have looked at the connections between the social, economic and environmental components of GF in the banking industry (Akter et al., 2018; Raihan, 2019; G. W. Zheng et al., 2021a). Recently, Zheng et al. (2021a) investigated the development of GF in the Bangladeshi banking sector, particularly in PCBs, and found that the level of consciousness, perceptions and comprehension of the important dimensions of GF and green financing among PCBs bankers was adequate for the successful implementation of GF in

Bangladesh to facilitate the country's long-term eco-development. The study also highlighted renewable energy, energy efficiency, alternative energy, waste management, green sector growth, and so on as key sources of green financing by banking institutions.

2.4 Environmental Performance

Environmental performance is an element of environmental sustainability efficiency that relates to the company's natural environment activities and goods (Klassen and Whybark, 1999), and can be best assessed via the effective use of the material, as stated by Tung et al. (2014). Furthermore, the emission intensity was applied to estimate the environmental performance of the firm (Qi et al., 2014), and the study stated that the firm's environmental impact can be calculated using different index, ranking or environmental score. Also, the environmental performance of the firm determines the priorities of sustainability that set the strategic goals in order to meet the objectives of stakeholders, investors, staff, consumers, distributors, and local authorities and also fulfill the regulatory and legal requirements of organizations (Shaumya and Arulrajah, 2017; Akter et al., 2018; Risal and Joshi, 2018). While environmental performance is not the same as organizational protection of the environment, constructive and consistent effort to achieve such well-defined goals of conserving natural resources and business productivity is something far wider (Shaumya and Arulrajah, 2017). Hence, the banking sector is considered one of the key stakeholders in the idea of GF, which has a direct and indirect detrimental effect on environmental performance (Rehman et al., 2021). As a result, the environmental performance of banking institutions can be measured by the activities and strategies that assist organizations in reducing paper usage and energy consumption, improving banks' compliance with environmental standards, lowering carbon emissions, and providing staff with environmental protection and energy savings training (X. Zhang et al., 2022).

2.5 Hypotheses Development

2.5.1 Corporate Social Responsibility and Environmental Performance

While several scholars have studied the association between CSR and financial and non-financial performance, only a few have explored the relationship between CSR and environmental performance in the context of developing countries (Suganthi, 2020). More recently, the relationship between CSR and environmental performance for long-term business success was investigated by Suganthi, (2020). The study discovered that CSR initiatives significantly improve an organization's environmental performance, demonstrating that CSR initiatives enable a business look inwards and drives employees to adopt solid and liquid waste reduction. Organizations that invest in CSR projects are more likely to achieve cost savings, enhanced quality, adaptability, better delivery, as well as overall long-term sustainability (Famiyeh, 2017). Furthermore, Sidhoum and Serra (2017) investigated the relationship between CSR and many aspects of performance across United States electric utilities, including the environment, social, economic and governance. The study discovered that economic and environmental performance as well as economic and social performance are strongly linked. It also stated that environmentally friendly technology will promote financial health and aid in the development of a better environmental system, resulting in improved economic outcomes as well as sustainability. Furthermore, CSR perception has a substantial effect on environmental performance (Channa et al., 2021). Despite this, CSR had no significant impact on environmental performance (Kraus et al., 2020). Environmental performance can be enhanced through management commitment to CSR; they can reduce contamination and materials waste during the production process, resulting in recyclable products (Rivera et al., 2017). In this study, CSR initiatives can be defined as initiatives that "organizations undertake for the benefit of society and the environment in order to achieve overall organizational performance, including the environmental performance. Hence, the following hypothesis has been formulated:

Hypothesis 1 (**H_1**): CSR activities positively influence the banks' environmental performance.

2.5.2 Economic Aspects of Green Finance and Environmental Performance

The economic element of GF is recognized as the most powerful factor driving sustainable funding in banking industries, thus contributing to organizational sustainability (Zheng et al., 2021a). Banks, like other corporate sectors such as energy, manufacturing or chemical industry, cannot ignore ecological problems and must accept environmental responsibility to meet economic goals, enhance their reputation and operate more efficiently (Gallego-Álvarez and Pucheta-Martínez, 2020). Environmental measures pursued by financial institutions are a source of competitive advantage (Carnevale and Mazzuca, 2014). Kala et al. (2020) identified the various green initiatives adopted by the banking institutions to improve their environmental performance. Recently, the research has demonstrated that the economic aspects of GF boost the sustainability performance of banking institutions significantly (Zheng et al., 2021a). This implies that the economic aspect of GF plays an important role in improving the bank's environmental performance because it addresses issues that lead to sustainable economic growth, competitive advantage and the acquisition of financial implications of climate change from the government. Based on the above reasoning, the following hypothesis has been formulated.

Hypothesis 2 (**H_2**): The economic aspect of GF positively influences the banks' environmental performance.

2.5.3 Social Aspects of Green Finance and Environmental Performance

The pursuit of environmental benefits as a result of social responsibility is the most important motivation for banking financial institutions to generate green credit and for businesses to perform eco-innovation (Wu et al., 2021). Banking organizations are primarily involved in money and credit transactions, which have no direct impact on the environment (Jaeggi et al., 2018). Green bond issuance lowers financing costs of companies and increases their resource

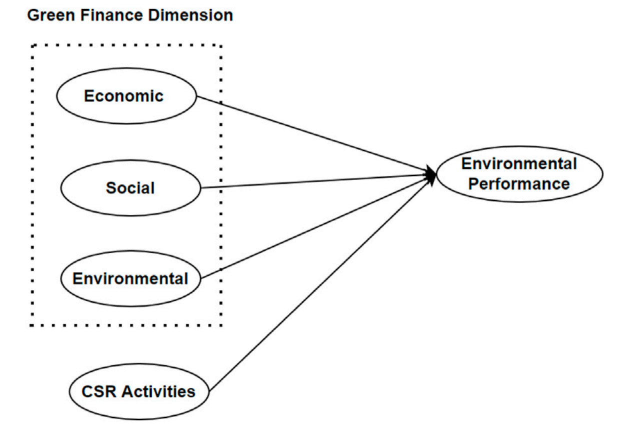


FIGURE 1 | Conceptual framework of the study.

efficiency, thus allowing them to better serve the society and fulfill their social responsibilities (X. Zhou and Cui, 2019). Zheng et al. (2021a) researched the factors impacting the sustainability performance of financial institutions in Bangladesh and discovered that the social element of GF had a favorable impact on sustainability performance. Furthermore, the literature indicates that banking institutions' financing of various eco-friendly initiatives may contribute to societal benefits such as engaging the local community in development programs, offering staff benefits, and improving brand awareness (Raihan, 2019; Zheng et al., 2021a). As a result, it can be concluded that the social side of GF plays an important role in enhancing banks' environmental performance through sponsorship of eco-friendly projects. Thus, the following research hypothesis is advanced.

Hypothesis 3 **(H_3):** The social aspect of GF positively influences the banks' environmental performance.

2.5.4 Environmental Aspects of Green Finance and Environmental Performance

GF encompasses a wide range of financial instruments and policies targeted at reducing carbon emissions, including carbon market instruments, green banks, green bonds and community-based green funds (Ilma, 2020). It also includes financing investment in various socially responsible initiatives that deliver environmental advantages in the larger framework of sustainable development, such as air, water and soil pollution reduction (Guild, 2020). GF is an investment that is meant to have a positive impact on the environment (Koirala, 2019). On the other hand, sustainable finance is a broader concept that encompasses all three aspects of sustainable development including environmental, social and economic (Mehralian et al., 2016). According to a study by Zheng et al. (2021a), the environmental element of GF has a direct impact on the sustainability performance of financial institutions. According to the study of Raihan, (2019) and Zheng et al. (2021a), GF provides a variety of environmental benefits, including reduced energy usage and carbon emissions from banking activities, hence boosting overall organizational environmental sustainability. In this study, we therefore argue that the environmental element of GF is essential in improving the environmental performance of banking institutions due to its direct link with organizational sustainability. Thus, the following research hypothesis is postulated:

Hypothesis 4 **(H_4):** The environmental aspect of GF positively influences the banks' environmental performance.

2.6 Conceptual Framework of the Study

The hypothesized conceptual framework of the study is shown in **Figure 1**. The conceptual research model was designed based on the theoretical foundation and review of the recent literature on CSR activities, different aspects of GF (social, economic and environmental), as well as the environmental performance of organizations.

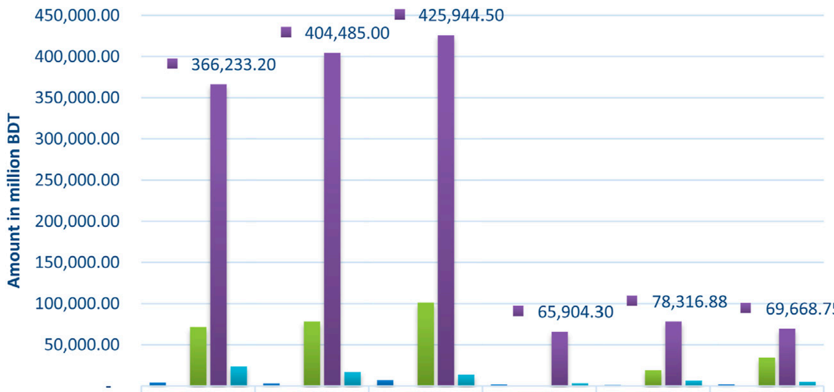
3 RESEARCH METHODOLOGY

3.1 Sample and Data Collection

This paper aims to examine the effects of CSR activities and various dimensions of GF namely social, economic and environmental on the environmental performance of banking institutions in Bangladesh. As illustrated in **Figure 2**, PCBs were specifically chosen for this study due to their major contribution to direct GF in Bangladesh (Hossain, 2019). Due to the unknown features of the population for this study, a non-probability convenience sampling method was employed to obtain a sample from the required population. The primary data was acquired using a structured questionnaire approach from 388 commercial bank staffs, including managers, assistant managers, officers, senior officers, and junior officers. A total of 467 questionnaires were distributed, out of which 79 were excluded due to incomplete responses. The final sample size is 388, indicating an effective rate of 83.08%, which exceeds the response rate of 25–30% suggested by Murphy (2003). The data was collected during the period between February and March 2019 from the sample banks located in Dhaka, Bangladesh. Of the respondents, 75.3% were male, while 24.7% were female. In terms of age, around 65% of the respondents are in age range 26–35, while only 6.3% are above 55. In addition, 48.5% had masters' degree; 27.6%, undergraduate degree; and 15.2%, higher secondary certificate.

3.2 Survey Instruments

A structured questionnaire was used to collect the primary data. **Table 1** shows the variables that were adapted from previous studies and included 21 items to measure GF dimensions (social, economic, and Environmental), CSR practices, and environmental performance. The questionnaire items represent the constructs of CSR, environmental performance and the various dimensions of GF, namely social, economic and environmental. The social (three items), economic (five items) and environmental (three items) dimensions of GF were adapted from the previous studies (Raihan, 2019; Zheng et al., 2021a; Zheng et al., 2021b). The five items used to measure CSR were adapted from earlier studies of Maignan and Ferrell (2000) and



	2015	2016	2017	2018	2019	2020
SCBs	3,977.70	3,248.20	7,220.60	1,815.20	1,219.44	1,908.91
DFIs	349.00	30.10	18.90	45.40	3.56	9.83
FCBs	71,514.30	78,316.10	101,524.90	192.60	19,213.16	34,332.69
PCBs	366,233.20	404,485.00	425,944.50	65,904.30	78,316.88	69,668.75
NBFIs	23,813.60	17,142.00	13,907.70	3,389.60	6,499.87	5,295.20

FIGURE 2 | Green financing by banks and non-banks financial institutions in Bangladesh during the period 2015–2020.

TABLE 1 | Items of the questionnaire to measure GF dimensions, CSR practices, and Envrionmental Performance.

Social dimension (Raihan, 2019; Zheng et al., 2021a)	
Indicate your level of agreement with the following statements about social dimension of GF (1 = strongly disagree, 5 = strongly agree)	
SD1	Engaging local community in development program
SD2	Providing employee benefits, such as health and safety
SD3	Increasing brand awareness, trust, and image of the banking institutions
Economic dimension (Raihan, 2019; G. Zheng et al., 2021a)	
Indicate your level of agreement with the following statements about economic dimension of GF (1 = strongly disagree, 5 = strongly agree)	
ED1	Generating more economic benefit (economic value added)
ED2	Creating more competitive advantage
ED3	Increasing revenues and saving operating costs
ED4	Improving existing assets (addition to capital)
ED5	Reducing overall risk
Environmental dimension (Raihan, 2019; Zheng et al., 2021a)	
Indicate your level of agreement with the following statements about environmental dimension of GF (1 = strongly disagree, 5 = strongly agree)	
END1	Reducing energy consumptions from banking activities
END2	Reducing carbon emissions from banking activities
END3	Energy requirements of products and services
CSR practices (Maignan and Ferrell, 2000; Saeidi et al., 2021)	
Indicate your level of agreement with the following statements related to CSR practices (1 = strongly disagree, 5 = strongly agree)	
CSR1	CSR practices related to ethical
CSR2	CSR practices related to legal
CSR3	CSR practices related to conomic
CSR4	CSR practices related to discretionary
Environmental performance (Shaumya and Arulrajah, 2017; Risal and Joshi, 2018; Kala et al., 2020; Suganthi, 2020; Rehman et al., 2021)	
Indicate your level of agreement with the following statements related to environmental performance (1 = strongly disagree, 5 = strongly agree)	
EP1	CSR and GF significantly reduce paper usage and energy consumption in our bank
EP2	CSR and GF improve banks' compliance with environmental standards
EP3	CSR and GF reduce energy consumption outside the bank
EP4	CSR and GF reduce carbon emission from banking activities
EP5	Analyzing suppliers' environmental risk
EP6	Providing training to the staff on environmental protection and energy savings

Saeidi et al. (2021), while environmental performance scale was measured with the six items culled from previous works (Shaumya and Arulrajah, 2017; Risal and Joshi, 2018; Kala et al., 2020; Suganthi, 2020; Rehman et al., 2021). Except for demographic questions, all questionnaire items were graded on a 5-point Likert scale, with 1 indicating "strongly disagree" and 5, "strongly agree." Respondents were asked demographic questions such as their gender, age and level of education.

TABLE 2 | Descriptive statistics and correlation analysis of the study variables.

Variables	Mean	SD	Skewness	Kurtosis	SD	ED	END	CSR	EP
SD	4.09	0.581	−1.135	2.945	1				
ED	4.06	0.594	−0.788	0.947	0.404***	1			
END	4.08	0.597	−0.508	0.290	0.319***	0.349***	1		
CSR	3.93	0.724	−1.194	2.087	0.416***	0.456***	0.162**	1	
EP	4.06	0.576	−0.949	2.200	0.411***	0.555***	0.323***	0.411***	1

Notes: SD, standard deviation; correlation significant at 0.001 and 0.05 (two-tailed).
Source: Authors' own calculation.

TABLE 3 | Convergent validity of survey items.

Constructs	Items	Factor loading	AVE	Cronbach's alpha
Social dimension of GF	SD1	0.731	0.556	0.785
	SD2	0.812		
	SD3	0.688		
Economic dimension of GF	ED1	*Excluded*	0.540	0.766
	ED2	*Excluded*		
	ED3	0.539		
	ED4	0.787		
	ED5	0.761		
Environmental dimension of GF	END1	0.658	0.506	0.711
	END2	0.784		
	END3	0.686		
CSR practices	CSR1	0.770	0.541	0.830
	CSR2	0.810		
	CSR3	0.659		
	CSR4	0.735		
Emvironmental performance	EP1	0.826	0.556	0.837
	EP2	0.687		
	EP3	0.783		
	EP4	0.631		
	EP5	*Excluded*		
	EP6	*Excluded*		

Notes: ED1, ED2, EP5, and EP6 were excluded from the final analysis due to the poor factor loadings.
Source: Authors' own calculation.

3.3 Data Analysis Techniques

The study used Confirmatory Factor Analysis (CFA) and the Structural Equation Model (SEM) to analyze the acquired primary data. Nunnally and Bernstein (1994) argued that the validity of the scale is critical for the instrument used in diverse cultures. Hence, the CFA model was used to validate the research instrument, and also evaluate the model's reliability, convergent and discriminant validity, and overall fit based on previous studies (Fornell and Larcker, 1981; Bentler, 1992; Hu and Bentler, 1999). Finally, SEM was employed to test the proposed hypotheses.

4 RESULTS AND DISCUSSION

4.1 Descriptive Statistics

Table 2 shows the descriptive statistics and correlation analysis of study variables. The mean value indicates that social, economic and environmental dimension of GF are the most important determinants of environmental performance. The skewness and kurtosis values were both less than the cut-off values, ±3 and ±10, respectively, as indicated by Kline (2011). The correlation analysis revealed a weak connection between the research variables, demonstrating the absence of multicollinearity problem.

4.2 Confirmatory Factor Analysis

In agreement with Gerbing and Anderson (1988), the outcomes of CFA, standardized coefficients and various model fit indices were used to assess the measurement model of the study. Furthermore, the Cronbach's Alpha (CA) and Composite Reliability (CR) values were employed to determine the reliability and validity of the research data. As highlighted in **Table 1**, the CA values for all the variables ranged from 0.711 to 0.837, which is satisfactory and exceed the standard value of 0.70 (Nunnally and Bernstein, 1994). Similarly, in **Table 3**, the CR values ranged from 0.753 to 0.833, which is higher than the minimal cut-off value of 0.7 (Fornell and Larcker, 1981). Based on the findings of CA and CR, the validity of the constructs and internal

TABLE 4 | Discriminant validity, composite reliability and AVE.

Variables	CR	AVE	SD	ED	END	CSR	EP	VIF
SD	0.789	0.556	**0.745**					1.365
ED	0.778	0.540	0.381	**0.735**				1.454
END	0.753	0.506	0.367	0.347	**0.711**			1.194
CSR	0.824	0.541	0.376	0.606	0.360	**0.736**		1.379
EP	0.833	0.556	0.422	0.495	0.450	0.199	**0.746**	-

Bold indicates the square root of AVE.
Note: CR, composite reliability; AVE, average variance extracted.
Source: Authors' own calculation.

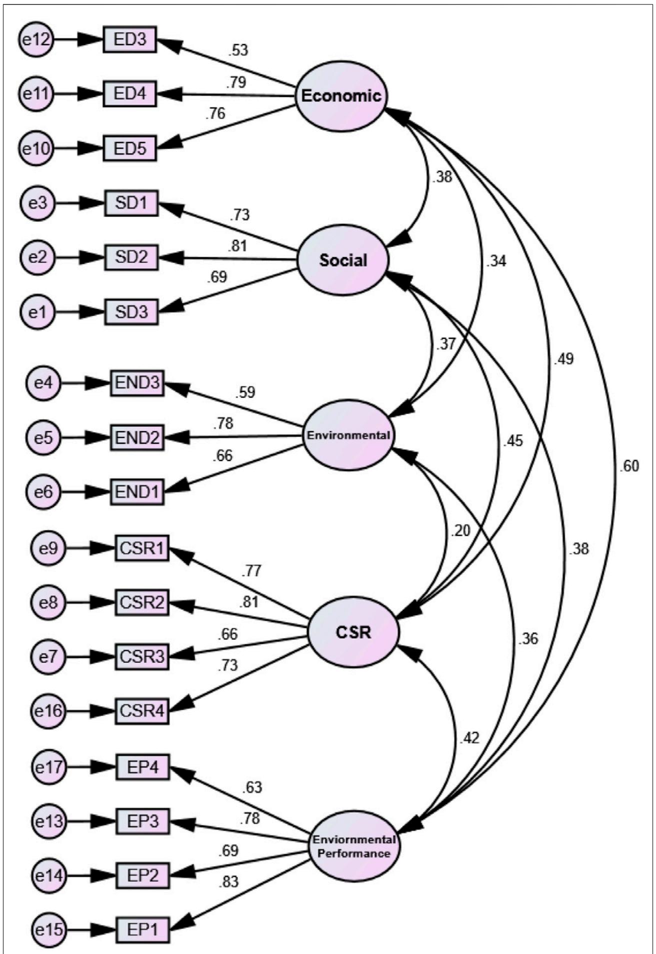


FIGURE 3 | CFA measurement model of the study.

consistency of the measuring items are appropriate and acceptable. **Table 3** provides the standard estimates of factor loadings that were used to determine the proposed model's convergent validity. In the CFA analysis, the standard factor loadings (see **Table 3**) varied between 0.631 and 0.826, which is greater than the 0.5 cut-off value provided by Hair et al. (2010). On the other hand, the AVE values (see **Table 4**) ranged between 0.431 and 0.558, which is greater than the recommended limit of 0.50 (Fornell and Larcker, 1981).

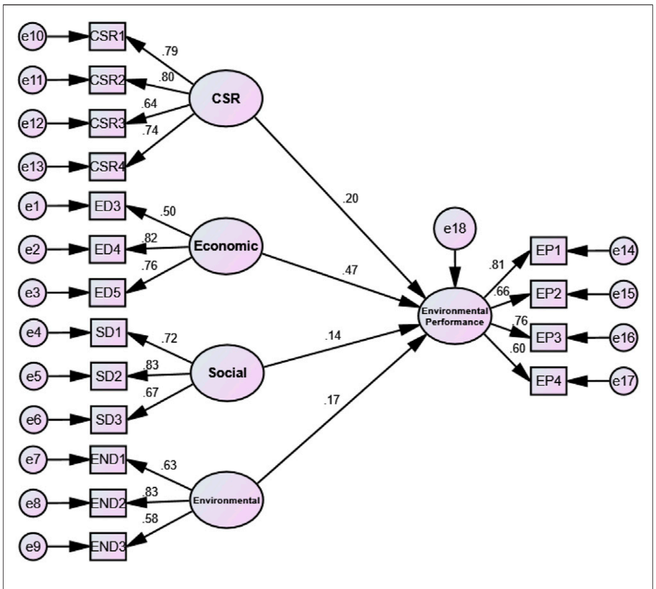


FIGURE 4 | Structural model with standardized estimates.

Accordingly, the convergent validity of measurements is deemed adequate and satisfactory.

Furthermore, the constructs' discriminant validity was estimated using the Fornell–Larcker criteria and the Heterotrait–Monotraits ratio (HTMT). To determine the discriminant validity, the square root of a construct's AVE value must be greater than its highest correlation with any other construct in the model (Fornell and Larcker, 1981). **Table 4** shows that the AVE for each factor surpasses the squared inter-factor correlation. As a result, discriminant validity was observed in all constructs. For robustness, this study also measured the HTMT value due to its supremacy over Fornell-Larcker in various situations (Henseler et al., 2015), and recorded a value lower than 0.90 (see, appendix **Appendix Table A1**), implying the absence of a discriminant validity problem (Henseler et al., 2015). Therefore, the results indicate a high level of discriminant validity between the factors employed in the model. Also, the result in **Table 4** indicated that the Variance Inflation Factor (VIF) varied between 1.194 and 1.454, which satisfy the standard value of one to five (Zuur et al., 2010). This shows that multicollinearity was not a barrier to proceeding to the next analysis. The VIF is a useful approach for determining whether or not independent variables exhibit multicollinearity, as suggested by Kleinbaum et al. (1988). Moreover, **Appendix Table A2** (see, appendix) shows the results of the measurement model and reveals the model fit indices as being within the acceptable limits (Hu and Bentler, 1999). The measurement model fit statistics are p-value = 0.000; Chi-square/df = 1.933; RMR = 0.030; GFI = 0.939; AGFI = 0.915; CFI = 0.957; IFI = 0.958; TLI = 0.946; RMSEA = 0.051. Therefore, the overall model fit is adequate and satisfactory. The outputs of the CFA measurement model with standardized estimates, as can be shown in **Figure 3**.

TABLE 5 | Test of research hypotheses.

Research hypothesis	Estimate (β)	Standard error	*t*-test value	*p*-value	Remarks
H_1: CSR→ EP	0.197***	0.045	3.536	0.000	H_1 is accepted
H_2: ED → EP	0.475***	0.057	7.306	0.000	H_2 is accepted
H_3:SD → EP	0.143**	0.051	2.534	0.011	H_3 is accepted
H_4: END →EP	0.171**	0.053	2.898	0.004	H_4 is accepted

Note: significant at the p-value *of 0.001 and 0.05.*
Source: Authors' own calculation.

4.3 Outcomes of Structural Equation Modeling and Test of Research Hypotheses

Figure 4 demonstrates the structural model of the study, which shows the impacts of the relationship between the latent variables and the constructs. It can be concluded that the CSR and three dimensions of GF (social, economic and environmental) have a positive effect on banks' environmental performance. Further, the model fit indices were also used to identify the structural model suitability. **Appendix Table A2** (see, appendix) shows that the findings of the structural model fit indices were within the acceptable standards limit (Hu and Bentler, 1999). The structural model fit statistics are p-value = 0.000; Chi-square/df = 1.923; RMR = 0.029; GFI = 0.940; AGFI = 0.920; CFI = 0.961; IFI = 0.960; TLI = 0.952; RMSEA = 0.049. Therefore, the overall structural model can be considered acceptable and satisfactory.

Table 5 shows the outcomes of the research hypotheses. The results revealed that CSR has a positive impact on banks' environmental performance; therefore, H_1 is supported. **Table 5** indicates that H_2 is also supported, indicating that the economic aspect of GF has a positive and significant impact on environmental performance. Furthermore, the results showed that social aspect of GF has a significant positive relationship with the environmental and therefore supports H_3. In addition, the results revealed a significant positive association between the environmental aspect of GF and EP, thus corroborating H_4. Hence, it can be concluded that CSR activates, and GF dimensions play a critical role in enhancing overall environmental performance of banking institutions in Bangladesh, thereby aiding the country's sustainable economic development.

5 DISCUSSIONS AND CONCLUSION

The link between CSR and firm performance including cost, market, environmental, and sustainability has been thoroughly researched all around the world. However, the evidence of relationship is still inconclusive (Bahta et al., 2021), which could be due to the neglect of the social, economic and environmental elements of GF. The relationship between CSR and environmental performance can be better understood when examined from the standpoint of green financing. As a result, the current study used SEM to examine the relationship between CSR activities, GF dimensions and bank environmental performance in Bangladesh. The findings of this study demonstrated a significant link between CSR and bank environmental performance, implying that the evolution of socially responsible acts improves environmental performance while also providing several business benefits. In other words, participation in CSR activities such as ethical, legal, economic and discretionary can help banks enhance their internal and external environmental performance, and hence their overall sustainability. In comparison to earlier research, our findings support the notion that CSR policies have a favorable impact on the environmental performance of banking institutions in developing countries like Bangladesh. This empirical investigation is corroborated by past studies (Sidhoum and Serra, 2017; Bamgbade et al., 2018; Suganthi, 2020; Ahmad et al., 2021), which discovered a strong link between CSR policies and environmental performance in large manufacturing companies. Besides that, the empirical finding is consistent with the legitimacy theory, which explains the engagement of banking institutions in spending and implementing CSR initiatives, as social pressure and regulatory standards have required businesses to engage in CSR practices in order to promote social acceptance and environmental sustainability (Suttipun et al., 2021). Hence, the findings of this study contribute to past research on CSR and environmental performance, and strengthen the evidence that CSR has an impact on banking organizations' environmental performance.

Furthermore, the empirical results indicated that the three dimensions of GF namely social, economic and environmental performance have a substantial influence on the environmental performance of banking institutions in Bangladesh. This suggests that the participation of banking institutions in green financing is related to better environmental performance. Research has also established a definite relationship between various dimensions of GF (social, economic and environmental) and sustainability performance in financial institutions. The present study is the first to investigate these relationships in the Bangladeshi banking sector; in particular, endorsement of this findings has not been reported in the related GF and environmental performance literature. However, Zheng et al. (2021a) conducted a very similar study and discovered that the social, economic and environmental aspects of GF have a substantial influence on the sustainability performance of financial institutions in Bangladesh. Less obvious supports can also be found in the studies of Raihan (2019) and Zheng et al. (2021a). The findings corroborate with the legitimacy theory (Dowling and Pfeffer, 1975), which states that firms actively seek and maintain legitimacy by aligning their principles, policies, and strategies with community values. As a result, green finance can be viewed as a strategy for an organization to achieve and maintain legitimacy (Chariri, Anis et al., 2018). Hence, it can be concluded that GF and its dimensions play a critical role in enhancing overall environmental performance of banking institutions in Bangladesh, thereby aiding the country's achievement of SDGs.

In light of the existing literature on CSR, GF and environmental performance in the context of financial institutions in emerging economies, the empirical findings of the study offer a number of theoretical implications. First, this study is one of the first to empirically examine the effect of various components of GF (social, economic and environmental) on the environmental performance of banking institutions in Bangladesh. Furthermore, the model developed in this study could be applied to new scenarios or to developing countries in general. Researchers can continue to expand and replicate this research in the future, as the measurement scales have been validated using AMOS statistical analysis techniques, such as structural equation modeling. Second, the significant positive link between CSR and environmental performance in the context of banking sector represents a novel contribution to the existing literature on CSR and organizational sustainability. As a result, the study's empirical findings are consistent with the concepts of green finance and legitimacy theory, which illustrate that green finance and CSR practices improve firms' environmental performance by highlighting the need of societal consent in attaining long-term sustainable growth (Indriastuti and Chariri, 2021). The study provides several avenues for future research to identify how banking organizations might improve their overall sustainability performance while implementing environmental policies, such as pollution reduction and control.

Furthermore, the study's empirical findings suggest a variety of practical implications for scholars, academic researchers, banking institutions, managers, governments and legislators concerned with promoting environmental sustainability for financial institutions, primarily through the financing of various ecofriendly projects and socially responsible programs. The findings showed that Bangladeshi banks' CSR activities play a significant role in the implementation of environmentally sustainable projects. Therefore, the study outcomes direct top managers in the industry and legislators to spend more on social responsibility, improve their managerial attitudes towards the natural environment and set up the right kinds of sustainability cultures in their banks. For example, Bangladesh Bank (BB), the country's central bank, and the government could encourage environmental sustainability and ultimately promote the country's long-term development by reimbursing or rewarding financial institutions that carefully follow socially responsible practices and strategies. This should be a straightforward itinerary for industry managers to follow, which can also help them improve their environmental performance. Furthermore, the study also found that the three dimensions of GF positively influence the environmental performance of banking institutions. Therefore, we conclude that financing of various environmentally friendly projects such as renewable energy, green industry development, alternative energy, waste management and so on could improve banking institutions' internal and external environmental performance, thus aiding the achievement of the country's SDGs. The findings advise the financial institutions to incorporate GF into their regular financing procedures to improve their environmental performance. In this context, the BB should assess and advise financial institutions on how to enhance their environmental performance, as well as promote green financing as a tool for the country's long-term economic development.

A significant limitation of this study is its use of data from Bangladesh only, and hence, the generalizability of the findings is limited to the Bangladeshi banking system. Future research should validate the hypothesis using data from the financial sectors of other emerging nations as well. Furthermore, additional research can evaluate the impact of other dimensions such as green banking activities including employee, daily-operation, policy and customer-related practices on environmental performance via the mediating effect of green financing. Another disadvantage of this study is that the CSR initiatives, GF and environmental performance were evaluated from the viewpoint of internal stakeholders. Hence, future research based on external stakeholders such as consumers and suppliers may be conducted to examine the influence of CSR programs and green financing on the overall performance of banking institutions in other emerging nations.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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APPENDIX

TABLE A1 | Heterotrait–Monotrait ratio (HTMT).

Variables	SD	ED	END	GF	EP
Social dimension (SD)	-				
Economic dimension (ED)	0.408	-			
Environmental dimension (END)	0.384	0.402	-		
Green financing (GF)	0.469	0.556	0.210	-	
Environmental performance (EP)	0.397	0.661	0.416	0.454	-

Source: Authors' own calculation.

TABLE A2 | Model fit indices for measurement and structural model of the study.

Factors model fit indices	Value for CFA	Value for SEM	Standard value
p-value	0.000	0.000	***$p < 0.001$
Chi-square/df	1.933	1.923	<0.05
Root mean square residual (RMR)	0.030	0.029	<0.08
Goodness-of-fit index (GFI)	0.939	0.940	>0.900
Adjusted goodness of fit index (AGFI)	0.915	0.920	>0.900
Comparative fit index (CFI)	0.957	0.961	>0.900
incremental fit index (IFI)	0.958	0.960	>0.900
Tucker–lewis index (TLI)	0.946	0.952	>0.900
Root mean square error of approximation (RMSEA)	0.051	0.049	<0.08

Note: model significant at 0.001 level.
Source: Authors' own calculation.

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The Impact of COVID-19 Pandemic on Government Bond Yields

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The COVID-19 pandemic is a real shock to society and business and financial markets. The government bond market is an essential part of financial markets, especially in difficult times, because it is a source of government funding. The majority of existing ESG studies report positive impacts on corporate financial performance regarding environmental, social, and governance. Thus, understanding governments' financial practices and their relevant ESG implications is insufficient. This research aims to value the impact of the COVID-19 pandemic on different government bond curve sectors. We try to identify the reactions to the COVID-19 pandemic in the government bond market and analyze separate tenors of government bond yields in different regions. We have chosen Germany and the United States government bond yields of 10, 5, and 3 years tenor for the analysis. As independent variables, we have chosen daily cases of COVID-19 and daily deaths from COVID-19 at the country and global levels. We used daily data from 02 January 2020–19 March 2021, and divided this period into three stages depending on the COVID-19 pandemic data. We employed the methods of correlation-regression analysis (ordinary least squares and least squares with breakpoints) and VAR-based impulse response functions to evaluate the effect of the COVID-19 pandemic on government bond yields both in the long and short run. Our analysis revealed the impact of the spread of the COVID-19 pandemic on government bond yields differs depending on the country and the assessment period. The short-term responses vary in direction, strength, and duration; the long-term response of Germany's yields appeared to be more negative (indicating the decrease of the yields), while the response of the United States yields appeared to be more positive (i.e., increase of yields).

Keywords: COVID-19 pandemic, bond market, government bond yields, impulse response function (IRF), ESG (environment, social, governance)

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1 INTRODUCTION

The COVID-19 pandemic strongly impacted the outlook of global economic activity, financial market, society's sentiments, and consumer and business confidence indicators (Teresiene et al., 2021a). The COVID-19 pandemic is different from other financial and economic crises (Yue et al., 2020a, Yue et al., 2020b, Yue et al., 2021). This time, it substantially affected almost all sectors, and the biggest reason for such consequences was a lockdown in all countries. But the lockdown was the only way to protect society and the economy from much more significant adverse effects. The government bond market is substantial in dire and difficult times because it is the primary source of government funding, and yield volatility is related to the debt costs. The role of the government in critical moments is essential. The support is needed not only for society but for business as well. Government bonds are the main part of pension funds and central banks' investment portfolios, directly connecting with the benefits to society and the economy.

The International Monetary Fund (IMF) noted in its World Economic Outlook 2021 that "the ravage of the new COVID-19 pandemic has made the prospects for the global economic recovery extraordinarily uncertain." The COVID pandemic affected the economy in all countries. Different authors focus on separate issues related to the pandemic environment (Edrus et al. (2022).

In parallel with the COVID 19 pandemic, Environmental, Social, and Governance (ESG) is a newly emerging investment for extensive companies to create economic value and balance financial earnings and environmental, social sustainable development (Abhayawansa and Tyagi, 2021). Since the concept of ESG was formally proposed by the United Nations in 2004, more and more investors have paid attention to ESG and gradually integrated it into the business practice of corporate social responsibility (Eccles and Viviers, 2011). The emergence of ESG connects corporate social responsibility with global sustainable development issues and reveals the need for upgrading and business transformation of responsible investment in the new era (Leins, 2020). ESG aims to meet the needs of the present without jeopardizing future generations and human capital (Kotsantonis and Serafeim, 2020). ESG is perceived as an emerging investment strategy with a clear, logical chain - corporate ESG performs well, demonstrating corporate capabilities in environmental protection, social responsibility, governance model, and risk control, thus achieving win-win economic, social, and ecological benefits (Chen andYang, 2020, Orazbayev et al., 2019).

Economic activities are increasingly affecting the environment comprehensively. Companies and their relevant investors shoulder the responsibility to lead a sustainable agenda for their economic activities (Christensen et al., 2022). Based on ESG evaluation and rating information, investors observe the ESG performance of enterprises and evaluate their contribution to enterprises (investment objects) in promoting sustainable economic development and fulfilling social responsibility (Avetisyan and Hockerts, 2017; Amel-Zadeh and Serafeim, 2018; Xiong et al., 2020). ESG contributes to creating long-term value and continuously sustainable development and boosts the confidence of society, investors, and customers (Suttipun, 2021).

In the era of financial turbulence and economic uncertainty of COVID19, however, there are challenges for both companies' strategic decisions to maintain economic returns and ESG performance. Existing research focuses on the company's ESG performance (Halbritter and Dorfleitner, 2015; Hill, 2020), ESG data (Kotsantonis and Serafeim, 2019), and disclosure (Lokuwaduge and Heenetigala, 2017), reporting the positive ESG influences on corporate financial performance. Nevertheless, most research overlooked ESG from the perspective of governments. First, the company's capability to do ESG relies on its financial sourcing from bank loans and the regional government fiscal measures. ESG is pertinent to the effect on the cost of debt financing (Raimo et al., 2021). Second, Although the green bond market has grown quickly in recent years, it is still a niche market that is priced differently from conventional bonds (Hachenberg and Schiereck, 2018). Within this study, we focus on the perspective of government bonds in the context of COVID 19 financial turbulences to inform ESG implications. Therefore, this research aims to value the impact of the COVID-19 pandemic on different government bond curve sectors in different regions. We choose the government bond as our research object. The reasons are the circulating connections among companies, banks, and government banks. Banks hold an average of 9% government bonds assets on regular times (Gennaioli et al., 2018), especially when banks make fewer loans and operate in less financially developed countries. By comparison, banks with the average exposure to government bonds exhibit a lower growth rate of loans than banks without bonds during default years. This research is significant and adds value to the finance literature analyzing government bond yield dynamics in critical moments and stressful scenarios. Governments need to reconsider the maturity of new debt in critical moments. It is also significant for portfolio managers and pertinent changes in fund management and accountability relative to ESG issues (Holland, 2011), especially institutional ones, to manage huge government bond portfolios for pension schemes or income generation for the government budget.

This article sheds light on bond yield volatility during critical moments using the case of the COVID- 19 pandemics. We create value to the literature by analyzing different regions and government bond sectors according to their maturity. We have covered three different markets as most authors focused on one market. We had an aim to compare the impact of the pandemic in separate regions.

This paper consists of different sections. In **Section 2**, we present a literature review where we analyze different views about the impact of the COVID-19 pandemic on financial markets. We point out that we add value to literature analysis by comparing different regions and different maturities of government bonds. The latter focus is essential for practitioners in portfolio management and diversification decisions. In **Section 3** we describe the methodology and finally present our results. For methodological issues, we analyzed the research of Golmankhane et al. (2021) and Rashid et al. (2021), which gave us valuable insights. To value the impact of the COVID-19 pandemic, we have chosen two government bond markets: Germany and the United States. We used three different maturities for the analysis–10 years, 5 years, and 3 years - as we wanted to compare the pandemic's effect on long and mid-term government bond markets. Our results first present the main tendencies of government bond yields from the pandemic's start. After that, by dividing the period into three stages, we tried to value the impact of the COVID-19 pandemic in different periods. The dependent variables selected for the research are 10 years German government bond yield; 5 years German government bond yield; 3 years German government bond yield; 10 years United States government bond yield; 5 years United States government bond yield; 3 years United States government bond yield.

2 LITERATURE REVIEW

The government bond market is essential for every country and economy related to public finance and the governments' ability to attract funds using financial markets. Since the COVID-19 pandemic spread widely and affected all over the World, the financial markets also demonstrated a substantial response. Financial markets first reacted to the news about the pandemic and started the process of "flight to quality." Loayza and Michael Pennings (2020), in their research, pointed out that in the periods of "flight to quality"—when investors are choosing safe assets for their portfolios emerging, and developing countries face difficulties to finance budget deficits because of higher debt costs. Only international financial markets can help in such moments, and emerging countries have to use opportunities to attract funds using Eurobonds or international bonds. A similar situation we had during the financial crisis in the 2008–2009 period. Acharya et al. (2016) investigated the European sovereign debt crisis and the role of central banks. They pointed out that it was hazardous for commercial banks because they increased their risk by including risky domestic debt in investment portfolios, especially in peripheral countries. The central bank's impact on sovereign bond yields during a recession period was analyzed by Altavilla et al. (2019), but these authors also analyzed other financial markets.

Different authors analyzed the government bond market, trying to identify the impact of monetary or fiscal policy decisions during the COVID-19 pandemic period (Beirne et al., 2020; Beirne et al., 2020; Bordo and Duca, 2020; Central Bank of Malaysia, 2020; Kothari, 2020; Macchiarelli, 2020; Zaghini, 2020; Elfayoumi and Hengge, 2021; Fendel et al., 2021; Fratto et al., 2021; Rebucci et al., 2021). Other authors focused more on the COVID-19 pandemic risks and paid more attention to sovereign credit default spreads and credit risk (Cevik and Ozturkkal, 2020; Nelufule, 2020; Novick et al., 2020; OECD, 2020; PwC, 2020). While some of them even tried to identify the opposite impact of low bond yields on various business sectors during the pandemic period (EIOPA 2020).

Some authors focused more on the United States Treasuries, pointing to stress and illiquidity issues using treasury inconvenience yields during the pandemic (He et al., 2020), while others analyzed corporate or municipal bond markets COVID-19 pandemic effects (Lonski 2020). Beirne et al. (2020) tried to value the impact of fiscal stimulus and quantitative easing of central banks and analyzed global financial markets in different countries, identifying the COVID-19 pandemic effect. Still, those authors focused more on capital flows and revealed that emerging markets had experienced a more substantial impact of COVID-19 on the bond market than developed economies. We add value to this type of research by analyzing different regions and different tenors of government bonds.

But the most common way of analyzing the government market was the 10 year government bond tenor sector. Our article adds value to the literature and practical investment decisions framework because we analyze the government bond market, consider different government bonds' maturities, and use that approach for other regions. Our results, in some cases, support Sène et al. (2021) findings that confirmed cases of COVID-19 pandemic lead to increased yields because additional information calmed investor concerns about future trends in economics. The latter research focused on the Eurobond market and revealed that announcements from international organizations: International Monetary Fund, the World Bank, and other official institutions calmed down the markets. It means that the negative effect of the COVID-19 pandemic was not so significant because of the support from official organizations.

Orazio and Maximilian (2020) researched the COVID-19 pandemic effect on long-term E.U. bond yields. Finlay et al. (2020) investigated the Australian government fixed income market in the pandemic period. The authors' most significant attention was paid to the bond market's functioning and the central bank's role. Central banks all over the World helped to reduce high volatility in financial markets. Investors focus on central banks' future steps and easing monetary policy as a tool and support for economic growth.

The effect of the COVID-19 pandemic on financial markets was analyzed by Zhang et al. (2020), who found a substantial increase in global market price volatility. The authors focused more on stock market volatility and pointed out that monetary and fiscal policy responses can encourage further uncertainties in the global financial markets. Hu et al. (2021) analyzed stock market using the sample of film and drama sector. Chen et al. (2021) analyzed whether investor sentiment has a higher possibility of predicting energy assets volatility than VIX and other uncertainty indices. Hao et al. (2021) focused on the combined effect of foreign direct investment spillovers and remittances inflow on the real effective exchange rate. Teresiene et al. (2021b) and Pan and Yue (2021) analyzed the impact of the COVID-19 pandemic on economic and economic sentiment indicators, which influence financial markets.

Sovereign debt issues attract the attention of different scientists, especially in critical moments of the economic cycle. Ferreira (2018) wrote about the Greek debt crisis and discussed the issues related to public debt. The author made an investigation covering fifteen different European countries and applied a time-varying analysis of the Hurst exponent. The results of the following research showed that there was a long-range memory in sovereign bonds. The Hurst exponent method was also applied by Carbone et al. (2004), but this research focused on the German market's high-frequency data. Bariviera et al. (2012) also analyzed the European bond market using the Hurst exponent, focusing on the corporate and sovereign bonds market's informational efficiency. The main findings showed that financial crises had different impacts on corporate and sovereign bonds' informational efficiency. An interesting fact was that the financial crisis affected the informational efficiency of the corporate bond market.

Zunino et al. (2012) analyzed the efficiency of sovereign bond markets using bond indices from developed and emerging countries. The authors used a sophisticated statistical tool–the complexity –entropy causality plane, which helped rank separate bond markets and distinguished different market dynamics. The authors revealed a correlation between permutation entropy, economic development, and financial market size in the latter study.

Sanchez and Wilkinson (2020) analyzed the effect of the COVID-19 pandemic on the municipal bond market and found that the pandemic affected the United States municipal bond market from different sides as the Federal Reserve changed the direction of the yields. Firstly, the investors tried to refuse the exposure in such positions because of possible credit risk increases. Still, lately, when the Federal Reserve decided to take municipal bonds for collateral purposes for particular loans, the situation had changed, and the yields decreased. So we see that the direct effect of the COVID-19 pandemic can be changed and managed by the financial system players. Wei et al. (2020) revealed that the Federal Reserve emergency lending facilities' impact on municipal bonds and state government bonds was significant. The authors stressed the importance of liquidity backstops.

3 METHODOLOGY

For the assessment of the impact of the spread of the COVID-19 pandemic on the government bond market, we selected the yields of two countries–Germany and the United States government bonds. The yields of three different maturities–10 years, 5 years, and 3 years, were analyzed to compare the pandemic's effect on long and mid-term government bond markets. The main reason for our choice to analyze German yields is related to practical issues. In practice, portfolio managers consider the German yield curve a benchmark for Europe. The United States bond yield curve is a benchmark for the American continent. The chosen maturities are the most popular points on the curve considering asset management issues. For future research, it would be interesting to add 2 year duration bonds as well.

From the analysis of scientific literature, it can be noticed that different authors (for example, Acharya and Sascha 2020; Verma et al., 2021; Albulescu 2021; and others) use the regression approach to evaluate the impact of the COVID-19 pandemic on financial markets. Different authors used similar variables to identify the impact of the COVID-19 pandemic on government bond yields. Klose (2020) analyzed 10 years bond yields as a dependent variable and chose COVID-cases, change of COVID-cases, and statistics of COVID-cases-World and its changes as well as independent variables.

The analysis of scientific literature (for example, Xu 2021; Milani 2020; Beirne et al., 2020; Ahundjanov et al., 2020; Fabiani et al., 2020; Thakur 2020; Brueckner and Vespignani 2020; Mzoughi et al., 2020 and others) also revealed that to determine the reaction of economics and financial markets to the spread of COVID-19 pandemic, impulse response functions are widely used. For example, Mzoughi et al. (2020) have used the VAR model-based impulse response functions to assess the effect of COVID-19 on the oil process, CO_2 emissions, and stock markets and revealed the positive but short-lived response of equity market volatility to the COVID-19 pandemic. Brueckner and Vespignani (2020) have also used VAR-based impulse response functions and identified a significant positive effect of COVID-19 infections on the performance of the Australian stock market. Xu (2021) employed structural GARCH-in-Mean VAR-based impulse response functions and revealed a small magnitude negative impact of COVID-19 cases growth on the stock markets.

Our research consists of the following stages, which are discussed briefly.

At first, in Stage 1, the trends of the government bond yields are analyzed, and the relationship between the yields of different countries' government bond yields is being estimated using the method of correlation analysis (Pearson correlation coefficient) (**Section 4.1**). Afterward, in Stage 2, the impact of the spread of the COVID-19 pandemic on the yields of Germany and the United States government bonds is being assessed. Stage 2 itself consists of 2 steps:

Firstly, taking into account the wide application of the regression approach in similar research, we use the correlation-regression analysis to assess the effect of the COVID-19 pandemic on government bond yields (**Section 4.2**). To determine the potential linear association between selected government bond yields and COVID-19 related variables, the Pearson correlation coefficient is being calculated. To evaluate the impact of the spread of the COVID-19 pandemic on selected countries' government bond yields, simple linear or bivariate regression models are constructed for each pair of dependent (yield) and independent (COVID-19 related) variables. And finally, the statistical characteristics (t-value, p-statistics, R squared) of these models are being assessed. It is essential to mention that the impact is assessed in a longer and a shorter run: the pandemic's longer-term effect on government bond yields is set by analyzing the period from 02 January 2020–19 March 2021 (whole period investigated); before constructing regression models, the stability of the data of the whole period was also estimated using Breakpoint Unit Root test. The data were also analyzed for structural breaks using minimized Dickey-Fuller t-statistics and CUSUM of Squares test. For variables with structural breaks, linear regression was conducted using least squares with breakpoints (BREAKLS).

For the shorter-term pandemic effect, the historical period is divided into three phases; the selection of these phases is based on the dynamics of the COVID-19 related variables (see **Figure 1**): 1) Phase I covers data from 02 January 2020–30 April 2020; 2) Phase II covers data from 01 May 2020–30 September 2020–; and 3) Phase III covers data from 01 October-2020–19 March 2022. Phases I and III reflect the first and the second wave of the COVID-19 pandemic, while Phase II reflects a relatively quiet period with a lower growth rate of infection cases.

Secondly, we use the impulse response functions to determine the response of government bond yields to the shock of the COVID-19 pandemic (**Section 4.3**). The impulse response functions are constructed based on two-variable vector autoregression (VAR) models for each pair of dependent (yield) and independent (COVID-19 related) variables:

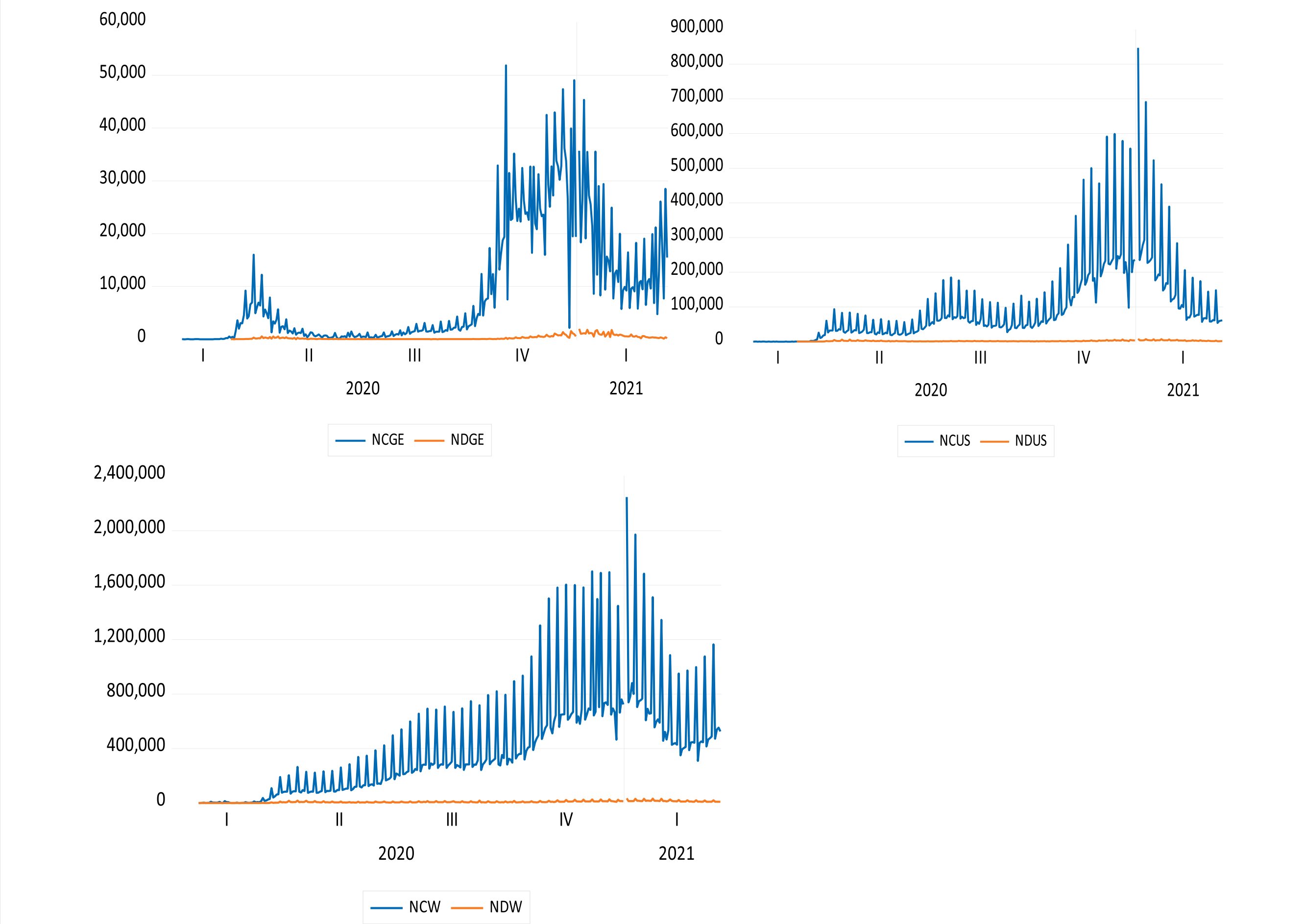

FIGURE 1 | Dynamics of COVID-19 related variables (2020/01/02–2021/03/19). Note: M1 = January; M2 = February; M3 = March; M4 = April; M5 = May; M6 = June; M7 = July; M8 = August; M9 = September; M10 = October; M11 = November; M12 =December; for variable abbreviations see **Table 1**.

TABLE 1 | Research variables and abbreviations.

Variable Abbreviation	Full Name	Source
Dependent variables		
Y10GEt	10 years German government bond yield	Thomson Reuters database
Y5GEt	5 years German government bond yield	
Y3GEt	3 years German government bond yield	
Y10USt	10 years United States government bond yield	
Y5USt	5 years United States government bond yield	
Y3USt	3 years United States government bond yield	
Independent variables		
NCGEt	New cases on COVID-19 confirmed in Germany per day	Our World in Data Coronavirus Pandemic (COVID-19) database
NDGEt	New deaths from COVID-19 reported in Germany per day	
NCUSt	New cases of COVID-19 infection confirmed in the United States per day	
NDUSt	New deaths from COVID-19 reported in the United States per day	
NCWt	New cases of COVID-19 infection are confirmed per day globally	
NDWt	New deaths from COVID-19 are reported in the World per day.	

At first, the unit root test is conducted: we use the Augmented Dickey-Fuller (ADF) test to check the stationarity of variables–the results (see **Table 1**) shows that all research variables are stationary. Thus, it is meaningful to construct VAR models. Secondly, we use Akaike information criteria to determine the most suitable lag selection (the lags suggested by this criterion are indicated in

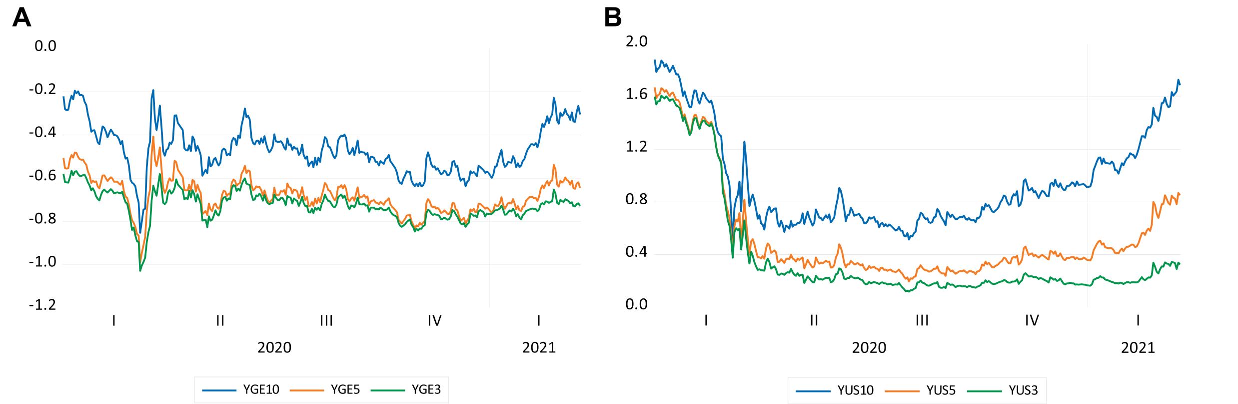

FIGURE 2 | Dynamics of Germany **(A)** and United States **(B)** government bond yields at different maturities (2020/02/01–2021/19/03).Note: M1 = January; M2 = February; M3 = March; M4 = April; M5 = May; M6 = June; M7 = July; M8 = August; M9 = September; M10 = October; M11 = November; M12 =December; for variable abbreviations see **Table 1**.

Supplementary Figures S4–S9). Finally, the impulse response functions (as well as accumulated impulse response functions) are constructed, and results are interpreted.

It is important to notice that in our research, we do not construct multiple regression models due to the multicollinearity of regressors. Thus, given the results of literature analysis and data availability, we select six dependent variables; and based on previous studies (for example, Klose 2020; Albulescu 2021; Ashraf, 2020; Brueckner and Vespignani 2020; and others). We select six independent COVID-19 related variables (see **Table 1**). We chose COVID-cases and COVID-deaths variables to assess whether the bond markets reach differently to the growth of COVID-19 cases and deaths caused by COVID-19 infection, and we choose country-level and global-level variables to assess whether the reaction to the spread of the COVID-19 in the country and to the global spread of COVID-19 is different.

Descriptive statistics of selected independent (COVID-19 related) and dependent (yield) variables are provided in **Supplementary Appendix Table SA**.

We use the daily data for our research (**Figure 1**),, and the period from 2020–01-02 to 2021–03-19 is analyzed (only the trading days are analyzed; thus, the research sample consists of 302 observations). The selected government bond yields data is retrieved from the Thompson Reuters database. In contrast, the data on daily COVID-19 cases and deaths from COVID-19 is collected from the Our World in Data Coronavirus Pandemic (COVID-19) database. For data analysis, Eviews 11 software package is used.

4 RESULTS AND DISCUSSION

In this section, the dynamics of the government bond yields in Germany and the United States are analyzed, and the impact of the spread of the COVID-19 pandemic on Germany and United States government bond yields of different maturities is estimated.

4.1 Analysis of the Trends of Government Bond Yields

The COVID-19 pandemic had a strong shock on financial markets. The demand for safe assets increased, and yields started decreasing. Later, investors understood that there was significant support from governments, central banks, and international organizations. Because of the latter, investors started to take more risk and began investing in riskier assets supporting their market value growth. We could see significant inflows of funds in the equity market. Ten-year yield growth was supported by inflation expectations in all regions, especially the United States

The dynamics of Germany and the United States government bond yields at different maturities are provided in **Figure 2**.

As shown in **Figure 2**, during the primary outbreak of the COVID-19 (first quarter of 2020), the yields of selected countries' government bonds decreased sharply as investors started to search for safe assets in the face of rapidly increased uncertainty in the markets. In the cases of all countries analyzed, a market adjustment is observed in later periods when the demand for riskier assets increases as a result of reduced uncertainty.

Moreover, the correlation analysis of the yields of different maturities in selected countries revealed that (see **Supplementary Appendix Table SB**) the yields of German government bonds of different maturities are directly correlated with the yields of United Stated government bonds (statistically significant positive correlation in the cases of 3, 5, and 10 years maturities).

Further, it is essential to analyze how the spread of the COVID-19 pandemic is related to the recent changes in government bond yields.

4.2 Assessment of the Spread of the COVID-19 Pandemic on the Government Bond Yields

At first, the impact is estimated using the long period's data (2020/1/02 to 2021/03/19). The research results are provided in **Supplementary Appendix Table SC** and **Tables 2–3**.

TABLE 2 | Linear regression (Least Squares with Breakpoints) models for COVID-19 effect on Germany government bond yields.

Variable	Periods according Breaks (Bai-Perron)	Model Const.	Coef.	*t*-Value	*p*-Stat	R sq.	Observ.
			Y10GEt				
NCGEt	1/23/2020–5/25/2020	−0.494	1.08×10^{-5}	3.601	0.000**	0.402	81
	5/26/2020–10/09/2020	−0.428	-2.20×10^{-5}	−3.292	0.001**		99
	10/13/2020–1/19/2021	−0.576	1.85×10^{-7}	0.215	0.830		70
	1/20/2021–3/19/2021	−0.352	-2.62×10^{-6}	−1.452	0.148		43
NDGEt	1/23/2020–6/01/2020	−0.475	9.46×10^{-5}	1.442	0.151	0.546	57
	6/02/2020–9/18/2020	−0.486	0.003	3.988	0.001**		79
	9/21/2020–1/25/2021	−0.564	7.43×10^{-6}	0.525	0.599		89
	1/26/2021–3/19/2021	−0.269	−0.0001	−5.885	0.000**		39
NCWt	1/23/2020–9/24/2020	−0.456	-1.73×10^{-8}	−0.502	0.615	0.354	172
	9/25/2020–1/15/2021	−0.560	2.13×10^{-8}	3.372	0.738		79
	1/18/2021–3/19/2021	−0.327	-1.05×10^{-7}	−2.740	0.007**		45
NDWt	1/23/2020–9/24/2020	−0.462	4.69×10^{-8}	0.316	0.723	0.383	172
	9/25/2020–1/15/2021	−0.568	1.71×10^{-7}	0.122	0.902		79
	1/18/2021–3/19/2021	−0.254	-9.17×10^{-6}	−4.709	0.000**		45
			Y5GEt				
NCGEt	1/23/2020–5/25/2020	−0.689	1.20×10^{-5}	5.098	0.000**	0.357	82
	5/26/2020–10/09/2020	−0.646	-1.66×10^{-5}	−3.142	0.002**		99
	10/12/2020–1/15/2021	−0.772	4.99×10^{-7}	0.722	0.471		68
	1/18/2021–3/19/2021	−0.634	-1.90×10^{-6}	−1.492	0.138		45
NDGEt	1/23/2020–10/08/2020	−0.672	0.0001	2.731	0.007**		150
	10/09/2020–1/19/2021	−0.774	3.01×10^{-5}	2.119	0.029b	0.406	71
	1/20/2021–03/19/2021	−0.596	−0.0001	−4.262	0.001**		43
NCWt	1/23/2020–3/26/2020	−0.687	2.18×10^{-5}	4.777	0.000**	0.345	46
		−0.650	-6.63×10^{-8}	−2.251	0.025*		136

(Continued on following page)

TABLE 2 | (*Continued*) Linear regression (Least Squares with Breakpoints) models for COVID-19 effect on Germany government bond yields.

Variable	Periods according Breaks (Bai-Perron)	Model Const.	Coef.	*t*-Value	*p*-Stat	R sq.	Observ.
	3/27/2020–10/07/2020						
	10/08/2020–1/15/2021	–0.763	5.47×10^{-9}	0.315	0.751		70
	1/18/2021–3/19/2021	–0.626	5.47×10^{-8}	–1.851	0.065		45
NDWt	1/23/2020–3/26/2020	–0.685	4.34×10^{-5}	4.787	0.000**	0.345	46
	3/27/2020–10/07/2020	–0.662	-7.18×10^{-7}	–0.433	0.665		136
	10/08/2020–1/15/2021	–0.775	1.22×10^{-6}	1.043	0.298		70
	1/18/2021–3/19/2021	–0.589	–4.68 × 10–6	–3.064	0.002**		45
			Y3GEt				
NCGEt	1/28/2020–5/15/2020	–0.746	8.55×10^{-5}	4.124	0.000**	0.293	76
	05/18/2020–7/20/2020	–0.669	-1.90×10^{-5}	–0.819	0.413		46
	7/21/2020–11/06/2020	–0.727	-3.77×10^{-6}	–5.363	0.000**		79
	11/09/2020–3/19/2021	–0.718	-1.61×10^{-6}	–3.097	0.002**		93
NDGEt	3/10/2020–5/25/2020	–0.763	0.0003	5.572	0.000**	0.428	52
	05/26/2020–10/02/2020	–0.727	0.002	4.559	0.000**		94
	10/05/2020–12/22/2020	–0.793	8.76×10^{-6}	0.459	0.647		57
	12/23/2020–3/19/2021	–0.706	-3.65×10^{-5}	–2.857	0.005**		61
NCWt	1/23/2020–3/24/2020	–0.740	2.48×10^{-7}	–0.539	0.591	0.266	44
	3/25/2020–10/07/2020	–0.690	-6.01×10^{-8}	–2.328	0.021*		138
	10/08/2020–1/01/2021	–0.792	3.48×10^{-9}	0.193	0.847		60
	1/04/2021–3/19/2021	–0.718	-2.37×10^{-8}	–1.276	0.203		55
NDWt	1/23/2020–10/09/2020	–0.723	1.77×10^{-6}	1.742	0.083	0.235	183
	10/09/2020–1/01/2021	–0.804	1.09×10^{-6}	0.849	0.396		59
	1/04/2021–3/19/2021	–0.702	-2.02×10^{-6}	–1.733	0.084		55

**99%c.l; *95%c.l.

*Note: Model Const., Model constant; Coef., Coefficient; p-Stat, p-Statistics; R sq., R s Observ., Observations; for variable abbreviations see **Table 1**.*

TABLE 3 | Linear regression (Least Squares with Breakpoints) models for COVID-19 impact on the United States government bond yields.

Variable	Periods accordingBreaks (Bai-Perron)	Model Const.	Coef.	*t*-Value	*p*-Stat	R sq.	Observ.
			Y10USt				
NCUSt	1/23/2020–3/27/2020	1.321	-3.08×10^{-6}	−7.648	0.000**	0.777	46
	3/30/2020–10/16/2020	0.692	-4.13×10^{-7}	−1.074	0.284		140
	10/19/2020–1/11/2021	0.848	1.99×10^{-7}	1.616	0.107		57
	1/12/2021–3/19/2021	1.511	-1.53×10^{-6}	−5.891	0.000**		47
NDUSt	1/23/2020–6/10/2020	0.809	-4.72×10^{-5}	−5.579	0.000**	0.867	70
	6/11/2020–10/02/2020	0.702	-4.33×10^{-5}	−1.568	0.118		80
	10/05/2020–1/11/2021	0.782	3.74×10^{-5}	5.074	0.000**		66
	1/12/2021–3/19/2021	1.689	−0.0001	11.339	0.000**		47
NCWt	1/23/2020–3/27/2020	1.366	-8.89×1^{-9}	−8.257	0.000**	0.763	46
	3/30/2020–10/19/2020	0.668	6.43×10^{-9}	0.091	0.927		141
	10/20/2020–1/07/2021	0.869	2.70×10^{-8}	0.544	0.587		54
	1/08/2021–3/19/2021	1.398	-1.55×10^{-7}	−2.223	0.027*		49
NDWt	1/23/2020–3/27/2020	1.359	−0.0002	−8.798	0.000**	0.780	46
	3/30/2020–10/19/2020	0.676	-0.70×10^{-7}	−0.175	0.861		141
	10/20/2020–1/18/2021	0.839	5.27×10^{-6}	1.709	0.089		60
	1/19/2021–3/19/2021	1.611	-1.96×10^{-5}	−4.690	0.000**		43
			Y5USt				
NCUSt	1/23/2020–3/27/2020	1.121	-4.01×10^{-5}	−10.227	0.000**	0.738	46
	3/30/2020–1/11/2021	0.315	1.71×10^{-7}	2.071	0.000**		197
	1/12/2021–3/19/2021	0.727	-1.07×10^{-6}	−4.225	0.000**		47
NDUSt	3/03/2020–4/27/2020	0.557	-4.77×10^{-5}	−7.250	0.000**	0.782	39
	4/28/2020–6/25/2020	0.338	4.83×10^{-6}	0.369	0.717		42
	6/26/2020–10/16/2020	0.301	-2.05×10^{-5}	−1.001	0.318		78
	10/19/2020–1/22/2021	0.365	9.79×10^{-6}	1.782	0.076		65
	1/25/2021–03/19/2021	0.873	-8.45×10^{-5}	−10.417	0.000**		39
NCWt	1/23/2020–3/27/2020	1.178	-1.14×10^{-5}	−11.292	0.000**	0.777	46
	3/27/2020–1/07/2021	0.317	3.42×10^{-8}	1.234	0.218		195
	1/08/2021–3/19/2021	0.650	-9.35×10^{-8}	−1.429	0.154		49
NDWt	1/23/2020–3/27/2020	1.169	−0.0002	−11.874	0.000**	0.790	46
	3/27/2020–1/07/2021	0.294	4.23×10^{-5}	2.249	0.025*		197
	1/08/2021–3/19/2021	0.808	-1.44×10^{-5}	−3.683	0.000**		47
			Y3USt				
NCUSt	1/23/2020–3/27/2020	1.087	-4.42×10^{-5}	−11.453	0.000**	0.809	46
	3/30/2020–3/19/2021	0.214	-5.41×10^{-8}	−0.704	0.483		244
NDUSt	3/03/2020–4/27/2020	0.470	-5.36×10^{-5}	−10.817	0.000*	0.339	39
	04/28/2020–6/25/2020	0.219	4.13×10^{-6}	0.419	0.675		42
	6/26/2020–1/22/2021	0.172	5.19×10^{-6}	1.681	0.094		143
	1/25/2021–3/19/2021	0.339	-3.10×10^{-5}	−5.07	0.000*		39
NCWt	1/23/2020–3/27/2020	1.147	-1.25×10^{-5}	−13.120	0.000**	0.809	46
	3/30/2020–3/19/2021	0.215	-1.46×10^{-8}	−0.622	0.534		244
NDWt	1/23/2020–3/27/2020	1.137	−0.003	−13.467	0.000**	0.829	46
	3/30/2020–3/19/2021	0.206	1.53×10^{-6}	0.177	0.859		244

***99% c.l; *95% c.l.*

*Note: Model Const, Model constant; Coef, Coefficient; p-Stat, p-Statistics; R sq, R squared; Observ, Observations; for variable abbreviations see **Table 1**.*

The results of correlation analysis (**Supplementary Appendix Table SC**) show that:

1) in most cases, the yields of different maturities of German government bonds are inversely related to COVID-19 variables both in Germany and globally (statistically significant negative correlation is observed);
2) a more reverse situation is observed in the case of U.S. government bonds, where the yields of shorter-term (3 and 5 years) bonds are directly related to COVID-19 variables both in the U.S. and globally, while the yields of longer-term (10 years) bonds are inversely related to COVID-19 variables.

Further, the regression analysis is conducted to get a clearer view of the impact of the spread of the COVID-19 pandemic on the government bond yields. The Breakpoint Unit Root test (**Supplementary Appendix Table SD**) showed that 11 variables are stationary, and 1 of the variables are stationary at the first difference; thus, they can be used for further analysis. On the other hand, minimized Dickey-Fuller t-statistics and CUSUM of Squares test (**Supplementary Appendix Figures SE–F**) indicated the

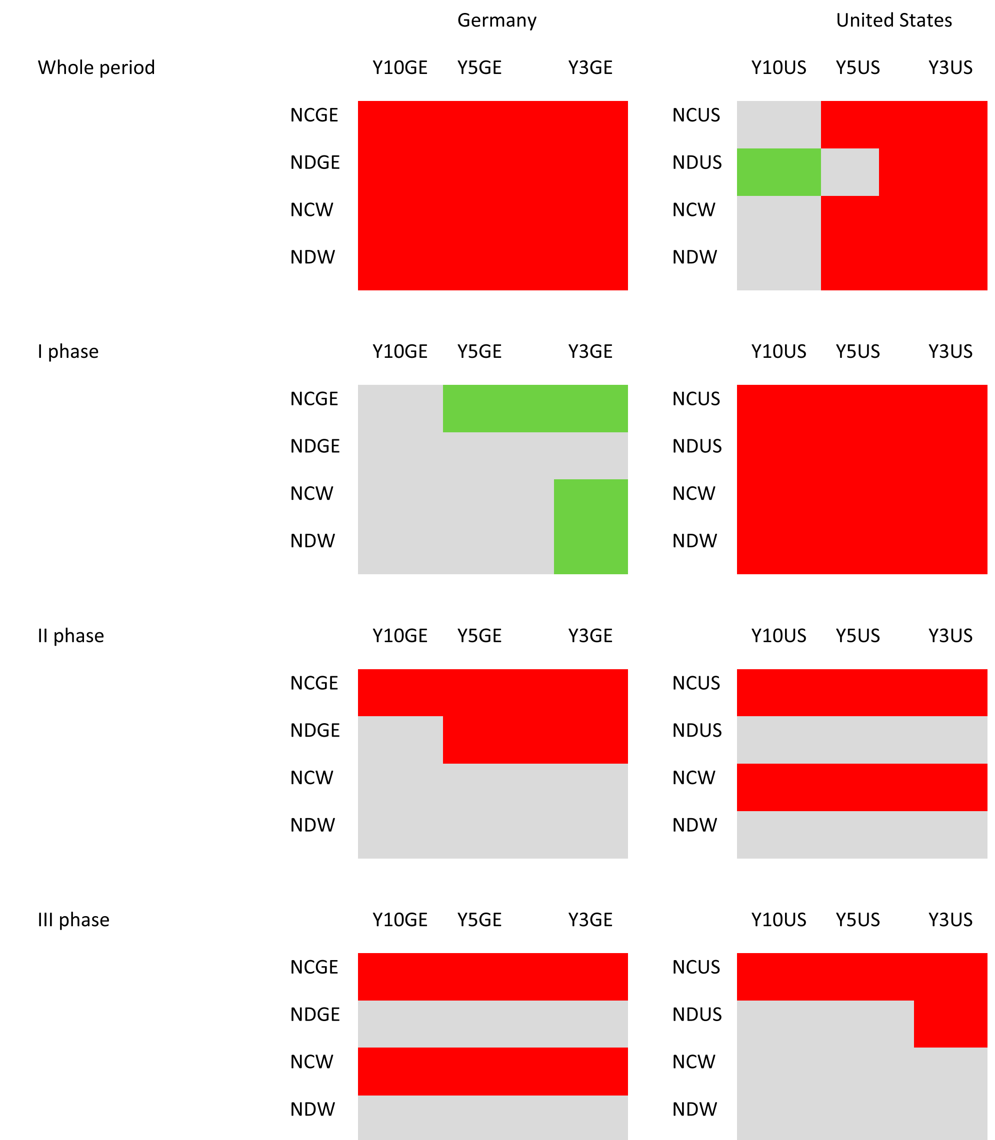

FIGURE 3 | Summary of the results of the COVID-19 pandemic impact on selected countries' government bond yields of different maturities in different periods.Note: Whole period = 2020/1/02-2021/03/19; I Phase = 2020/1/02-2020/04/30; II Phase = 2020/05/01-2020/09/30; III Phase = 2020/10/1-2021/03/19; for variable abbreviations see **Table 1**.

existence of structural breaks in selected variables. Taking this into account, linear regression models using least squares with breakpoints (BREAKLS) instead of ordinary least squares were conducted. The results are provided in **Tables 2–3**. The results allow discussion of the similarities and differences of government bond market reactions to COVID-19 in different countries.

The linear regression models for the COVID-19 effect on Germany government bond debt yields are provided in **Table 2**.

Based on the results of **Table 2** (t-values, p-statistics, and R-squared, it can be stated that:

1) in the case of Germany, the yields of 3, 5, and 10 years government bonds were positively affected by the spread of the COVID-19 pandemic in the country during the first wave of the pandemic (the statistically significant positive impact has been identified), i.e., the yields have initially increased in the face of the COVID-19 pandemic; the yields of 5 years bonds were influenced by both country and global level pandemic situation, while the yields of 10 and 3 years bonds positively reacted only to the country-level situation;
2) it is also worth mentioning that during the last 2 months of investigated period, the reaction of 10 years Germany's government bond yields to the global-level COVID-19 situation was negative;
3) the results appeared to be mixed during the recovery period and at the beginning of the second wave of the COVID-19 pandemic.

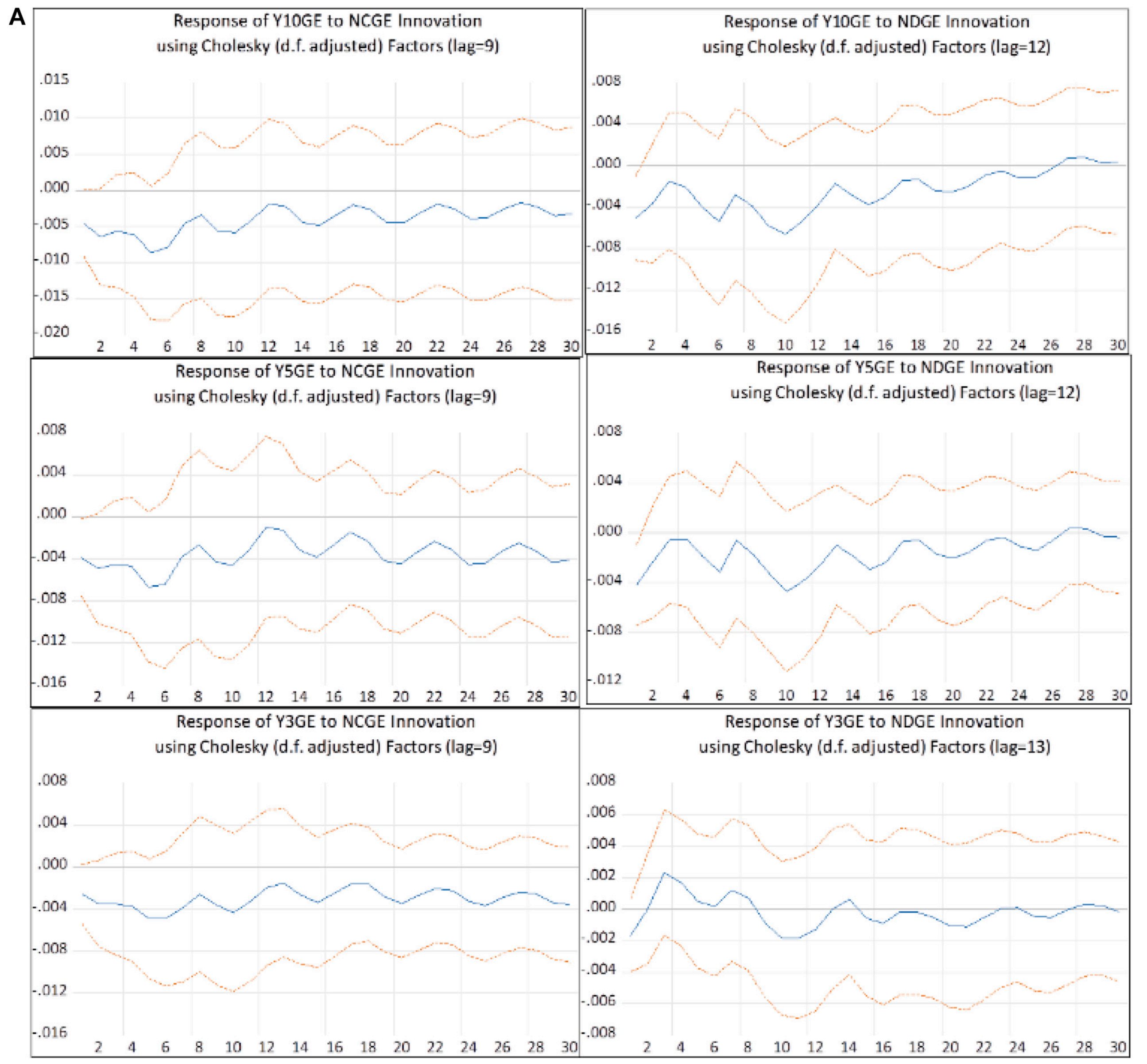

FIGURE 4 | Response of German government bond yields to the spread of the COVID-19 pandemic in the country and global level. Note: The effect of the country-level COVID-19 situation can be seen in **(A)**, while the effect of the global level situation is shown in **(B)**.

These results show that even though the primary reaction to the COVID-19 pandemic was related to the increase of bond yields, in the later stages of the COVID-19 pandemic, the yields of different maturities of Germany's government bonds decreased, showing the importance of the Germany government bonds as the benchmark, low-risk assets in the periods of financial markets distress.

The linear regression models for the COVID-19 effect on United States government bond debt yields are provided in **Table 3**.

Based on the results of **Table 3** (t-values, p-statistics, and R-squared, it can be stated that:

1) contrary to the previously analyzed case of Germany, in the United States, the statistically significant negative impact of COVID-19 variables on the yields of the United States government bonds (of different maturities) was established; the effect is observed both in the country and global level;
2) the negative impact is also observed during the last months of investigated period (which partially coincides with the second wave of the COVID-19 pandemic), while the response to the changes in the pandemic situation during the so-called quiet period appeared to be mixed.

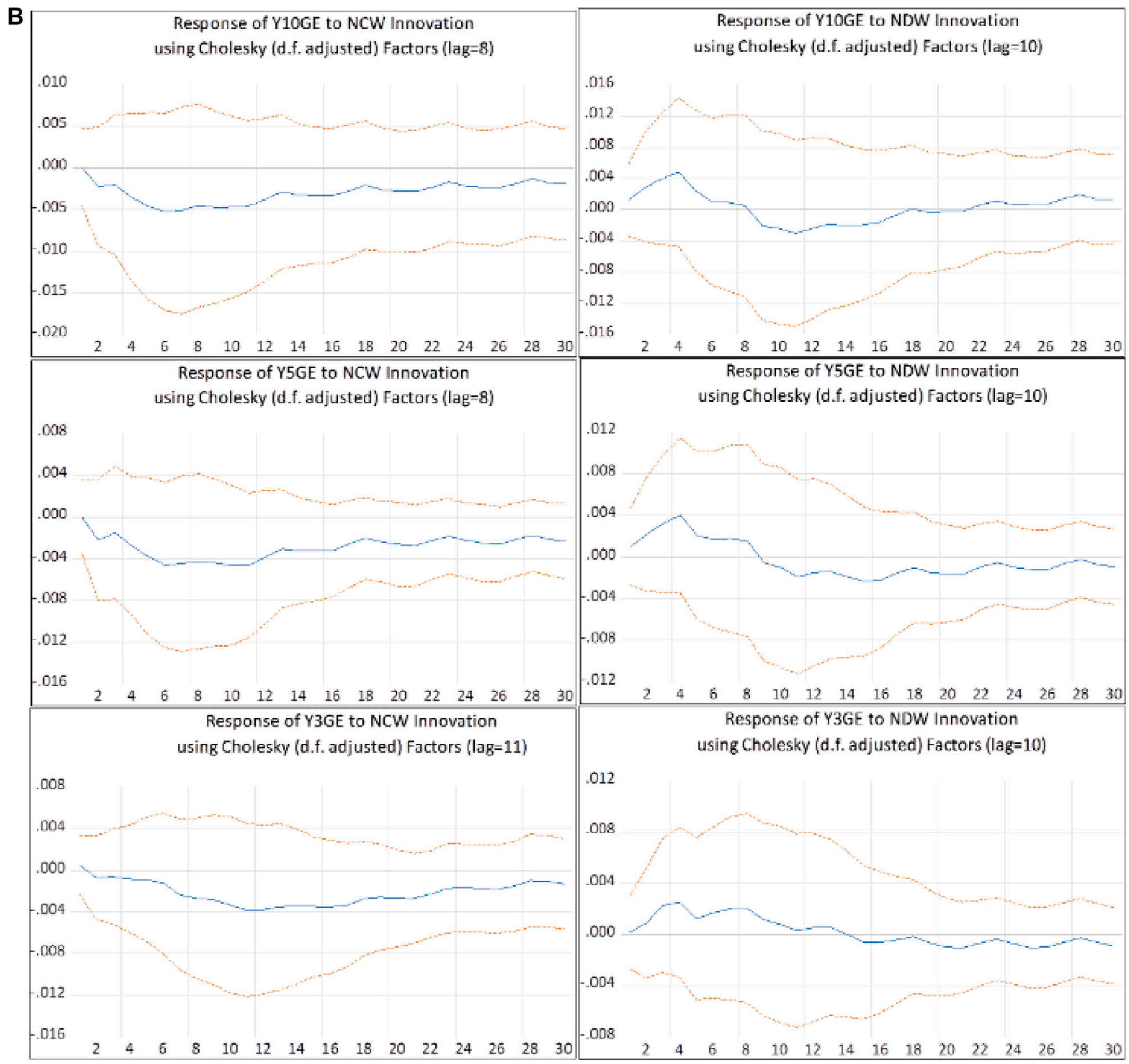

FIGURE 4 | (Continued). Response of German government bond yields to the spread of the COVID-19 pandemic in the country and global level.

To sum up, the long and mid-term yields of the United States government bonds have decreased in the face of the COVID-19 pandemic. The main reason for such tendencies could be the pandemic risks that are not concentrated over a long period.

Summarizing the regression analysis results, it can be stated that initially, the yields of German government bonds were positively affected by the global COVID-19 situation, i.e., the spread of the COVID-19 pandemic has caused the increase in Germany's yields. At the same time, the subsequent negative effect can also be observed. Contrary, the yields of the United States government bonds were initially affected inversely, i.e., decreased in the face of the COVID-19 pandemic and reacted to both country-level and global situations.

Secondly, the impact of the spread of the COVID-19 pandemic on government bond yields is assessed from a short-term perspective (regression models for different phases). The results of the assessment are provided in **Figure 3** (Panels c–h) (summarized results) and **Supplementary Appendix Tables SG–SJ** (detailed results).

The assessment results of the spread of COVID-19 impact on bond yields in the short term (in separate phases) show significant differences between countries and between periods (phases). These differences are related to the

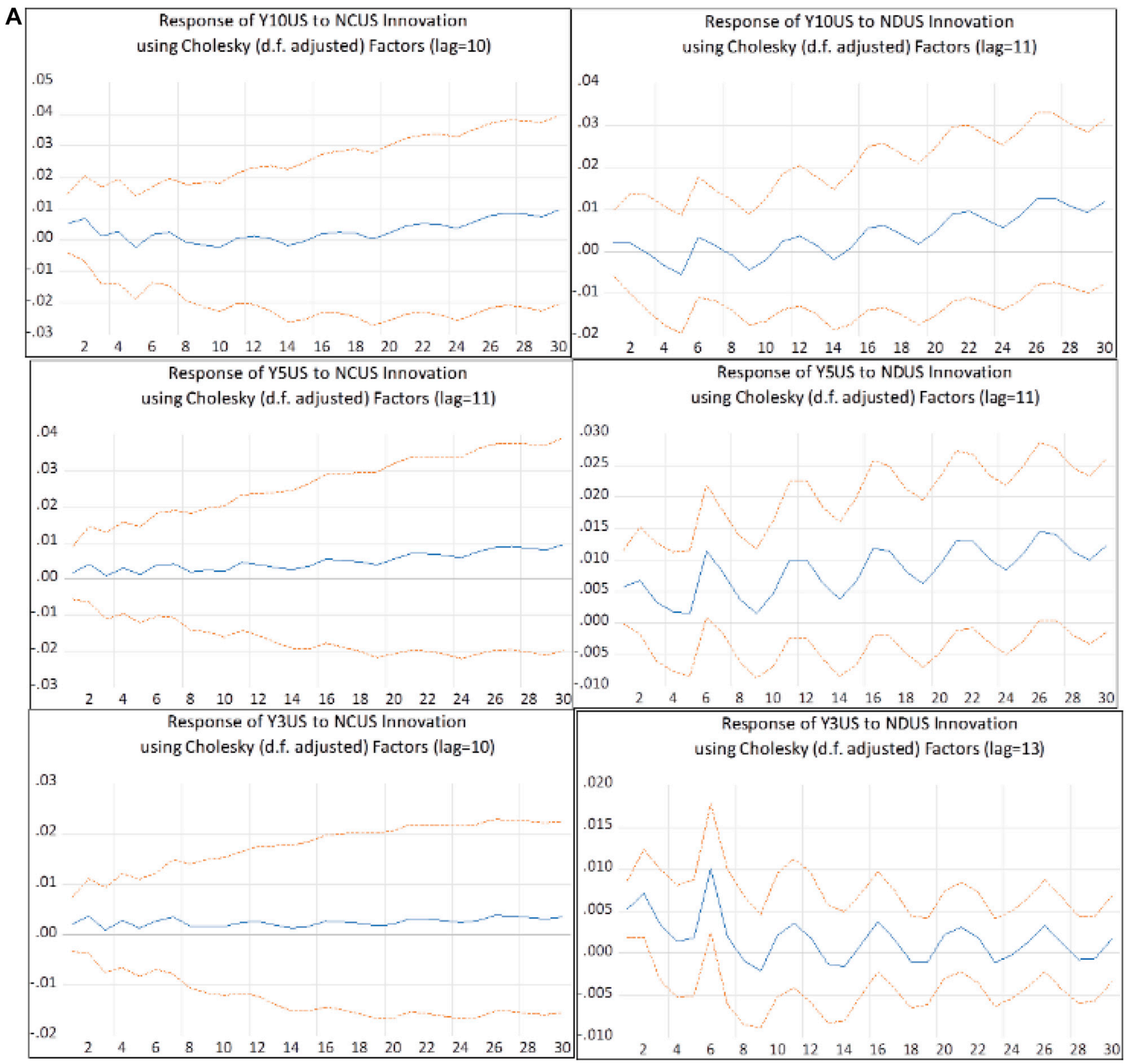

FIGURE 5 | Response of the United States government bond yields to the spread of the COVID-19 pandemic in the country and global level. Note: The effect of the country-level COVID-19 situation can be seen in **(A)**, while the effect of the global level situation is shown in **(B)**.

effect's significance and direction and are worth further discussion.

Assessing the impact of the spread of the COVID-19 pandemic on government bond yields during Phase I (the first wave of a pandemic) (**Figure 3**, Panels c–d), it can be observed that:

1) in the case of Germany, the impact during the first wave is also significantly different: the 10 years yields remained unaffected while the five and 3 years yields were affected directly, i.e., increased; the 3 years yields reacted to both country-level and global COVID-19 situation;
2) however, such significant differences are not observed in the United States' case–the effect seemed to be inverse, i.e., the yields (of all maturities) decreased.

Assessing the impact of the spread of the COVID-19 pandemic on government bond yields during Phase II (relatively "calm" period) (**Figure 3**, Panels e–f), it can be observed that:

1) generally, the direction of the COVID-19 impact has also changed in comparison with Phase I in Germany, causing the yields of bonds (all maturities) to decrease; conversely to the results of the whole period and Phase 1, the

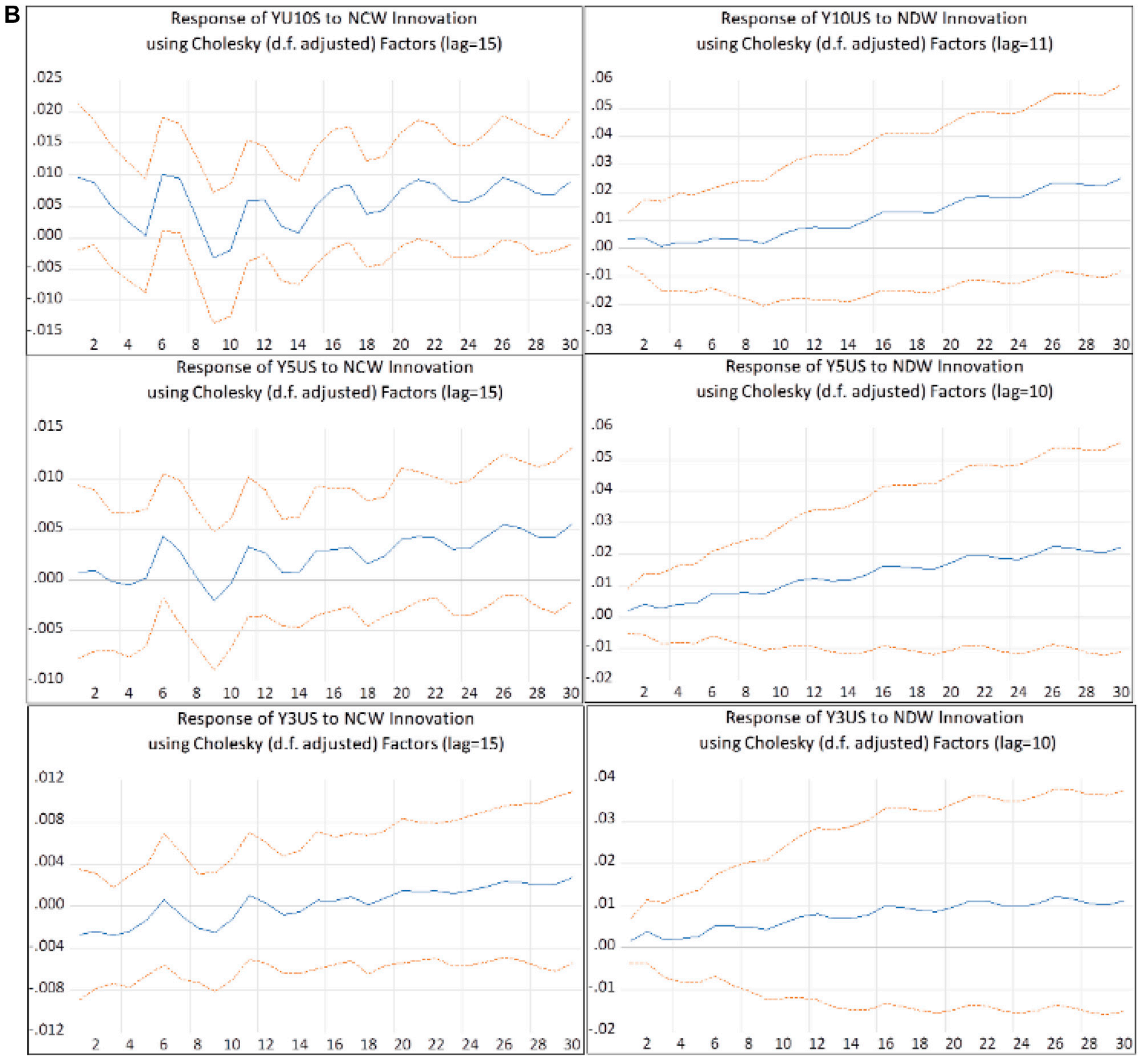

FIGURE 5 | (Continued). Response of the United States government bond yields to the spread of the COVID-19 pandemic in the country and global level.

reaction to global level COVID-19 situation is not observed in Phase II;
2) In the United States case, the effect is similar to the effect observed during Phase I and the whole period, except for the fact that the market reacted only to the deaths variable (both at the country and global level).

Assessing the impact of the spread of the COVID-19 pandemic on government bond yields during Phase III (the second wave of a pandemic) (**Figure 3**, Panels g–h), it can be observed that:

1) the results demonstrate a negative effect on selected countries' government bond yields (all maturities), i.e., the spread of the COVID-19 pandemic caused the yields to decrease in Phase III;
2) in Germany, markets react to both country-level and global situations, while in the United States, the reaction only to country-level daily cases is observed.

It is worth mentioning that the models showing this impact have higher R's than models showing the impact of country-lever COVID-19 situation, i.e., are of higher explanatory power

4.3 Evaluation of the Response of Government Bond Yields to the Shock of the COVID-19 Pandemic

Finally, to better assess the primary response of the yields of selected countries government bonds (the direction, strength, and duration of this response), using the baseline models of VAR with one dependent and one independent variable, the impulse response functions (**Figures 4**, **5**, **Supplementary Appendix Figures SK–SL**) are constructed, and the results are discussed.

Figure 4 shows the dynamic effects of COVID-19 daily new cases and deaths on the yields of German government bonds. The effect of the country-level COVID-19 situation can be seen in Panel a, while the effect of the global level situation is shown in Panel b.

In the case of Germany, the analysis of the impulse response functions shown in **Figure 4** and **Supplementary Appendix Figure SK** reveals:

1) the negative response of yields (different maturities) to the increase of daily cases reported in Germany (Panel a): the response of yields (different maturities) reaches its peak at day six and does not exceed 0.01%; accumulated long-term response of yields (different maturities) (see **Supplementary Appendix Figure SK**) is also negative;
2) the negative response of longer-term (5 and 10 years) yields and initial positive response of shorter-term (3 years) yields to the growth of deaths caused by COVID-19 in the country (the response of 3 years turn to positive at day nine and remains volatile) (Panel a); however, after the initial negative response, the accumulated long-term response (see **Supplementary Appendix Figure SK**) to new deaths in the country becomes positive;
3) the initial negative response of the yields (of all maturities) to the global increase of COVID-19 cases (Panel b): the response of 3, 5, and 10 years yields reaches its peak at days 6, 6, and 11, respectively and approaches to zero in 30 days, and long-term yield appeared to demonstrate the strongest negative response; after an initial negative response, the long-term accumulated response appeared to be negative for long-term and around zero for shorter-term bonds (see **Supplementary Appendix Figure SK**);
4) the initial positive response of yields (different maturities) to the increase of deaths from COVID-19 reported globally: the response of 3, 5, and 10 years yields reaches its peak at day 4, and turn to negative at day 8, 9, and 13, respectively; the accumulated long term response is positive in case of 10 years-yield and slightly negative in case of 3 and 5 years yield (see **Supplementary Appendix Figure SK**).

Figure 5 shows the dynamic effects of COVID-19 daily new cases and deaths on the United States government bonds' yields. The effect of the country-level COVID-19 situation can be seen in Panel a, while the effect of the global level situation is shown in Panel b.

In the case of the United States, the analysis of the impulse response functions shown in **Figure 5** and **Supplementary Appendix Figure SL** indicates:

1) the slightly positive response of shorter-term (3 and 5 years) yields and the volatile response of long-term (10 years) yield to the increase of daily new cases of COVID-19 at a country-level (Panel a); accumulated long-term response is positive;
2) the positive but volatile response of yields (all maturities) to the increase of daily deaths caused by COVID-19 at the country level; the accumulated long term response is also positive;
3) the initial positive response of longer-term yields (5 and 10 years) and negative response of shorter-term yield (3 years) to the global increase of daily cases of COVID-19: the response of 3 years yield turn to positive at day 15; accumulated long-term response appeared to be around zero;
4) the initial positive response of yields (different maturities) to the global increase of daily deaths from COVID-19: accumulated long-term response is also positive for all maturities.

As we can see from the results of impulse response function analysis, although the short-term initial responses vary in direction, strength, and duration, the long term response of German government bond yields appeared to be of a more negative nature (indicating the decrease of the yields), while the long term response of the United States government bonds appeared to be more positive (i.e., an increase of yields). The long-term response is related to the countries' inflation level expectations, which have strong connections with local monetary and fiscal policy issues.

In summarizing, it can be stated that the impact of the spread of the COVID-19 pandemic on Germany and United States government bond yields differs depending on the country and the assessment period.

5 CONCLUSION

The COVID-19 pandemic has caused economic pressure. The COVID-19 pandemic substantially impacted the financial markets, including the Government bond market. The fiscal and monetary policy influenced the direct effect because governments and central banks made substantial efforts to lower the pandemic shock's negative impact. More government departments and social organizations will use ESG information to make decisions and investments. Indeed, our research findings regarding the government bond market during the COVID-19 pandemic inform corporate decision-making. Countries' carbon neutrality and zero emissions targets have boosted the ESG demand and the need to raise funds via government bonds. Moreover, governments have increased their ESG attention. A green government-bond index could contribute to attracting foreign investment.

Our research showed different tendencies of government bond yields in two regions: the United States, and Germany (as a proxy for the euro area); as a result, the impact of the spread of the COVID-19 pandemic government bond yields seemed to be different depending on the country and the assessment period. We have chosen separate periods to value the actual effects and shocks of pandemic levels and waves, which helped us identify some tendencies.

Firstly, the results revealed different effects of the COVID-19 pandemic depending on the period investigated. In the first months of the pandemic, the yields of German government bonds demonstrated a positive reaction (increase). In contrast, the yields of the United States government bonds demonstrated a negative reaction (decrease) to the spread of the COVID-19 pandemic. The response both to the country-level and the global situation was identified.

The first wave in Germany was quite interesting as we noticed that long-term yields were not affected while the 3-year tenor sector increased. Long-term yields are usually impacted by inflation expectations which could lower the effect. Germany is like a benchmark yield curve for the euro area and the minor risky asset in this region. We think that 3 year maturity is not among those popular ones, so for this reason, it was affected contrarily. The most liquid and most minor risky assets are up to 2 years maturity. The COVID-19 pandemic situation during the first wave was not so bad in the United States compared with other regions. Because of that and, of course, of the currency issues, government bonds were very attractive for local investors and foreign investors. So, due to high demand, the yields decreased in all maturity buckets.

The results are, to some extent, different for the second phase: Germany and the United States bonds demonstrated a decrease in yield, we did not notice any differences compared to the United States's first stage. Tendencies of the second wave of the COVID-19 pandemic were very different in separate regions. In the United States case, effects in Germany and the United States were influenced strongly by other factors such as central bank interventions and substantial political risk volatility.

The analysis of impulse response functions revealed that yield response differs depending on the maturity of the bonds. The markets also respond differently to a country-level and global pandemic situation. Although the short-term initial yield responses vary in direction, strength, and duration, it could be stated that the long-term response of German government bond yields appeared to be of a more negative nature, while the reaction of the United States government bonds was more positive.

Summarizing our research results, we would like to stress that in stressful situations, for a short period, yields of government securities usually decrease because investors need safe assets, but later, other factors begin to influence stronger, and the negative effect of any crisis or pandemic decreases. As such, our empirical findings based on contexts Germany and the United States had practical implications to strengthen business investors' capability to cope with fear of failure at stressful situations of turbulent global financial markets (Dong, 2022).

Practitioners in asset management could use our research findings in the risk management and investment management area. For example, portfolio managers in commercial banks, investment companies, or central banking should pay attention to regional and term structure issues, risk management decisions, and diversification. In addition, the results of stressful situations suggest that financial players should pay significant attention to the investment horizon by investing in short-term debt securities.

The limitations of this research are that we focus only on specific markets and specific tenors of government bonds. The other limitation is that the COVID-19 pandemic environment must be valued if the research is repeated in the future. For further research, we would like to recommend analyzing different maturities of government bonds and focusing on only green and sustainable bonds. Also, it would be interesting to add more countries to the analysis and compare the government bond sector with the corporate bond sector in environmental investments.

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

Conceptualization, YZ, RK, DT, GK-S, AK; methodology, DT, GK-S; software, DT GK-S; formal analysis, DT, GK-S; investigation, DT, GK-S; data curation, DT, G.K-S; writing-original draft preparation, AK, DT, GK-S RD and YZ; writing-review and editing, DT, GK-S, YZ, RK, RD, and KP visualization, DT, AK, GK-S; supervision, RK All authors have read and agreed to the published version of the manuscript.

SUPPLEMENTARY MATERIAL

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Evaluation of ESG Ratings for Chinese Listed Companies From the Perspective of Stock Price Crash Risk

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ESG investment strategy has attracted increasing attention from the financial market, and the inconsistency of enterprise ESG rating results of different rating agencies has gradually become the focus of attention of regulators and investors. In this article, the listed companies with ESG ratings in Shanghai and Shenzhen A-shares from 2016 to 2020 were selected as the research samples. Combined with difference-in-differences model and ordinary least squares methods, the rationality of these ESG ratings was evaluated by examining the difference in the impact of three international ESG rating agencies, such as Bloomberg, and three Chinese ESG rating agencies, such as Sino-securities, on the stock price crash risk. The research findings are as follows: First, after incorporating the ESG ratings of FTSE Russell, MSCI, and China Alliance of Social Value Investment, the stock price crash risk of enterprises is significantly reduced. Second, the company's share price crash risk will be lower when the ESG evaluation results of Bloomberg or MSCI is better. Third, compared with social indicators, investors pay more attention to the environmental performance of enterprises in decision making. Enterprises with high environmental scores have lower stock price crash risk. The findings of this article play an enlightening role for China to improve its ESG system, construct an ESG disclosure policy, and improve the market role of ESG rating.

Keywords: ESG rating, stock price crash risk, information asymmetry, investors' attention, investors' trust, ESG investment

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1 INTRODUCTION

Since the financial initiative of the United Nations Environment Programme first put forward the concept of ESG (Environmental, Social, and Governance), ESG has gradually become an important indicator to measure the sustainable development capability and social responsibility of enterprises internationally. Many global investment agencies regard the ESG performance of enterprises as an important indicator of investment decision making, and many of them have carried out ESG rating analyses of enterprises, such as Morgan Stanley, China Alliance of Social Value Investment, Bloomberg, FTSE Russell, and Shanghai Sino-securities. However, rating agencies at home and abroad have their own unique considerations and handling habits in scoring methods, evaluation indicators, and coverage, which make the current ESG rating results of Chinese enterprises obtained by different rating agencies quite different. For example, Zijin Mining (stock code: 601899) has poor evaluation in the ESG rating of MSCI(Morgan Stanley Capital International) and Sustainalyticsl (CCC/56.01), medium evaluation in SynTao Green Finance and FTSE Russell (B+/2.4), and good evaluation in Sino-securities, Social Value Investment Alliance and Wonder (AA/A+/8.36). Different ESG ratings of the same company not only make ESG information disclosure contents of different listed companies vary widely but also interfere with investors' investment decisions, which is not conducive to the stability of the financial market. Reasonable evaluation of ESG ratings by different agencies and improvement of the ESG rating system will not only help to standardize ESG information disclosure standards and improve ESG data quality, but also effectively alleviate the information asymmetry between investors and enterprises, help investors accurately identify potential ESG values and risks, and reduce investment decision-making costs. It has important practical significance for the healthy development of financial markets.

So, how to reasonably evaluate ESG ratings by different agencies? In fact, for investors, an ESG rating is a reference index of value investment beyond short-term financial indicators. Using ESG rating can better tap sustainable companies. Therefore, the ESG evaluation of an enterprise is highly correlated with its stock price. SynTao Green Finance (2020) divided the Shanghai and Shenzhen 300 constituent stocks into high and low groups according to their ESG ratings. It was found that the combined stock price with high ESG would be higher, and was is a significant positive correlation between ESG performance and stock price. The performance of enterprises in the stock market has been widely concerned by enterprise managers, investors, and government departments, and the stock price crash risk has attracted more attention from stakeholders. The sudden plunge in a company's stock price will make the wealth of shareholders shrink rapidly, disturb the trading order of the capital market, affect the efficiency of resource allocation, and even lead to serious social and economic turmoil (Chen et al., 2001). For example, the global financial turmoil caused by the subprime mortgage crisis in 2008 and the stock market crash in China in 2015 all damaged investors' confidence and caused financial market turmoil, and at the same time had a huge impact on the social economy. In 2010, BP's Deepwater Horizon drilling rig exploded in the United States, which caused a large amount of oil leakage and was difficult to deal with. The explosion has caused an environmental tragedy. At the same time, the company's share return rate dropped sharply, and its market value shrank by tens of billions of dollars in a short time, which even caused people to reflect on the oil industry. Generally, existing research believes that information asymmetry is the direct cause of the stock price crash risk. When negative corporate news accumulates for a long time and suddenly breaks out, it will cause negative reactions from investors, leading to the company's stock price turmoil (Kim and Zhang, 2016; Wei and Zeng, 2018; Wu et al., 2019). Therefore, it is important to improve the information environment for stabilizing the financial market (Han et al., 2019; Bao et al., 2020). The more transparent the information disclosed by the company, the lower the stock price crash risk (Hutton et al., 2009). ESG is the off-balance sheet information that investors focus on. ESG evaluation can show investors the performance of enterprises in the environment, society, and management, and alleviate the problem of information asymmetry, thus affecting the stock price crash risk. In addition, from the perspective of investor confidence, Kim et al. (2014) found that the disclosure of corporate social responsibility can increase public confidence, thus reducing the stock price crash risk. Based on this, this article evaluated the rationality of ESG ratings by examining the differences in the impact of ESG ratings of different rating agencies on the stock price crash risk and revealed the characteristics of ESG ratings with higher rating effects.

The possible contributions of this article are as follows: 1) At present, there are many studies on the impact of ESG on enterprises. Some scholars have discussed the relationship between ESG rating and capital market performance (Eccles et al., 2014; Lins et al., 2017; Bae et al., 2021; Gu et al., 2022), enterprise value (Sassen et al., 2016; Aboud and Diab, 2018; Atan et al., 2018), investment and financing (Dhaliwal et al., 2011; Goss and Roberts, 2011; Cheng et al., 2014; Dimson et al., 2015; Qiu and Ying, 2019), institutional investors' shareholding preference (Zhou et al., 2020), and agency structure (Cucari et al., 2018; Manita et al., 2018; Liu et al., 2022). However, few scholars have examined the economic consequences of ESG rating from the perspective of risk. This study supplements the existing research. 2) There are many ESG rating agencies, showing a state of a hundred schools of thought contending, but the rating quality is also varied. By studying the relationship between ESG ratings of different agencies and the stock price crash risk, this study discussed the impact of different ESG ratings on the financial market performance of enterprises, providing a reference for managers, investors, and scholars engaged in related research when choosing ESG rating agencies. 3) Some scholars have explored the relationship between enterprises' information transparency (Jin and Myers, 2006; Hutton et al., 2009), social responsibility (Huang and Li, 2020; Tu et al., 2020; Huang et al., 2022), governance (Kim et al., 2011a; Quan et al., 2016; Bhargava et al., 2017; Xia and Jia, 2019), diversified operation (Shao et al., 2020) and enterprise risk. However, no scholar has yet examined the impact of an enterprise's sustainable development capability on the stock price crash risk. This study explored the influencing factors of the stock price crash risk from the angles of environment, society, and governance, enriching the research in related fields.

The rest of this article is as follows: the second part compares and analyzes ESG ratings of different agencies; the third part is the research design of this article, namely, data source and model design; the fourth part is empirical analysis, which studies the relationship between ESG ratings of different agencies and the stock price crash risk; the fifth part is the result discussion and conclusion. By discussing the results of empirical analysis, the conclusion of this article is drawn; and the sixth part is the conclusion and suggestions, summarizing the main conclusions of this article and putting forward corresponding suggestions.

2 COMPARATIVE ANALYSIS OF ESG RATINGS

With increasing attention paid to ESG by enterprises, investors, and governments, more and more agencies have promulgated their own ESG evaluation systems. Currently, there are over 600 ESG rating agencies worldwide. Among them, the evaluation scope of Bloomberg, Morgan Stanley (hereinafter referred to as

TABLE 1 | Comparison of ESG rating systems of different agencies.

Rating agency	Release time	Time range	Data source	Indicator system	Rating method	Number of enterprises (as of 2021)
Bloomberg	2018	2011–2017 (Backtracking)	Public information of listed companies	3 dimensions	1–100 points	1000
		2018–2022	Regulatory departments News and public opinions NGO	300 data points		
FTSE	2018	2018–2022	Public information of listed companies Regulatory departments	3 dimensions 14 second-level indicators	1–5 points	730
			News and public opinions NGO	300 or more data points		
MSCI	2018	2018–2022	Public information of listed companies Regulatory departments	3 dimensions 10 second-level indicators	1–100 points	478
			News and public opinions NGO Enterprise communication channel	37 third-level indicators		
SSII	2018	2009–2017 (Backtracking)	Public information of listed companies	3 dimensions	9 levels: from C to AAA	4167
		2018–2022	Regulatory departments	14 second-level indicators		
			News and public opinions	26 third-level indicators		
STGE	2018	2015–2017 (Backtracking)	Public information of listed companies	3 dimensions	10 levels: 10: D to A+	755
		2018–2022	Regulatory departments	13 second-level indicators		
			News and public opinions Social agency survey	200 + data points		
CASVI	2019	2016–2018 (Backtracking)	Public information of listed companies	3 dimensions	10 basic levels: from D to AAA	478
		2019–2022		9 second-level indicators 27 third-level indicators 55 fourth-level indicators	10 enhanced levels: From B- to AA+	

MSCI), and FTSE Russell (hereinafter referred to as FTSE) include Chinese listed companies, and their evaluation has a certain authority. Although China's ESG evaluation system was built later, it is also developing rapidly with the implementation of the concept of green development and sustainable development in domestic enterprises. At present, there are about 20 ESG rating agencies in China, among which Sino-Securities Index Information (hereinafter referred to as SSII), SynTao Green Finance (hereinafter referred to as STGF), and China Alliance of Social Value Investment (hereinafter referred to as CASVI) are the representatives. ESG ratings of different agencies have certain differences in coverage, rating method, and indicator, which also affect the choice of investors and enterprises. **Table 1** shows the comparison of ESG rating systems of different agencies.

(1) From the perspective of the company coverage, the ESG rating of SSII has the widest coverage, with 4,167 companies, basically, namely, all A-share listed companies. Other rating agencies in China cover 300–800 companies, and most of them are based on CSI 300 or CSI 800 constituent stock. Most of the reference data of international rating agencies cover the whole world, among which Bloomberg's ESG rating covers the largest number of Chinese companies, with 1,000 listed companies. The ESG systems of FTSE and MSCI cover less than 800 Chinese enterprises, respectively.
(2) In terms of the release date, STGF, together with Caixin Media and BusinessBigData, released the LANDSEA·China ESG Prosperity Index to describe the national macro-ESG development. Then, in June 2018, STGF announced the release of China's first A-share listed company ESG database and evaluation system. Other local Chinese agencies, such as SSII and CASVI, also started to release ESG ratings in 2018 and 2019, respectively. ESG indicators of international agencies were built earlier, but they included Chinese listed companies in 2018 and later. In terms of the time range, FTSE and MSCI include the data released from 2018 to the latest 2022. The data of STGF and CASVI can date back to 2015 and 2016, respectively. The ESG ratings of

SSII and Bloomberg cover a wider time range, dating back to 2009 and 2010, respectively.

(3) From the data analysis, the data of ESG rating agencies mainly come from the official website and announcements of listed companies as well as from regulatory authorities, news, and public opinions. In addition, the data source of MSCI and FTSE includes data from NGOs and industry associations, and the data source of MSCI also includes corporate communication channels. STGF has the channels of a social agency investigation. On the analysis method, SSII adopts a web crawler and semantic analysis naming combined with entity recognition when processing data; CASVI has built a "social value evaluation model of listed companies" which consists of two parts: "screening submodel" and "scoring submodel."

(4) From the perspective of rating indicators, the ESG evaluation system generally includes three levels of indicators. The first-level indicators include three dimensions, namely, environment, society, and corporate governance. The second-level indicators are the subdivision issues under the above three dimensions. The third-level indicators are the specific indicators and data points under key issues. In terms of the first-level indicators, all agencies include three dimensions, namely, environment, society, and governance. On this basis, CASVI has added the indicator of economic benefits and conducted ESG evaluation on enterprises from the perspective of objectives, methods, and benefits. This is also the difference between the evaluation model of CASVI and those of other agencies. For first-level indicators related to environment and society, the choices of different agencies are mostly similar. However, in terms of corporate governance indicators, SSII only chose two aspects, management structure and shareholders' equity, without including salary management and information disclosure indicators that most agencies and investors are concerned about. STGF and MSCI pay extra attention to anti-corruption indicators. On the whole, different countries have different concerns about economic activities at different times, and the ESG evaluation system should also observe the customs of the place and keep pace with the times. For example, the ESG evaluation indicator system of SSII incorporates more indicators that are in line with the current development stage of China, such as the punishment of CSRC and targeted poverty alleviation.

(5) Judging from the evaluation methods, ESG evaluation methods of different agencies can basically be divided into two categories: "rating" and "scoring". FTSE, MSCI, and Bloomberg choose "scoring" ESG; SSII, STGF, and CASVI choose "rating" ESG. In the "scoring" evaluation, FTSE sets scores to 0–5, while MSCI and Bloomberg set scores to 0–100. In the "rating" evaluation, agencies usually divide enterprises into 7–10 grades, while CASVI has set up 10 enhanced grades from B- to AA+ in addition to the 10 basic grades from D to AAA to slightly adjust the enterprise scores.

(6) Judging from the rating results, the specific ESG rating system of each agency is different, and their rating results for the company are also different. Some scholars used 500 companies listed in the United States from 2010 to 2017 as samples and found that the average correlation among six rating agencies, such as MSCI is 0.45. Among them, the average correlation of corporate governance was the lowest, while the average correlation of environment was the highest (Gibson Brandon et al., 2021). Some scholars have also studied the correlation between ESG ratings of China's STGF and SSII, and found that the correlation coefficient between them is about 0.17 (Shen et al., 2022). Berg et al. (2019) studied five ESG rating agencies, such as MSCI, and found that the differences among ESG ratings of different agencies mainly come from the differences in scope, measurement, and weight, and the overall differences are mainly caused by measurement differences.

To sum up, ESG's scoring method includes quantitative and qualitative elements, namely, different weighting factors of each industry, and subjective judgments of enterprises and relevant indicators according to the information disclosed by enterprises and other public information scores aggregated to form an overall score. However, the evaluation methods of ESG rating agencies are not consistent, and different information service providers use different indicators, methods, and basic data, and different subcategories and different numbers, weights, and scopes of indicators. Especially, there are obvious differences between overseas agencies' ESG evaluation of Chinese enterprises and that of domestic agencies, which is mainly reflected in the evaluation indicators and the important weight distribution of indicators. However, the definition and statement of ESG-related indicators by Chinese rating agencies are not uniform. This reduces the comparability among evaluation systems and affects the consistency of ESG evaluation.

3 RESEARCH DESIGN

3.1 Sample Selection and Data Sources

In this study, listed companies with ESG ratings in Shanghai and Shenzhen A-shares are selected as research samples. Since almost all the rating agencies to be evaluated in this study began to publish their ESG ratings of Chinese listed companies in 2018, to investigate the changes in stock price crash risk before and after different ESG agencies published their ratings, this study selected 2 years before and after ESG publishing as the research interval. That is, the sample period is from 2016 to 2020. ESG rating data of enterprises come from the WIND database and Bloomberg etc., and financial accounting data of enterprises come from the CSMAR database. Referring to the practices of existing related literatures, we screened the initial samples as follows to avoid the influence of abnormal samples: 1) the samples of financial enterprises are excluded because the financial statement structure and business model of the financial industry are quite different from those of general non-financial enterprises; 2) the samples of ST and *ST companies are eliminated because companies with troubled operations are more likely to have the stock price crash risk; and 3) company samples with missing data are eliminated. In addition, all continuous variables are winsorized at 1 and 99 percentiles to reduce the influence of outliers.

3.2 Definition and Measurement of Variables

3.2.1 Explained Variables

As for the measurement method of stock price crash risk, this article used the methods of Chen et al. (2001), Kim et al. (2011b), and Xu et al. (2012) for reference to calculate the stock price crash risk of each enterprise. First of all, the following regression was made to the weekly returns of stocks:

$$r_{j,t} = \alpha_j + \beta_{1,j} r_{m,t-1} + \beta_{2,j} r_{i,t-1} + \beta_{3,j} r_{m,t} + \beta_{4,j} r_{i,t} + \beta_{5,j} r_{m,t+1} + \beta_{6,j} r_{i,t+1} + \varepsilon_{j,t}. \quad (1)$$

In model **(1)**, $r_{j,t}$ is the weekly return rate of the *j*th stock in the *t*th period considering the reinvestment of cash dividend; $r_{m,\ t}$ is the weekly return rate of the market weighted by the circulating market value in the *t*th period; $r_{i,t}$ is the weekly return rate of the industry calculated by weighting the circulating market value of industry i; $\varepsilon_{j,t}$ represents the part of the weekly stock return rate of the *j*th company, that is, not explained by the weekly market return rate and the weekly industry return rate. If $\varepsilon_{j,t}$ is negative and the value is smaller, then the degree to which the weekly stock price crash risk of the *j*th company deviates negatively from the weekly stock return rate of the market and industry is greater, which means that the stock price crash risk of the company is greater. To make $\varepsilon_{j,\ t}$ with highly deviated distribution present normal distribution, the logarithm of $\varepsilon_{j,\ t}$ was converted to obtain the firm-specific weekly returns $W_{j,t}$,t of each firm.

$$W_{j,t} = ln\left(1 + \varepsilon_{j,t}\right). \quad (2)$$

Based on model **(2)**, this study constructed the stock price crash variable: negative coefficient of skewness, *NCSKEW*.

$$NCSKEW_{j,t} = -\left[n(n-1)^{3/2} \sum W_{j,t}^3\right] \Big/ \left[(n-1)(n-2)\left(\sum W_{j,t}^2\right)^{3/2}\right]. \quad (3)$$

In model **(3)**, n is the number of trading weeks of j stock in a year. The larger the value of *NCSKEW*, the more serious the skewness coefficient, and the greater the stock price crash risk of the company.

3.2.2 Explanatory Variables

Firstly, this study constructed a dummy variable (*ESG*): whether the enterprise is included in the ESG rating. The value takes one in the year when the enterprise was included in the ESG rating and in the following years, otherwise, it takes 0. Although the year in the ESG databases of agencies, such as SSII and Bloomberg, can be traced back to around 2010, all companies' *ESG* values were 0 for years before 2018 because the database was launched in that year. According to the specific ESG evaluation results (*ESGL*), the ESG evaluation results of different agencies can basically be divided into "rating" and "scoring". For "scoring" ESG, FTSE, MSCI, and Bloomberg select the original score to represent *ESGL*; for "rating" ESG, SSII, STGF, and CASVI assign values from one and from low to high and use the values to represent ESG evaluation results. It should be noted that CASVI sets ten enhanced grades from B- to AA+ in addition to the ten basic grades from D to AAA. For the enhanced grades, they are concrete to the last two decimal places. For example, B+, BB- and BB are assigned values of 5.33, 5.67, and 6 respectively.

3.2.3 Other Control Variables

With reference to the related literature on the stock price crash risk, this study controlled the company SIZE (*SIZE*), asset-liability ratio (*LEV*), CASH holding level (*CASH*), return on total assets (*ROA*), book-to-market ratio (*BM*), Tobin Q value (*TQ*), the largest shareholder's shareholding ratio (*TOP1*), property right nature (*SOE*), the mean of firm-specific weekly returns over the fiscal year (*RET*), the standard deviation of the mean of firm-specific weekly returns over the fiscal year (*SIGMA*), accounting information transparency (*DA*). In addition, this study also introduced dummy variables of year and industry to control the related influences. Specific definitions and measurements of variables are shown in **Table 2**.

3.3 Model Setting

Firstly, to explore the impact of incorporating the ESG rating system on the risk of stock price crash risk, this article constructs a model **(4)**. Because other information such as the current ESG performance of the enterprise will be fed back to the investors in the capital market, which will affect the risk of the stock price crash in the next period of the enterprise, this study dealt with the explanatory variables and all control variables in a lag period and controlled the fixed effects at time and company level. In terms of the time range, the model includes the year when the ESG evaluation system was launched, 2 years before and after, and the period from 2016 to 2020. CASVI launched the rating system in 2019, so the range of data selection of this agency is 2017–2020.

$$NCSKEW_{j,t+1} = \alpha_j + \beta_1 ESG_{j,t} + \beta_2 NCSKEW_{j,t} + \beta_3 ControlVariable_{i,t} + YEAR + FIRM + \varepsilon_{j,t}. \quad (4)$$

Model **(4)** mainly focuses on the coefficient β_1 of *ESG*. When the coefficient β_1 is significantly negative below the level of 10%, it indicates that the stock price crash risk is significantly reduced after the listed company is included in the ESG rating. This suggests that the information asymmetry between enterprises and investors can be significantly alleviated after the ESG rating of this agency is released, which then alleviates the stock price crash risk. In addition, the coefficient β_1 of ESG ratings issued by different agencies can be compared at the same time. The larger the ESG rating coefficient β_1 of a rating agency, the more effective of ESG rating is in alleviating information asymmetry.

To study the relationship between ESG evaluation results and stock price crash risk, this article set up a model **(5)**. This model controls not only variables but also time and industry.

TABLE 2 | Variable definition.

Variable symbol	Variable name	Variable definition
NCSKEW	Negatively skewed return coefficient	Indicating the stock price crash risk. See model **(3)** for the specific calculation process. The larger the NCSKEW, the greater the stock price crash risk
ESG	Whether ESG is included	When a listed company is included in the ESG rating, the value of the current year and following years is 1, otherwise it is 0
ESGL	ESG evaluation	See above for specific definitions
SIZE	Company size	The natural logarithm of total assets at the end of the period
LEV	Asset-liability ratio	Total liabilities/total assets at the end of the period
CASH	Cash holdings	Monetary capital/total assets at the end of the period
ROA	Return on total assets	Net profit of the enterprise/[(total assets at the end of the period+total assets at the beginning of the period)/2]
BM	Book-to-market ratio	Total owner's equity/company market value
TQ	Enterprise value	(Market value of equity+book value of total liabilities)/book value of total assets
TOP1	The shareholding ratio of the largest shareholder	The shareholding ratio of the largest shareholder
SOE	Nature of the property right	For state-owned enterprises, the value is 1, otherwise it is 0
RET	Average weekly return rate	the mean of firm-specific weekly returns over the fiscal year, in which the weekly specific return rate is obtained by **(1)**, **(2)**
SIGMA	Income fluctuation	The standard deviation of the company's weekly specific return rate in the current year, in which the weekly holding return rate is obtained by **(1)**, **(2)**
DA	Accounting information transparency	Discretionary accrual profit of enterprises

TABLE 3 | Descriptive statistics of ESG results of agencies.

Agency	Observed value	Average	Median	Maximum	Minimum	Sd
Bloomberg (2018–2020)	3,151	22.806	21.074	64.115	5.785	8.066
FTSE (2018–2020)	1,247	1.208	1.100	3.900	0.300	0.505
MSCI (2018–2020)	1,243	32.019	30.062	82.132	0.657	15.291
SSII (2018–2020)	9,332	6.427	6.000	9.000	1.000	1.216
STGF (2018–2020)	2,018	4.227	4.000	7.000	2.000	0.939
CASVI (2019–2020)	733	6.758	6.670	9.330	1.000	1.199

$$NCSKEW_{j,t+1} = \alpha_j + \gamma_1 ESGL_{j,t} + \gamma_2 NCSKEW_{j,t} + \gamma_3 ControlVariable_{i,t} + YEAR + IND + \varepsilon_{j,t}. \tag{5}$$

Model **(5)** mainly focuses on the coefficient γ_1 of *ESGL*. If the coefficient γ_1 of *ESGL* should be significantly negative below the level of 10%, it means that the higher the ESG evaluation result of a listed company, the lower the stock price crash risk of the company. This suggests that the agency's ESG rating can be an effective decision-making basis for investors, helping investors accurately identify potential ESG values and risks. In addition, the *ESGL* coefficient γ_1 of different agencies can be compared at the same time. The larger *ESGL* the coefficient γ_1 of a rating agency, the higher the investment reference value of the ESG rating.

4 EMPIRICAL ANALYSIS

4.1 Descriptive Statistics

Descriptive statistical results of ESG rating are shown in **Table 3**. From the results of descriptive statistics, it can be seen that the ESG rating of SSII contains the largest number of Chinese listed companies, and its sample size is also the largest. CASVI has the smallest sample size because of its late launch. The average ESG rating of each agency is slightly larger than its median, and the ESG rating results tend to be slight to the right. In addition, among the ratings of all agencies, MSCI has the largest standard deviation of 15.291, and FTSE has the smallest standard deviation of 0.505.

4.2 Correlation Analysis

Table 4 shows the correlation coefficients between ESG evaluations of agencies. It can be seen that ESG ratings of all agencies are significantly positively correlated, but the correlation coefficients are all below 0.7. It is worth noting that the correlation coefficients of international agencies Bloomberg, FTSE, and MSCI are all above 0.5, while the correlation coefficients of ESG ratings of domestic rating agencies are all less than 0.4. This reflects that there are more similarities in the rating methods among international agencies, and their evaluation systems are more consistent. On the contrary, China's ESG rating started late, lacking the support of relevant policies and systems, and lacking financial market supervision. The evaluation systems adopted by different agencies in China may be quite different, resulting in low correlation coefficients.

TABLE 4 | Correlation analysis.

	Bloomberg	FTSE	MSCI	SSII	STGF	CASVI
Bloomberg	1	0.625***	0.596***	0.366***	0.550***	0.499***
FTSE	0.650***	1	0.524***	0.326***	0.535***	0.405***
MSCI	0.643***	0.564***	1	0.244***	0.402***	0.402***
SSII	0.287***	0.273***	0.227***	1	0.283***	0.356***
STGF	0.446***	0.469***	0.346***	0.233***	1	0.365***
CASVI	0.336***	0.261***	0.265***	0.319***	0.289***	1

Pearson correlation coefficient is in the upper right corner, and Spearman correlation coefficient is in the lower left corner.

TABLE 5 | Impact of ESG rating on the stock price crash risk.

	International agencies			Chinese agencies		
Variables	Bloomberg $NCSKEW_{t+1}$ (1)	FTSE $NCSKEW_{t+1}$ (2)	MSCI $NCSKEW_{t+1}$ (3)	SSII $NCSKEW_{t+1}$ (4)	STGF $NCSKEW_{t+1}$ (5)	CASVI $NCSKEW_{t+1}$ (6)
ESG	0.016	-0.064**	-0.101***	0.310	-0.036	-0.148***
	(0.532)	(-2.009)	(-2.965)	(1.016)	(-1.197)	(-3.572)
NCSKEW	-0.217***	-0.217***	-0.216***	-0.216***	-0.216***	-0.268***
	(-24.155)	(-24.147)	(-24.088)	(-24.191)	(-24.058)	(-26.686)
LEV	-0.307***	-0.332***	-0.340***	-0.312***	-0.324***	-0.363**
	(-2.677)	(-2.884)	(-2.958)	(-2.724)	(-2.816)	(-2.437)
CASH	0.141	0.142	0.142	0.140	0.141	0.031
	(1.230)	(1.231)	(1.230)	(1.215)	(1.223)	(0.234)
SIZE	0.184***	0.193***	0.207***	0.185***	0.191***	0.218***
	(5.054)	(5.251)	(5.529)	(5.072)	(5.197)	(4.922)
TQB	0.026**	0.028***	0.031***	0.027**	0.028***	0.019
	(2.499)	(2.689)	(2.916)	(2.550)	(2.678)	(1.560)
ROAB	-0.000	-0.011	-0.010	-0.001	-0.003	-0.002
	(-0.001)	(-0.052)	(-0.051)	(-0.006)	(-0.012)	(-0.008)
SOE	0.004	0.003	0.003	0.003	0.003	-0.035
	(0.069)	(0.046)	(0.045)	(0.049)	(0.053)	(-0.481)
TOP10	-0.001	-0.000	-0.000	-0.001	-0.000	0.000
	(-0.358)	(-0.230)	(-0.275)	(-0.306)	(-0.280)	(0.099)
BM	-0.819***	-0.849***	-0.884***	-0.825***	-0.843***	-0.915***
	(-9.054)	(-9.408)	(-9.597)	(-9.176)	(-9.296)	(-8.510)
RET	1.056	0.413	0.032	0.886	0.527	-1.562
	(0.757)	(0.298)	(0.023)	(0.645)	(0.377)	(-0.981)
SIGMA	-0.955*	-0.878*	-0.859*	-0.920*	-0.880*	-0.897
	(-1.931)	(-1.780)	(-1.741)	(-1.866)	(-1.776)	(-1.633)
DA	-0.019	-0.022	-0.020	-0.017	-0.021	-0.089
	(-0.173)	(-0.199)	(-0.188)	(-0.153)	(-0.197)	(-0.693)
YEAR	YES	YES	YES	YES	YES	YES
FIRM	YES	YES	YES	YES	YES	YES
_cons	-3.851***	-4.069***	-4.350***	-3.878***	-4.024***	-4.447***
	(-4.933)	(-5.140)	(-5.405)	(-4.961)	(-5.087)	(-4.712)
N	13919	13919	13919	13919	13918	11765
adj. R^2	0.098	0.098	0.098	0.098	0.098	0.117

** * *, * *, and * indicate being significant at 1%, 5% and 10% levels, respectively. The brackets below the regression coefficient are T values that are miscalculated by using the clustering robust standard. Same as the following table.*

4.3 Analysis of Results

4.3.1 Impact of Inclusion in ESG Rating on the Stock Price Crash Risk

The impact of inclusion in ESG rating on the stock price crash risk of Chinese listed companies is shown in **Table 5**. In column (2) and column (3) of **Table 5**, the influence coefficients of ESG ratings of FTSE and MSCI on the stock price crash risk are −0.064 (p value < 0.05) and −0.101 (p value < 0.01), respectively. This indicates that compared with Chinese enterprises that are not included in the ESG ratings of FTSE and MSCI, the stock price crash risk of Chinese enterprises that are included in the ESG ratings of FTSE and MSCI is lower. According to column (1) in **Table 5**, the influence coefficient of ESG rating on the stock price crash risk is 0.016 (p value > 0.1). This shows that the inclusion in Bloomberg's ESG rating will not significantly affect the stock price crash risk of Chinese companies. The impact of inclusion in

TABLE 6 | The impact of ESG evaluation on the stock price crash risk.

	International agencies			Chinese agencies		
Variables	Bloomberg *NCSKEW$_{t+1}$* (1)	FTSE *NCSKEW $_{t+1}$* (2)	MSCI *NCSKEW $_{t+1}$* (3)	SSII *NCSKEW $_{t+1}$* (4)	STGF *NCSKEW $_{t+1}$* (5)	CASVI *NCSKEW $_{t+1}$* (6)
ESGL	-0.004**	0.030	-0.002*	-0.002	-0.009	-0.022
	(-2.263)	(0.722)	(-1.833)	(-0.241)	(-0.552)	(-0.741)
NCSKEW	0.044**	0.026	0.016	0.046***	0.042*	0.027
	(2.403)	(0.866)	(0.551)	(4.200)	(1.909)	(0.682)
LEV	-0.110	-0.001	-0.235*	-0.071	-0.230**	-0.345*
	(-1.172)	(-0.006)	(-1.692)	(-1.342)	(-2.033)	(-1.754)
CASH	-0.149	-0.007	-0.222	-0.138*	-0.248	-0.154
	(-1.113)	(-0.038)	(-1.199)	(-1.873)	(-1.636)	(-0.539)
SIZE	0.063***	0.024	0.047*	0.030***	0.065***	0.088*
	(3.879)	(0.848)	(1.785)	(3.353)	(3.078)	(1.914)
TQB	0.033**	0.016	0.015	0.003	0.005	0.038*
	(2.513)	(1.004)	(1.122)	(0.413)	(0.399)	(1.830)
ROAB	0.644**	0.483	0.210	0.334*	0.408	-0.067
	(2.118)	(0.972)	(0.433)	(1.945)	(1.107)	(-0.100)
SOE	-0.043	0.058	0.002	-0.020	-0.034	0.016
	(-1.530)	(1.345)	(0.051)	(-1.076)	(-1.037)	(0.267)
TOP10	-0.002**	-0.003*	-0.001	-0.000	-0.002**	-0.002
	(-2.025)	(-1.931)	(-0.998)	(-0.176)	(-2.015)	(-0.950)
BM	-0.091	-0.205*	-0.250**	-0.232***	-0.309***	-0.309**
	(-1.153)	(-1.719)	(-2.109)	(-4.351)	(-3.261)	(-2.024)
RET	5.538**	6.557*	6.348**	6.886***	5.585**	-0.222
	(2.309)	(1.723)	(2.100)	(4.756)	(2.054)	(-0.044)
SIGMA	0.821	0.965	0.628	-0.375	1.118	1.386
	(0.978)	(0.665)	(0.453)	(-0.772)	(1.065)	(0.722)
DA	-0.275	-0.425	-0.434	-0.247**	-0.497**	-0.634
	(-1.332)	(-1.419)	(-1.619)	(-2.121)	(-2.076)	(-1.454)
YEAR	YES	YES	YES	YES	YES	YES
IND	YES	YES	YES	YES	YES	YES
_cons	-1.716***	-0.867	-1.113*	-0.920***	-1.499***	-2.241**
	(-4.764)	(-1.259)	(-1.785)	(-4.596)	(-3.172)	(-2.257)
N	3151	1247	1243	9332	2018	733
adj. R^2	0.063	0.071	0.072	0.031	0.071	0.085

the Chinese ESG rating on the stock price crash risk is shown in **Table 5** (4)–(6). The regression results show that the stock price crash risk has not changed significantly when enterprises are included in the ESG evaluation systems of SSII and STGF, but it has dropped significantly when enterprises are included in the ESG evaluation system of CASVI.

4.3.2 Impact of ESG Rating Results on the Stock Price Crash Risk of Enterprises

The regression results of international agencies' ESG evaluation on the stock price crash risk are shown in **Table 6** (1)–(3). It can be seen that when the ESG data of Bloomberg and MSCI are used, the regression coefficients of ESG rating on the stock price crash risk are –0.004 (p value < 0.05) and –0.002 (p value < 0.1), respectively. This indicates that the higher the ESG evaluations of Bloomberg and MSCI on Chinese listed companies, the lower the stock price crash risk of these listed companies. When using the ESG data of FTSE, the coefficient of ESG is not significant, indicating that the ESG rating results of FTSE will not significantly affect the stock price crash risk of Chinese listed companies. The regression coefficients of ESG ratings of domestic agencies on the stock price crash risk of enterprises are shown in **Table 6** (4)–(6). The regression coefficients of the ESG rating of domestic agencies on the stock price crash risk of listed companies are all not significant, which is also in sharp contrast with international agencies. This shows that the local ESG ratings in China will not significantly affect the stock price crash risk of listed companies.

4.3.3 Impact of Different Indicators on the Stock Price Crash Risk of Enterprises

Bloomberg and MSCI publish not only ESG comprehensive rating results, but also specific ratings in three dimensions, namely, environment (E), society (S), and governance (G), to the international community. Columns (1) and (3) of **Table 6** show that the comprehensive ESG rating results of Chinese enterprises by Bloomberg and MSCI significantly alleviate the stock price crash risk of these enterprises. Do these specific rating results have the same impact on the stock price crash risk? To further study the impact of environment, society, and governance on the performance of enterprises in the capital market, this article explored the relationship between E, S, and G and the stock price crash risk of listed companies based on the rating data of Bloomberg and MSCI from 2018 to 2020. The regression results

TABLE 7 | Impact of ESG sub-indicators on the stock price crash risk.

	Bloomberg			MSCI		
Variables	***NCSKEW*$_{t+1}$** (1)	***NCSKEW*$_{t+1}$** (2)	***NCSKEW*$_{t+1}$** (3)	***NCSKEW*$_{t+1}$** (4)	***NCSKEW*$_{t+1}$** (5)	***NCSKEW*$_{t+1}$** (6)
Env	-0.002**			-0.003**		
	(-2.138)			(-2.020)		
Soc		-0.002			-0.001	
		(-1.420)			(-0.860)	
Gov			-0.001			-0.010***
			(-1.020)			(-3.733)
NCSKEW	0.014	0.017	0.017	0.046**	0.046**	0.044**
	(0.487)	(0.573)	(0.587)	(2.399)	(2.433)	(2.293)
LEV	-0.241*	-0.233*	-0.230*	-0.164*	-0.163*	-0.150
	(-1.729)	(-1.676)	(-1.658)	(-1.674)	(-1.652)	(-1.534)
CASH	-0.233	-0.220	-0.221	-0.151	-0.145	-0.116
	(-1.256)	(-1.186)	(-1.196)	(-1.069)	(-1.026)	(-0.820)
SIZE	0.054**	0.043	0.030	0.060***	0.051***	0.061***
	(2.008)	(1.630)	(1.235)	(3.530)	(3.141)	(3.868)
TQB	0.015	0.015	0.015	0.038***	0.039***	0.039***
	(1.102)	(1.105)	(1.078)	(2.609)	(2.649)	(2.664)
ROAB	0.211	0.203	0.185	0.495	0.503	0.489
	(0.433)	(0.419)	(0.381)	(1.522)	(1.548)	(1.512)
SOE	0.006	0.003	-0.001	-0.039	-0.041	-0.026
	(0.154)	(0.068)	(-0.012)	(-1.326)	(-1.405)	(-0.879)
TOP10	-0.001	-0.001	-0.001	-0.002*	-0.002*	-0.002*
	(-0.922)	(-0.961)	(-0.994)	(-1.757)	(-1.869)	(-1.822)
BM	-0.259**	-0.263**	-0.225*	-0.070	-0.060	-0.057
	(-2.180)	(-2.193)	(-1.901)	(-0.834)	(-0.716)	(-0.692)
RET	6.383**	6.251**	6.842**	5.893**	5.902**	6.222**
	(2.120)	(2.052)	(2.272)	(2.347)	(2.350)	(2.474)
SIGMA	0.592	0.674	0.580	0.725	0.734	0.544
	(0.427)	(0.487)	(0.420)	(0.819)	(0.828)	(0.617)
DA	-0.447*	-0.438	-0.421	-0.292	-0.282	-0.276
	(-1.669)	(-1.629)	(-1.570)	(-1.342)	(-1.298)	(-1.275)
YEAR	YES	YES	YES	YES	YES	YES
IND	YES	YES	YES	YES	YES	YES
_cons	-1.301**	-1.061*	-0.744	-1.676***	-1.493***	-1.317***
	(-2.026)	(-1.665)	(-1.236)	(-4.420)	(-4.093)	(-3.714)
N	1243	1243	1243	2903	2903	2903
adj. R^2	0.073	0.071	0.070	0.061	0.060	0.065

are shown in **Table 7**. It can be seen that in Bloomberg's data, the regression coefficient corresponding to *E* indicators of the enterprise is −0.002(p value < 0.05), while the coefficients corresponding to the *S* and *G* indicators are not significant; in MSCI data, the corresponding influence coefficients of enterprises *E* and *G* are −0.003 (p value < 0.05) and −0.01 (p value < 0.01) respectively. This indicates that the better the company's performance in terms of *E* indicators disclosed by Bloomberg and *E* and *G* indicators disclosed by MSCI, the lower the stock price crash risk.

5 DISCUSSION

(1) After being included in the ESG evaluation system, the stock price crash risk of enterprises will be affected, but the market reaction to ESG rating varies from agency to agency. After being included in the ESG ratings of MSCI, FTSE, and CASVI, the stock price crash risk of listed companies is significantly reduced. However, the inclusion in the ESG ratings of Bloomberg, SSII and STGF will not significantly affect the stock price crash risk. Kim et al. (2014) and Ye et al. (2015) believe that the higher the information transparency of enterprises, the lower the stock price crash risk. After an enterprise is included in the ESG rating, its ESG performance is disclosed to the market, and its information transparency is also improved, thus reducing the stock price crash risk. According to the test results, it can be found that compared with other rating agencies, ESG ratings of MSCI, FTSE, and CASVI have played a better role in information transmission. The possible reason is that although only a small number of Chinese listed companies are covered in FTSE, MSCI, and ESG evaluation systems, they generally have high social attention. When these listed companies that are widely concerned among investors are included in the ESG rating, they can better alleviate information asymmetry

and improve information transparency, thus alleviating the stock price crash risk.

(2) The higher the ESG rating, the lower the stock price crash risk. The influence coefficients of ESG ratings of different agencies on the stock price crash risk are mostly negative. The influence coefficients of ESG ratings of Bloomberg and MSCI on the stock price crash risk are significantly negative at significance levels of 5% and 10%. This shows that the higher the ESG rating of an enterprise, the more confidence investors have in it, and the lower the stock price crash risk of the enterprise. As the information disclosure of enterprises' environment and society will affect investors' decisions (Aerts et al., 2008), when the disclosure quality is high, it will also increase investors' confidence, thus suppressing the stock price crash risk of enterprises (Kim et al., 2014). However, the ESG ratings of FTSE and local agencies in China cannot significantly affect the stock price crash risk of listed companies. Compared with other rating agencies, the ESG rating results of Bloomberg and MSCI are more trusted by investors. With the improvement of the ESG rating of enterprises by these two agencies, investors have more confidence in enterprises. Bloomberg and MSCI were established in 1981 and 1935, respectively, while FTSE and other four agencies were established after the 21st century. The results show that investors may trust the ESG ratings of senior agencies more. At the same time, Bloomberg and MSCI have accumulated more users during their years of operation, thus attracting more investors' attention to the market. Of course, this result cannot rule out that the ESG ratings of Bloomberg and MSCI may be more reasonable.

(3) The higher the rating time coverage, the greater or more significant the impact of ESG evaluation on the stock price crash risk. According to the theory of limited attention, investors' time and energy are limited, and it is difficult for them to obtain and understand all the information in the market. Therefore, investors will choose more attractive information to analyze and judge, and apply the judgment results to the stock market, thus causing the change in the company's stock price. Rating agencies with a wide range of time make it easier for investors to obtain the historical ESG data of enterprises and make a comprehensive evaluation of the long-term performance of enterprises. Bloomberg's ESG rating covers more than 1,000 A-share companies in China, and the coverage time can be traced back to 2011. Its time coverage is significantly higher than that of other international ESG agencies. Thus, its ESG rating is more comparable. Investors will also pay more attention to the data disclosed by this agency when examining the ESG performances of different companies.

(6) In terms of specific indicators, investors pay more attention to the environment (E) performance of enterprises. With the proposal of China's "carbon peaking and carbon neutrality" goals, more and more investors pay attention to the environmental governance ability of enterprises, especially in China. Therefore, whether the ESG rating of Bloomberg or that of MSCI, the environment (E) performance of enterprises significantly affects their stock price crash risk.

6 CONCLUSION

This article has evaluated three international ESG ratings, such as Bloomberg, and three Chinese ESG ratings, such as SSII, by empirically testing the impact of ESG ratings on the stock price crash risk. The findings are as follows: First, seen from the results before and after being included in the ESG rating, the ESG rating systems of FTSE, MSCI, and CASVI can play a better role in information transmission. After being included in the ratings of these three agencies, the stock price crash risk of enterprises is significantly reduced. Secondly, seen from the ESG rating results, the better the ESG evaluation results of listed companies by Bloomberg and MSCI, the lower the stock price crash risk. The ESG evaluation results of these agencies are more trusted by investors, and their high ESG rating results can effectively enhance investors' confidence in enterprises and reduce the stock price crash risk. Third, compared with social indicators, investors pay more attention to the environmental performance of enterprises. Enterprises with high environment scores have lower stock price crash risk.

The findings of this article have the following enlightenment for China to improve its ESG system, formulate ESG disclosure policies, and improve the market function of ESG rating:

(1) Promoting the standardization of the ESG evaluation system and building a resilient evaluation system. At present, agencies at all levels have their own unique choices when choosing specific indicators and data points of ESG evaluation, and the calculation methods and weights of specific indicators are also different, thus affecting the consistency of indicators and methods of different agencies. A standardized ESG evaluation system can ensure that different agencies have a unified general direction in data judgment, reduce unfavorable subjective judgments, improve the toughness of ESG indicators, and enhance investors' confidence in the data of the agencies.

(2) Improving the ESG information disclosure system and building a disclosure mechanism suitable for local situations. At present, the ESG data of each agency mainly comes from publicly available information, such as corporate annual reports and social responsibility reports, and it is difficult to fully and truly understand the ESG situation of enterprises. At the government level, China has issued the policy documents related to ESG disclosure, such as the *Guide to Social Responsibility* and the *Governance Guidelines for Listed Companies*. On this basis, China should continue to improve ESG disclosure policies and promote the improvement of enterprise information disclosure quality in light of the actual situation of investment and market in China.

(3) China's rating agencies should strengthen publicity to increase investors' attention. It is found that the ESG

ratings issued by the late-established agencies have not received enough attention from investors, and their results have no significant relationship with the stock price crash risk. Therefore, China's rating agencies should strengthen the publicity of their ESG rating results and increase the exposure of their own ESG rating, thus improving the usability of their ESG rating results in the financial market.

(4) Communication among rating agencies should be strengthened. Rating indicators and methods should be optimized, and the ESG evaluation model should be improved. It is found that the ESG ratings of senior agencies are easier to gain the trust of investors, and their results are significantly related to the stock price crash risk. By learning from the rating experience of other rating agencies, introducing new important indicators to replace the backward ones, and adjusting the rating methods, it is beneficial to further improve the ESG evaluation system, strengthen the standardization of ESG rating, increase the recognition of investors, and then, improve the usability of ESG rating results in the financial market.

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

SiL and ShL led the conceptual design of the manuscript, SiL and PY wrote the initial drafts, SiL advised the formal analysis, and all authors reviewed the manuscript and provided comments and feedback.

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Data element embedding and firm performance: The influence of ESG investment

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ESG is a brand-new concept about how environmental, social and corporate governance supports sustainable development in enterprises. However, little research is done on how to reshape the internal mechanism by which data element embedding drives enterprise performance based on the brand-new sustainable concept. From the perspective of contingency theory and organizational agility, a conceptual model including ESG investment, data element embedding, organizational agility and environmental uncertainty is constructed to study the internal mechanism by which data element embedding affects enterprise performance. The model is empirically researched through the data obtained from the survey of 287 manufacturing enterprises in China. The results show that, ESG investment and external data element embedding impose no direct impact on enterprise performance, but create an indirect impact through organizational agility; environmental uncertainty negatively moderates the effect of ESG investment on organizational agility. Through the hierarchical analysis of ESG investment and data elements embedded in enterprise performance, the value creation mechanism of data elements is revealed, which enriches and expands the theory of data elements and organizational agility, and provides enlightenment for ESG investment to drive the value creation of data elements.

KEYWORDS

ESG investment, data element, organizational agility, enterprise performance, environmental uncertainty

Introduction

Under the background of "Internet + manufacturing", enterprises are faced with fierce market competition and changing consumer demands. Consumers hope that enterprises can respond to their individual needs through different channels, and change from the original pursuit of product quality to pursuit of consumer experience. This change makes the large-scale mass production model in the industrial economy era no longer appropriate, and enterprises need timely and accurate data to coordinate internal and external business activities of the organization, which makes data one of the basic elements in business success (Moyano-Fuentes and Martínez-Jurado, 2016). An enterprise is an organizational form linked with the effective allocation of resources. In essence, the competition among enterprises is a battle over the resource allocation efficiency. The accuracy, timeliness and effectiveness of resource allocation by enterprises is based on the correct data transmission inside and outside the organization, and the full mining and effective use of data increases the allocation and use efficiency of economic resources. Like traditional production factors, data factors can directly improve the enterprise production efficiency, but the difference between data factors and other factors is that when data factors are embedded in any factor such as labor, capital, and technology, it will produce a value multiplication effect. Seen from long-term development trends, data elements will eventually be embedded in production links on a large scale, thus increasing total factor productivity and creating an important impact on the resource allocation efficiency, which results in increased labor productivity, shortened production time, reduced production costs and circulation costs. In this way, it increases the final product value, accelerates the reproduction cycle of the industrial chain, thereby bringing about huge value creation under the condition of equal costs.

ESG is a new sustainable development concept about the integration and coordinated development of environment, society and corporate governance. It provides enterprises and investors with a comprehensive framework that integrates environmental, social and corporate governance, and conveys a development view of pursuing integration of economic and social values (Atan et al., 2018; Huang, 2021). Data element embedding is an enterprise information sharing infrastructure that runs through business functions and information exchange and coordination among business partners. Despite its importance, data element embedding is also affected by the relationship between the organization and external subjects (Closs and Savitskie, 2003). These findings suggest that the value creation of data elements is highly dependent on other antecedent processes. Therefore, it is very necessary to conduct empirical research on the value creation process of ESG investment-driven data elements. The research results will help enterprises better understand the mechanism by which data element embedding affects enterprise performance, so that we can effectively use data element embedding to achieve enterprise performance and actively enhance the strategic competitiveness of enterprises.

Although the academic and business circles have noticed the impact of environmental characteristics and organizational agility on the value creation of data elements, there is no unified understanding and definition of how to describe and reflect environmental characteristics and organizational agility. Hence, from the perspective that ESG drives data element embedding, this paper defines and measures enterprise environmental characteristics and organizational agility, analyzes the impact of environmental characteristics and organizational agility on the action process of data elements, establishes a theoretical model by which data element embedding affects enterprise performance based on contingency theory, and puts forward research hypotheses, trying to analyze the composition of data elements, the role of organizational agility and environmental characteristics. Moreover, it tests the theoretical model through empirical research methods to reveal the mechanism by which data element embedding affects enterprise performance.

1 Value of data elements based on contingency theory

The contingency theory shows that an enterprise organization is a subsystem in an open social macro system that is affected by the internal and external environment. The internal elements and external environmental background and conditions of each organization are rather different. Enterprises should maintain the best adaptation to the environment by taking effective organizational management models and measures. The effect of management is highlighted in the interaction between the management model and the various elements of the organization, and enterprise performance is a result of the matching between its organizational strategic behavior and internal and external environmental conditions (Drazin and Van de Ven, 1985). This process requires enterprises to adopt effective organizational strategies and processes to handle the specific external conditions in front of them. The most important core of contingency theory is to enable organizations to adapt to the environment. When the organizational environment changes complexly, enterprises need to explore new markets, discover changes in consumer needs, and develop new products or services in a targeted manner. In this process, enterprises need to integrate new market information, perform differentiated restructuring of the organization, and even expand new subsystems or new production processes to adapt to changes in the environment.

Contingency theory regards the organization as an open system that continuously exchanges information and follows a factor-process-performance path (Schoonhoven, 1981). Factors refer to the pre-factors and environments in the context. For instance, market demand fluctuations cause uncertainty and opportunities for enterprises, and then affect the organization operation process. Process means the organization and management of these pre-factors or adaptation to these pre-factors, such as information sharing, organizational operation adjustment and so on. Performance refers to the result of this series of actions and processes.

According to contingency theory, this paper argues that data element embedding is a strategic behavior of an organization to improve its coordinated operation process and benefit enterprise performance (Wong C W Y et al., 2011). The productivity of data elements lies in the fact that they can essentially drive and stimulate the enterprise potential, achieve self-reform, self-transformation, and self-control of enterprises, and cope with various internal and external uncertainties through the agility in efficient coordination, so that the technology chain, product

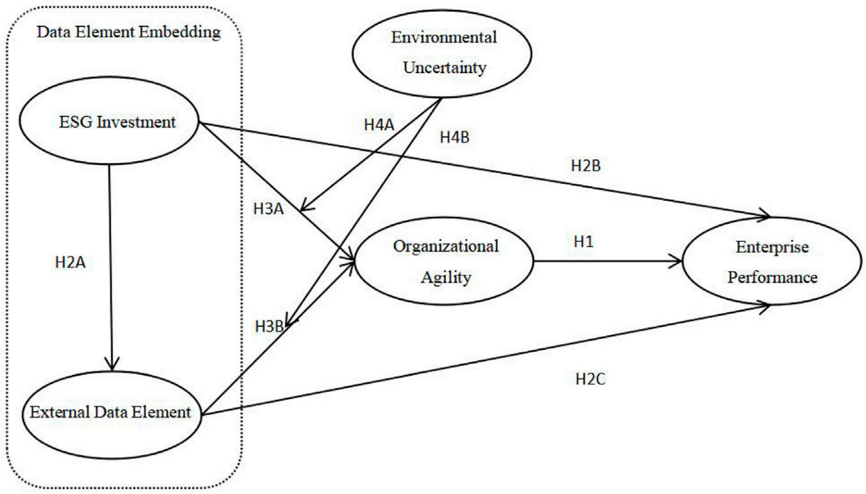

FIGURE 1
Theoretical model.

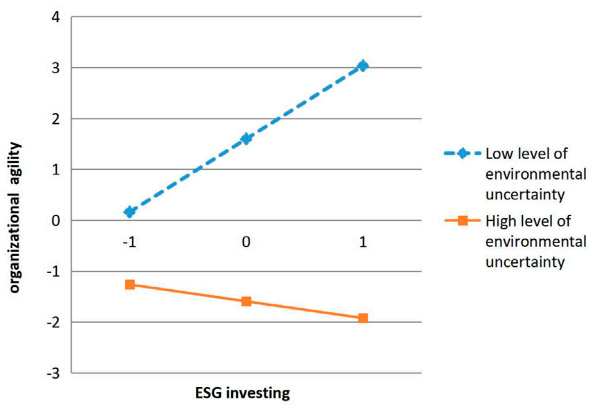

FIGURE 2
The interaction effect of environmental uncertainty on ESG investment and organizational agility.

chain, value chain and even the space chain of enterprises can be effectively expanded and reconstructed, making the enterprise production and operation process more closely coupled with the consumer market, thus enabling agile and flexible management, forming information aggregation in the virtual space, thereby driving enterprise organization and market innovation. Therefore, enterprises cannot ignore the impact of environmental factors on the relationship between organizational agility and organizational performance driven by data elements. Contingency theory provides appropriate theoretical guidance for studying the factors influencing the process in which data element embedding leads to enterprise performance.

2 Theoretical models and hypotheses

Based on the contingency theory, this paper establishes a mechanism model regarding the impact of ESG investment on enterprise performance, analyzes the composition of data elements and the main characteristics of organizational agility, and investigates the mechanism by which ESG investment affects enterprise performance through data element embedding and organizational agility. Where, according to the relevant theories, the intervening effect of enterprise environmental factors on the value creation process of data elements is proposed, the characteristics of environmental factors are measured by environmental uncertainty, and the effect of data element embedding on organizational agility is analyzed. The theoretical model is shown in Figure 1.

2.1 Organizational agility

Economic globalization and intensified corporate competition have put pressure on enterprises in their efforts to maintain a competitive advantage in such an unstable environment. In the face of fierce competition and dynamic environment, enterprises need to take competitive behaviors (such as constantly developing new products or improving service accuracy, etc.), integrate limited resources and organizational capabilities to drive organizational agility. Organizational agility is the ability to innovate and respond quickly to capitalize on opportunities for growth and prosperity in the face of uncertainty in the business environment, which is an extension of the concept of strategic flexibility in response to unstructural change (Zhang and Sharifi, 2000). Existing literature generally explains organizational agility from two perspectives: market agility and operational adjustment agility (Lu and Ramamurthy, 2011). Market agility refers to an enterprise's ability to respond proactively and exploit opportunities through continuous monitoring and rapid delivery of products or services to meet consumer needs. Market agility emphasizes dynamic, proactive growth-oriented corporate thinking about decision-making and judgment under conditions of change or uncertainty (Sambamurthy et al., 2003). Operational adjustment agility is the ability to adjust business processes and resources at the internal level of an enterprise to meet changes in the market or demand. Operational agility emphasizes the flexibility and rapid response capability of an enterprise's internal operating processes in the face of changes. Enterprises with high organizational agility have the skills to take competitive actions and respond flexibly to changes in the environment, and provide consumers with new product or service needs, thereby effectively reducing operating costs, increasing product-market fit and market share, thus acquiring higher profit and value (Chen and Wang, 2014). Therefore, the following hypothesis is made:

H1: Organizational agility is positively correlated with enterprise performance.

2.2 ESG investment and data element embedding

In 1997, the relevant United Nations agencies proposed that environmental, social and corporate governance factors must be incorporated in the corporate decision-making process. Many financial institutions and non-governmental third-party institutions then began to pay attention to and promote ESG concepts, information disclosure and ESG evaluation (Wong C W Y et al., 2011). At the same time, social rating agencies have gradually established a comprehensive multi-dimensional evaluation system, which further strengthens enterprises' emphasis on ESG concepts. ESG investment can not only enhance the external signal of the enterprise, reduce the enterprise financing cost by alleviating information asymmetry and agency problems, but also can establish a good social image of the enterprise and strengthen the relationship between the enterprise and its stakeholders (Yoon et al., 2018). ESG investment helps to win the trust and support of various stakeholders, strengthens the long-term cooperative relationship between enterprises and all parties in the supply chain, and then helps enterprises gather the data resources required for operation, thereby achieving sustainable development of enterprises. Hence, the following hypotheses are proposed:

H2A: ESG investment positively affects the external data element embedding of enterprises.

H2B: ESG investment positively affects enterprise performance.

Data element embedding means a high-level stage in utilization of enterprise information technology and other electronic resources. Sharing the integrated information between internal departments and external cooperative enterprises through electronic tools will facilitate cross-functional collaboration inside and outside the enterprise, which is represented as interaction and sharing of timely, accurate and standardized data between organizational functions within and outside the enterprise (Yoon et al., 2018). Previous research proposed multiple levels of data element embedding to support business coordination (Wong C W Y et al., 2011). Data element embedding, on the one hand, can drive enterprises to accurately identify consumer needs and dynamic changes, and then provide precise marketing, targeted advertising, a price system beneficial to users, high-quality personalized services, and faster product and service iterations, thereby gaining market competitiveness and increasing profits. On the other hand, it can drive the reduction of organizational operating costs, the improvement of operating efficiency, and the improvement of production quality, so that higher operating performance is possible. As one of the key factors in enterprise success, data element embedding also provides an open communication and information sharing mechanism between enterprise functional entities and supply chain partners to support enterprises to take appropriate performance improvement actions (Wong C W Y et al., 2011). For example, Dell continuously adjusts its production plan according to the market demand and makes suppliers adjust the production plan continuously, so that the production gradually approaches the real market needs in the process of continuous adjustment. Dell and its suppliers share so much information in the process that they work in close coordination as a unit. Integration of enterprise production plans and dealer procurement plans can help enterprises adapt to market demand changes and produce customized products. At the same time, order plans can be updated in time before market activities, so that enterprises and partners can jointly achieve the goal of improving performance. It can be said that data element embedding provides a collaborative mechanism to support the completion of intra and inter-enterprise tasks and reduce operating costs, thus bringing obvious first-mover advantages to enterprises. In the future, to some extent, enterprises will rely on digital element embedding to achieve competitiveness and sustainable growth (Sambamurthy et al., 2003). Hence, the following hypothesis is proposed:

H2C: External data element embedding positively affects enterprise performance.

Enterprises with agile responses can quickly take countermeasures against sudden changes in market demand. How to develop this ability? The first suggestion given is data sharing among supply chain members. Enterprises that actively participate in ESG activities also display higher consumer satisfaction and a sense of identity with supply chain enterprises, which weakens the differences between enterprises and external stakeholders, brings all-round, multi-level effects to the enterprise's operations and resource allocation, and then subtly increases organizational agility. Data element embedding emphasizes that in the mode of resource sharing, the long tail theory means to meet the ever-changing individual needs of consumers through multi-variety production in small batches, and let enterprises and other enterprises form economic benefits via the division of labor and cooperation. Wherein, the production operation mode, organizational management mode and service system will all be oriented towards rapid response. High data element embedding provides a timely and accurate support platform for enterprise operation adjustment and market response, thus enabling enterprises to conduct real-time dynamic analysis through real-time integration of internal and external data, quickly grasp market dynamics, adjust corresponding strategies and behaviors, adjust enterprise operations, optimize the process, and provide timely and rapid decision-making response (Fink and Neumann, 2007). Hence, the following hypotheses are made:

H3A: ESG investment positively affects organizational agility.

H3B: External data element embedding positively affects organizational agility.

2.3 The moderating effect of environmental uncertainty

The accelerated iteration of technology, the high penetration of the industry and the blurring of boundaries all make many enterprises face uncertainty. Such uncertainty is a result of superposition of various factors. For example, the innovation cycle has gradually shortened from the original long time, the information technology-driven integration of industries makes it difficult to distinguish one industry from another, and the boundaries are becoming more and more blurred. Strong competition does not necessarily come from traditional competitors, but may come from dimensionality reduction strikes from other industries (for instance, the emergence of new energy vehicles affects traditional vehicle industry, etc.). Therefore, enterprises strive to expand the previously unfamiliar market, which further accelerates the environmental instability. At the same time, with the rapid economic development and the constant technological innovation, consumer needs are gradually becoming diverse and personalized, and the business environment also exhibits a non-stationary trend (Newkirk and Lederer, 2006). In the field of business management research, environmental uncertainty is used as one important moderating variable to measure organizational behavior. The so-called environmental uncertainty refers to the unpredictable and non-sustainable unstable state or change of the business environment (Wang et al., 2015). Tallon et al. also suggested using environmental uncertainty as an important contextual variable in the information economy and information management (Tallon, 2008). Regarding the impact of original ESG investment and data element embedding on organizational agility, we ignore the contextual variable of the environment. Therefore, it is difficult to reflect the situational dependence in the realization of value embedded in data elements. Hence, the following hypothesis is made:

H4A: Environmental uncertainty moderates the relationship between ESG investment and enterprise organizational agility.

H4B: Environmental uncertainty moderates the relationship between external data element embedding and enterprise organizational agility.

3 Research methods

The data in each value creation link of data elements of manufacturing enterprises are acquired by questionnaire survey, the impact of organizational agility on enterprise performance is analyzed by structural equation method, the impact of data element embedding on organizational agility and enterprise performance is tested, and the moderating role of environmental uncertainty level in the impact of data element embedding on organizational agility is analyzed.

3.1 Scale development and questionnaire design

The data collection herein adopts the questionnaire survey method, the measurement variables basically come from the existing literature, and there is a certain guarantee on the measurement reliability and validity. Before the official questionnaire came out, a small-scale pre-investigation was carried out. According to the investigation results, the expressions and sentences of the questionnaire items were revised to form the final questionnaire. Except the basic enterprise information, the 5-point Likert scale was used. ESG investment originated from socially responsible investment (SRI), which means the three most important consideration factors in socially responsible investment. From this perspective, we selected the three benchmarking institutions for ESG research: the Sustainability Accounting Standards Board (hereinafter referred to as SASB) as a non-profit organization, Morgan Stanley Capital International (hereinafter referred to as MSCI) as an index research and development enterprise, and Standard & Poor's (hereinafter referred to as S&P), then compared the similarities and differences in ESG research process. We found that SASB, MSCI and S&P have quite different starting points in designing the ESG evaluation system, but all lead to the same goal. These ESG index systems can provide us with an analysis template for sustainable development and green development, and provide investors with a starting point for analysis framework and index. SASB selected five important aspects for evaluation, including Environment, Social Capital, Human capital, Business Model & Innovation, Leadership and Governance. The data element embedding was measured by the scales of Wong, Moyano-Fuentes, Roberts (Wong C W Y et al., 2011; Roberts and Grover, 2012; Moyano-Fuentes and Martínez-Jurado, 2016), etc., organizational agility was measured by the scales of Lu, Sambamurthy, et al. (Sambamurthy et al., 2003; Lu and Ramamurthy, 2011), environmental uncertainty was measured by the scale of Wong, Newkirk, Wang et al. (Newkirk and Lederer, 2006; Lu and Ramamurthy, 2011; Wang et al., 2015), and enterprise performance was measured by the scales of Wong and Narayanan (Wong C W Y et al., 2011; Narayanan et al., 2015).

3.2 Data collection

The surveyed areas are mainly concentrated in Shanghai, Jiangsu, Zhejiang and other Yangtze River Delta regions in China. In these regions, the manufacturing industry is relatively developed, and the application of information technology is relatively early, which is typical and representative. The survey data mainly comes from two sources. The first way is to distribute 125 questionnaires in college MBAs, and the second way is to conduct field research or postal research through alumni resources. The questionnaire was filled out by the head of the information technology department, ESG management department or marketing department of the enterprise. A total of 400 questionnaires were distributed in this way. A total of 317 questionnaires were recovered from the three research channels, and the questionnaire recovery rate reached 79.25%. The validity of the recovered questionnaires was screened. 21 questionnaires filled in with incomplete information, contradictory information, and almost with the same options, and nine questionnaires by respondents whose positions did not meet the requirements and who did not understand information technology and information management were eliminated. Therefore, a total of 287 questionnaires entered the final data analysis and model fitting stage.

3.3 Common method bias control

In the survey, the questionnaire is often completely filled out by one person, and there may be a problem of common method bias. In data analysis, two main steps are taken to address the problem of common method bias. First, adopt reasonable program control and process control, conduct anonymous survey and adjust the order of questionnaire items to control the questionnaire. Second, conduct Harman single factor test on the final survey data. In factor analysis, the variance of the first principal component factor is explained as 32.7% when there is no rotation, which has a significant statistical advantage, so it can be considered that the common method bias has no significant effect in this study.

4 Empirical analysis

This paper uses SPSS23 and SmartPLS3.0 as tools to conduct data research, tests the reliability and validity of the scale, calculates the influence of various variables, judges the fitness of the model and finally verifies the hypothesis of the model on this basis.

4.1 Evaluation of measurement tools

As can be seen from the Table 1, the minimum Cronbach's value of the construct in this paper is 0.781, and the minimum value of the combined reliability (CR) is 0.848, which far exceeds the critical value of 0.7, so the measurement model of the construct has relatively high reliability. The minimum value of the standardized factor loadings of all measurement items is 0.673, which is higher than the critical value of 0.6, indicating that the measurement model has high convergent validity. The average variance extracted value (AVE) for all constructs is above the critical value of 0.5. Through exploratory factor analysis, the maximum variance method is used for rotation, the Kaiser-Meyer-Olkin measurement test value is 0.854, which approaches 1, and the Bartlett sphericity test value is 4,289.83, with a degree of freedom of 276. The significance is less than 0.001, and the factor variance explained amount reaches 70.8%. The validity test is mainly to check the discriminant validity, which is measured by the square root of the average variance extracted value (AVE) greater than the correlation coefficient of the corresponding construct. As can be seen from the Table 2, the data in this paper meet the requirements, and it can be said that the discriminant validity of the scale is within a reasonable range.

4.2 Model fit

In PLS path analysis, the GoF index is generally used to measure the fitness or goodness of fit of the model. The calculation method of GoF is $GoF = \sqrt{communality + R^2}$, where $communality$ and R^2 respectively measure the predictive ability and explanatory ability of the model, and $communality$ is the mean of the common degree values of all endogenous latent variables involved in the model, R^2 is

TABLE 1 Reliability and validity analysis of the measurement model.

Constructs and measurement items	Factor loading
ESG investment Cronbach's α =0.833, CR = 0.882, AVE = 0.612	
Environment	0.782
Social capital	0.786
Human capital	0.738
Business model and innovation	0.814
Leadership and governance	0.747
External data element embedding Cronbach's α=0.852,CR = 0.886, AVE = 0.569	
Enterprises exchange information electronically with business partners	0.712
Enterprises and business partners develop electronic business models	0.693
Electronic information shared by enterprises and business partners is accurate	0.739
Electronic information shared by enterprises and business partners is timely	0.759
Electronic information shared by enterprises and business partners is standardized	0.822
The information shared by enterprises and business partners can meet the needs of business activities	0.776
Organizational agility Cronbach's α =0.854, CR = 0.896, AVE = 0.596	
Enterprises can respond to changes in consumer needs in a timely manner	0.749
The enterprise can respond in time to the competitors' launch of new products or services	0.797
Enterprises can reallocate resources in view of changes in demand	0.802
Enterprises can increase or decrease products or services in a timely manner to facilitate sales	0.856
Enterprises can timely and accurately identify consumer needs	0.768
Environmental uncertainty Cronbach's α =0.781,CR = 0.848, AVE = 0.743	
Demand for products/services is always fluctuating in this industry	0.840
It is difficult to predict/observe competitor actions	0.850
Consumer attitude towards product/service is unpredictable	0.678
The impact of new technology on the industry is uncertain	0.673
Enterprise performance Cronbach's α =0.831,CR = 0.880, AVE = 0.646	
The productivity of the enterprise is above the industry average	0.767
The product quality/service level of this enterprise is higher than the peer average	0.779
The operating cost of the enterprise is lower than the peer average	0.765
The enterprise's market share is higher than the peer average	0.720
The consumer satisfaction of this enterprise is higher than the peer average	0.819

the mean of the variances of all latent variables involved in the model. As a measure of the global model fit in PLS, the large, medium and small critical values of the GoF parameters are 0.36, 0.25, and 0.10, respectively. The global matching parameter of the research model is 0.465, which is much larger than the critical value of 0.36, indicating that the model has a high degree of global fitness.

4.3 Theoretical hypothesis verification

Structural equation based on partial least squares does not require very high data volume and data distribution of survey samples, which is suitable for exploratory research and is widely used in the fields of information technology and strategic management. In this paper, SmartPLS, a typical software in PLS, is used for data fitting and analysis. Table 3 reports the hypothesis testing results without considering moderating effects.

It can be seen from Table 3 that the path coefficient between organizational agility and enterprise performance is 0.535, which is significant at $p < 0.001$, indicating that there is a strong positive relationship between organizational agility and enterprise performance, so hypothesis H1 is verified. The path coefficient between ESG investment and external data element embedding is 0.523, which is significant at $p < 0.001$, suggesting that ESG investment has a direct and significant impact on external data element embedding, so hypothesis H2A is verified. The path coefficients between ESG investment, external data element embedding and organizational agility are 0.554 and 0.166, respectively, which are significant at $p < 0.001$ and $p < 0.05$, respectively, indicating a certain positive relationship between

TABLE 2 The discriminant validity test of the scale.

Construct	ESG investment	External data element embedding	Organizational agility	Environmental uncertainty	Enterprise performance
ESG investment	0.782				
External data element embedding	0.523	0.754			
Organizational agility	0.640	0.456	0.772		
Environmental uncertainty	0.365	0.424	0.323	0.862	
Enterprise performance	0.411	0.248	0.573	0.221	0.804

TABLE 3 Hypothesis testing.

Hypothesis	Path	Path coefficient	T value	Test result
H1	Organizational Agility→Enterprise Performance	0.535	9.069	Supported
H2A	ESG Investment → External Data Element Embedding	0.523	10.907	Supported
H2B	ESG investment → enterprise performance	0.090	1.240	Not supported
H2C	External Data Element Embedding→Enterprise Performance	-0.043	0.814	Not supported
H3A	ESG Investment → Organizational Agility	0.554	11.599	Supported
H3B	External Data Element Embedding → Organizational Agility	0.166	2.969	Supported

the variables, so hypotheses H3A and H3B are verified. However, the path coefficient between ESG investment, external data element embedding and enterprise performance does not reach the critical significance level of 0.05, so hypotheses H2B and H2C are not established, that is, data element embedding has no significant direct impact on enterprise performance.

4.4 Analysis of mediating effect

In the path analysis, the path coefficients from ESG investment to enterprise performance, from external data element embedding to enterprise performance, and from organizational agility to enterprise performance are calculated. The test results show that the path coefficients from data element embedding to enterprise performance are insignificant, while organizational agility has a significant positive impact on enterprise performance. Therefore, according to the recommendations of the literature (Tarafdar and Qrunfleh, 2017), there is need to further analyze the mediating role of organizational agility in the impact of data element embedding on organizational agility.

In the past, most mediating effect tests in structural equation models were tested by the Sobel method. Hayes' research shows that the data parameter distribution in the PLS method may not meet the normality requirement, so the traditional Sobel method is biased in effect test (Andrew F. Hayes, 2009; A. F. Hayes and Scharkow, 2013). According to the research recommendations of Nitzl and Roldan (Nitzl et al., 2016), by using the bootstrapping algorithm in PLS to estimate the relevant parameters, it is possible to effectively test the mediating effect. As shown in Table 4, the T-value test shows that all path coefficients pass the significance test at the 0.05 level, and 95% of the intervals are positive numbers, excluding 0, which verifies that organizational agility plays a mediating role between data element embedding and enterprise performance.

4.5 The moderating effect of environmental uncertainty

SmartPLS provides a cross-product method for moderating effect verification, but the requirement for the interaction term is that it must be a reflective construct. The constructs studied herein are all reflective and meet the preconditions for application. Before calculation, the data must be normalized to generate new interaction constructs ESG investment × environmental uncertainty, external data element embedding × environmental uncertainty. Then, we calculate the impact of the new interaction construct on organizational agility and use bootstrapping algorithm to estimate the coefficient significance. The calculation results show that environmental uncertainty negatively moderates the relationship between internal data element embedding and enterprise organizational agility, so H4A is confirmed. However, environmental uncertainty has no significant impact on the relationship between external data element embedding and

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TABLE 4 Test of the mediating effect of organizational agility.

Indirect effect path	Indirect effect	Bootstrap 1,000 times		95% confidence interval		
	Point estimation	Se	T	P	Low	Upper
ESG investment → organizational agility → enterprise performance	0.296	0.039	7.590	<0.001	0.223	0.372
External data element embedding→ organizational agility→ enterprise performance	0.089	0.031	2.87	<0.01	0.030	0.154

TABLE 5 Moderating effect test of environmental uncertainty.

Hypothesis	Path	Path coefficient	T value	Test result
H4A	ESG Investment × Environmental Uncertainty → Organizational Agility	-0.884	1.923	Supported
H4B	External data element embedding × environmental uncertainty → organizational agility	0.389	0.823	Not supported

enterprise organizational agility, so H4B is not supported, as shown in Table 5.

From the results in the above table, it can be seen that the path coefficient of the product terms ESG investment and environmental uncertainty with respect to organizational agility is -0.884, which is significant ($p < 0.05$, $T > 1.923$), indicating that environmental uncertainty negatively moderates the impact of ESG investment on organizational agility. For each standard deviation increase in environmental uncertainty, the slope of ESG investment against organizational agility decreases by 0.884 standard deviations. Neither of the other moderation paths passes the significance test, indicating that environmental uncertainty may not play a moderating role in the impact of external data element embedding on organizational agility. In order to make the results of the moderating effect more visible, this paper divides the environmental uncertainty into two groups, one with one standard deviation above the mean and one with one standard deviation below the mean. According to the organizational agility prediction equation after adding the interaction term, the interaction diagram two is plotted.

As can be seen from the Figure 2, when environmental uncertainty is at a lower level, ESG investment has greater impact on organizational agility, which further confirms the conclusion that environmental uncertainty negatively moderates the impact of ESG investment on organizational agility.

5 Discussion and enlightenment

5.1 Main findings

This paper develops a new scale on data element embedding in manufacturing enterprise, conducts confirmatory factor analysis on corresponding constructs, builds a value creation model for enterprise data elements, and conducts mediation path analysis and moderating effect test. The main findings are as follows:

5.1.1 Hierarchical characteristics and action mechanism of organizational agility driving factor

According to the survey data, two factors are extracted through confirmatory factor analysis, which proves that the driving factors of organizational agility are divided into two constructs: ESG investment and external data element embedding. Different from existing research, this paper verifies the conclusion that ESG investment has a significant direct impact on the external data element embedding of enterprises. This conclusion directly shows that data element embedding by ESG investment is a reasonable path, and a good ESG investment background provides a good guarantee for the external data element embedding of enterprises. Previous studies either blended ESG investment and external data element embedding into one, or regarded them as two separate parts, ignoring the structural and hierarchical effects within ESG investment. In addition, at a practical level, ESG investment is the trigger for enterprise performance improvement, so enterprises should strengthen data sharing channels and data quality construction between internal agencies and with external cooperative enterprises (Lai et al., 2008), thereby strategically preparing for good performance.

5.1.2 Organizational agility is the bridge between enterprise data element embedding and performance

The study found that neither ESG investment nor external data element embedding had a direct impact on enterprise performance, while organizational agility had a direct impact on enterprise performance. Through the mediating effect, it is tested that ESG investment and data element embedding play a positive role through organizational agility. This finding provides some guidance for how to improve enterprise performance. Therefore, when enterprise managers make strategic decision-making on data element embedding, they should timely direct data elements to drive the improvement of organizational agility, thereby ensuring high enterprise performance. At present, the main domestic and foreign literatures still focus on the direct effect of data element embedding on enterprise performance (Zhang and Sharifi, 2000; Junni et al., 2015), and hardly study the mediating effect of organizational agility.

5.1.3 The moderating effect of environmental uncertainty

Through the moderating effect, it is verified that environmental uncertainty plays a negative moderating role in the impact of corporate ESG investment on organizational agility, but environmental uncertainty does not make external data element embedding significantly affect organizational agility. That is to say, lower environmental uncertainty better helps us form corporate organizational adjustment and market responsiveness through corporate ESG investment. In the context of Chinese management, ESG investment is relatively easy for many enterprises, and the effect of ESG investment on organizational agility is effective when the degree of environmental uncertainty is low. However, once the market environment faced by enterprises changes drastically and consumer demands constantly change, corporate ESG investment is far less stable than the external data element embedding, so it is necessary to pay attention to the impact of the environment in ESG investment (Wong C Y et al., 2011).

5.2 Management enlightenment

From the perspective of practical application value, the main management enlightenments are as follows:

First of all, under the circumstance of low environmental uncertainty, enterprises should pay attention to ESG investment. The final purpose is how to combine new consumers, new production models, new products, etc. With data analysis to drive the business process speed and enhance enterprise competitiveness. Enterprises should pay more attention to data elements from a strategic perspective, and realize that enterprises are not making ESG investments to just reach relevant standards, but there is need to transit to data application capabilities. Through the training of IT capabilities among technical and managerial staff (Sun et al., 2020), the introduction of advanced information system software and hardware, and the cultivation of internal information sharing systems, it may be easier to achieve the prerequisite driving conditions for organizational agility. Enterprises should establish a collaborative mechanism in the aspects of human, finance, material, production, supply, and sales to realize the organic integration of internal resources, build an advanced environmental-society-governance framework within the enterprise, effectively utilize the internal data resources of the enterprise, optimize the internal management process, improve the management level and governance efficiency, thus laying a solid foundation for the enterprise to expand the use of external data elements.

Secondly, in the context of high environmental uncertainty, enterprises should not only pay attention to ESG investment, but also strengthen the construction of external data element embedding. Market information is crucial to suppliers, manufacturers and downstream retailers in the entire industry chain, but enterprises in different positions in the entire industry chain have certain differences in the way and ability to access information. Distributors and retailers in the downstream of the industry chain directly face consumers, who possess an incomparable advantage in accessing market information, and can directly predict products and adjust relevant market decisions based on the first-hand data of consumers. However, production enterprises in the upstream cannot directly access market information. Therefore, if they have a good information exchange system with distributors or retailers, through horizontal and vertical information sharing, enterprises can improve their grasp of market information and adjust production and operation processes in a timely manner. In this regard, in order to ensure that all subjects in the industrial chain can effectively share information, core enterprises can build an information sharing system as an information platform for the entire industrial chain to provide effective information services to participating subjects and enable the optimal embedding level of external data. For example, in recent years, the auto retail industry faces fierce competition. Many enterprises integrate supply chain information sharing, connect downstream sales information with information such as the factory's internal ERP system, and establish an e-commerce platform or implement ERP/MES system extension, so that internal enterprise information is shared with upstream supply chain, which can effectively improve organizational agility in the context of environmental uncertainty. Therefore, in the face of different environments, enterprises should grasp a reasonable "degree" between ESG investment and external data element embedding with a limited budget.

Finally, although different enterprises invest heavily in ESG investment, they must ultimately drive organizational agility through data elements. Seen from the outside of the enterprise, consumer needs are constantly changing, and competitors constantly appear, which puts forward new requirements for enterprises. That is, there is need to abandon the traditional experience management model, adopt digital element embedding to grasp market demand information and competitive information through data analysis. Through fast and accurate strategic and tactical decision-making, they need adjust organizational structure, production mode, product type, etc. To gain a competitive advantage. Organizational agility is a special ability of an organization, which is not a form of an organization, but means the ability of an organization to respond quickly, change flexibly, and empower actions. The difference between agile enterprises and other enterprises is that they are always consumer-oriented and continuously innovate products or services. For example, when developing a new product for consumers, they actively learn the consumer's attitude towards new product design solutions and continuously seek feedback and comments from consumers. Because the process from production to sales is too complicated for many manufacturing enterprises, although a lot of data has been accumulated for a long time, the data scores separately belong to each department or system and cannot be fully utilized. In addition, in order to better improve agility, the relevant decision-making departments of enterprises impose higher and higher requirements for ESG investment specifications, and the requirements for external data granularity become more and more refined. However, enterprise organizations find it difficult to effectively match the current operation, resulting in certain bottlenecks in the process in which ESG investment and data elements drive organizational agility, so effective value creation is impossible. Therefore, it is necessary to establish a scenario-based data application, use effective digitalization of operations, carry out forward-looking design and strategic planning for the overall goal, time and space of specific operations digitalization to empower organizational agility, and make full use of internal and external resources to create agility-oriented processes, so that the products or services provided by an enterprise are differentiated from those of its competitors, thus creating unique value recognized by consumers, which is the basis for maintaining the sustainable development of the enterprise. This not only reflects the adoption of digital technology, but also involves all-round reform in business strategies, management models, organizational processes, etc., which improves the internal and external information communication capability of the enterprise, breaks down internal and external information barriers by relying on real-time information sharing and increases organizational agility.

6 Conclusion

In the context of Chinese manufacturing enterprises, this paper studies the mechanism by which ESG investment and data element embedding affect enterprise performance, collects data by questionnaire survey, and fits the data using structural equation model. The research results show that corporate ESG investment and data element embedding have no direct and significant impact on enterprise performance, but have indirect effects on enterprise performance through organizational agility. At the same time, the research results also show that under different levels of environmental uncertainty, the impact of data element embedding on organizational agility will change. Specifically, the higher the level of environmental uncertainty, the lower the effect of ESG investment on organizational agility. Of course, this study also has some shortcomings. First, the data collected by the survey are cross-sectional data of enterprises, lacking time series data under dynamic conditions, which may affect the interpretation of the problem. In the future, some enterprises will be followed up for a long time. Secondly, the research model only considers the mediating effect of organizational agility. However, there may be other factors related to enterprise performance in practice (Shuradze et al., 2018). Future research will add other factors to improve the explanatory power and application effect of the model.

Data availability statement

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

Author contributions

GJ: Conceptualization, methodology, resource, Data curation, supervision, writing-original draft, writing review and editing. LR: investigation, writing review and editing. XJ: writing review and editing.

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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Policy effect of the "blue sky plan" on air pollution, ESG investment, and financial performance of china's steel industry

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This study aims to examine the policy effects of the "Three-Year Action Plan to Win the Blue Sky War" on the steel industry and air pollution in China. Specifically, we analyze the impact of the "Blue Sky Plan" on Chinese steel companies' ESG investments, corporate financial performance, and the emissions of sulfur dioxide and nitrogen oxides in the exhaust gas. Our evidence suggests that ESG investment in steel companies can lead to a significant decrease in financial performance. The "Blue Sky Plan" compensated for about one-third of corporate ESG investment losses and played a significant role in promoting the ESG investment of steel companies. In addition, we found that after the implementation of the "Blue Sky Plan," the emissions of sulfur dioxide and nitrogen oxides in the exhaust gases were significantly reduced.

KEYWORDS

steel industry, policy effects, Blue Sky Plan, ESG investment, air pollution

1 Introduction

Environmental pollution is widely recognized as an important issue for sustainable economic growth. In recent years, with rapid economic development, China has been consuming a large amount of fossil energy. Air pollution in China has reached a serious level, causing environmental and health problems (Chen et al., 2017), and has largely aroused residents' dissatisfaction. Since then, the Chinese government has attached great importance to the ecological environment and has made many efforts to achieve specific emission reduction targets in the "13th Five-Year Plan" (2016–2020) to tackle environmental deterioration. These reduction targets mainly focus on the emission of nitrogen oxides and sulfur dioxide. In 2018, the Chinese government issued a "Three-Year Action Plan to Win the Blue Sky war" (hereinafter the "Blue Sky Plan"). In 2015, China's total SO_2 and NOx emissions were 18.591 million tons and 18.518 million tons, respectively. The major goal of the "Blue Sky Plan" is to reduce the total emissions of sulfur dioxide and nitrogen oxides by more than 15% by 2020.

Environmental pollution can be classified into water and air pollution. In terms of water pollution, Chen et al. (2018) studied the water pollution regulation in China and found evidence that the regulation reduced pollution-intensive activities in highly regulated areas. Liu et al. (2017) estimated the impact of stricter wastewater discharge standards on all the textile printing and dyeing enterprises in Lake Tai. They find that enterprises facing new, more stringent standards decrease labor demand by approximately 7%. Most countries have begun to monitor air quality in recent years. Peng et al. (2019) examined the consistency of city- and individual-level air pollution perceptions and investigated how environmental transparency affects the actual perceived air pollution relationship. Ai et al. (2021) studied the relationship between the desulfurization price subsidy policy and SO_2 emission reduction from coal-fired power plants in China. They found an obvious causal relationship between the policy and SO_2 emission reduction, and the dynamic effect of the policy showed an upward trend throughout the sample period. In terms of studying policy effects, Lin et al. (2021) examined the impact of the Electricity Price Subsidy policy on NOX emission from China's coal-fired power generation industry. They found that the EPS policy significantly reduced NOX emissions by 1.1% and increased NOX removal by 2.8%.

This study focuses on the policy effects of the "Blue Sky Plan" on the steel industry as well as the emissions of sulfur dioxide and nitrogen oxides. Although the problem of environmental pollution has been raised for decades, the Chinese government has been balancing economic growth and environment problems until the serious air pollution occurred. Air pollution became the most serious environmental problem in China since 2013, which not only significantly harmed the public health, but also decreased satisfactory to the government. The implementation of "Blue Sky Plan" is the first time the Chinese government decided to protect the environment at the cost of sacrificing economic growth. In 2017, the major pollutant emissions from the steel industry exceeded those of the power industry and became the largest source of pollutant emissions in the industrial sector. The steel industry in China has become a major source of air pollutants such as particulate matter, SO_2, and NOx emissions. For the purpose of investigating the policy effect of the "Blue Sky Plan" on air pollution, we focus on the steel industry instead of the whole polluting industries, to avoid using irrelevant information (e.g. water pollution).

Gu et al. (2018) analyzed the sulfur dioxide emission reduction effect, energy-saving synergy effect, and carbon dioxide emission reduction of power generation, steel, and cement industries during the "11th Five-Year Plan" and "12th Five-Year Plan" periods. They showed that during the "11th Five-Year" period, the emission reduction of coal-fired power plants' desulfurization projects is critical to emission reduction. Both engineering and structural reductions can achieve low pollution emissions, but the contributions are not the same, owing to differences in related industries. Bo et al. (2021) used measurements from China's continuous emissions monitoring system to develop estimates of emissions from the steel industry. They assessed particulate matter, sulfur dioxide, and nitrogen oxide emissions associated with China's increasingly stringent policies from 2014 to 2018.

Recently, ESG investment has attracted substantial research attention (see Zhao et al., 2018; Gillan et al., 2021). Yuan et al. (2022) investigated the impact of ESG disclosure on the financial irregularities of Chinese listed firms. They find that ESG disclosures decrease corporate financial irregularity risks and help mitigate information asymmetry. Zhang et al. (2021) examined the heterogeneity of ESG investments in China before and after the release of the guidelines for establishing a green financial system in 2016. They show that high-ESG portfolios earn significantly higher abnormal returns than low-ESG portfolios after 2016.

Existing research rarely investigates policy effects on ESG investments in the steel industry. To the best of our knowledge, this is the first study to investigate the policy effects of the "Blue Sky Plan" on the steel industry in China. We close this gap and contribute to the literature in the following ways. First, we collected the latest available environmental, industrial, and financial data and analyzed the policy effect of the "Blue Sky Plan" on ESG investment and financial performance in China's steel industry. Second, we collected provincial economic and environmental data to investigate the policy effects on air pollution.

Our results suggest that ESG investment significantly reduces the financial performance of steel companies, contrary to the findings of Zhang et al. (2021). The "Blue Sky Plan" compensates for one-third of losses from corporate ESG investments and significantly stimulates ESG investment in the steel industry. In addition, we find that the "Blue Sky Plan" reduces SO_2 and NOx emissions significantly and alleviates China's air pollution problem to a large extent.

The remainder of this paper is organized as follows. Section 2 briefly describes the study's data. Section 3 introduces the model. The empirical results are presented in Section 4. Section 5 concludes the paper.

2 Data

The sample period for our data is from 2015 to 2020. We collected the latest and most complete relevant environmental and financial data for Chinese listed steel companies. Specifically, the ESG data come from China's SynTao Green Finance, including ESG investment and environmental scores. The financial data of the steel companies were sourced from the RESSET database, including a range of financial variables such as stock return, market cap, cash holdings, short-term debt, long-term debt, profitability, and book-to-market ratio. Provincial economic and environmental data for 28 provinces were collected from the

TABLE 1 Definition of variables.

Steel Company variables	Definition	Sources
ESG	ESG aggregate score	SynTao
Environment	Environmental score	
Return	Annual holding period return of stock	RESSET
Market cap	Natural Logarithm of firms' total market value at the end of the year	
Cash holdings	Money funds and short-term investment divided by assets	
Short-Term Debt	Total current liabilities divided by assets	
Long-Term Debt	Total long-term liabilities divided by assets	
Profitability	Operating income divided by assets	
Book to market	Book Value at the end of the period divided by assets	
Provincial variables	Definition	
SO_2	Sulfur dioxide emission of waste gas (10 thousand tons)	the National Bureau of Statistics of China
NOx	Nitrogen oxide emission of waste gas (10 thousand tons)	
Thermal Power generation	Thermal Power Generation by Region (10 billion kWh)	
Power consumption	Electricity Consumption by Region (100 million kWh)	
GDP Per Capita	Total output (gross domestic product, the total output of social goods and services) divided by total population (Yuan per capita)	
Industrial added value	The gross output value of industrial enterprises minus the purchase of raw materials	
Treatment of waste gas	Amount of investment completed in industrial waste gas pollution control projects	
Treatment of wastewater	Amount of investment completed in industrial wastewater pollution control projects	
Population	Total population at year end	
Secondary industry share	The share of the output value of the secondary industry in GDP	
tertiary industry share	The share of the output value of the tertiary industry in GDP	
R&D	Science and technology expenditure divided by GDP	
Cars	Civilian vehicles divided by the length of roads	
Afforestation area	In all the land that can be planted, trees and shrubs are planted by various methods, and the survival rate reaches 85% or more (hectare)	

National Bureau of Statistics of China, including SO_2 emissions, NOx emissions, thermal power generation, power consumption, GDP per capita, industrial added value, treatment of waste gas, treatment of wastewater, population, secondary industry share, tertiary industry share, R&D, cars, and the affected area. Table 1 briefly describes the definitions of the variables. Table 2 provides descriptive statistics of the data.

3 Models

First, we construct a heterogeneous timing difference-in-differences (HT-DID) model to examine the policy effect of the "Blue Sky Plan" on the relationship between ESG investment and the financial performance of steel companies. The model is represented as follows:

$$ret_{i,t} = a_0 + a_1 BSP2018 + a_2 ESG_{i,t} + \mathbf{X\beta} + \eta_i + \tau_t + \varepsilon_{i,t} \quad (1)$$

where $ret_{i,t}$ denotes the annual holding period stock returns of the steel companies. ESG is the aggregate ESG investment score. $BSP2018 = Treat_{i,t} \times Post_t$ represents the heterogeneous timing treatment effect of the "Blue Sky Plan." $Post_t$ equals 0 before 2018 and equals 1 otherwise. $Treat_{i,t}$ equals 1 if the company i started ESG investment before the year t, and 0 otherwise. $\mathbf{X}$ represents the vector of control variables. According to Lins et al. (2017) and Drempetic et al. (2020), major financial variables, including market cap, cash holdings, short-term debt, long-term debt, profitability, and book-to-market ratio, are selected. η_i and τ_t represent the firm and time-fixed effects, respectively.

Similarly, we construct the following HT-DID model to investigate the policy effect of the "Blue Sky Plan" on steel companies' ESG investment decisions.

$$ESG_{i,t} = a_0 + a_1 BSP2018 + \mathbf{X\beta} + \eta_i + \tau_t + \varepsilon_{i,t} \quad (2)$$

Finally, we studied the effect of the policy on air pollution. Specifically, we collected provincial economic and environmental data and investigated whether SO_2 and NOx emissions were reduced significantly after the "Blue Sky Plan." The model is introduced as follows.

TABLE 2 Descriptive statistics.

Variables	Mean	Std.Dev	Min	Max	Obs
ESG	0.258	0.255	0.000	0.656	174
Environment	0.247	0.259	0.000	0.759	174
Return	0.099	0.629	−0.554	5.875	174
Market cap	23.437	0.836	21.597	25.975	174
Cash holdings	0.128	0.079	0.003	0.4721	174
Short-Term Debt	0.512	0.178	0.096	1.006	174
Long-Term Debt	0.096	0.078	$0.035*10^{-3}$	0.354	174
Profitability	0.907	0.379	0.121	1.898	174
Book to market	1.401	1.041	$0.117*10^{-3}$	4.750	174
SO_2	2.850	1.173	−1.715	5.028	168
NOx	3.746	0.638	2.160	5.244	168
Thermal power generation	7.167	0.769	5.472	8.621	168
Power consumption	7.567	0.591	6.480	8.845	168
GDP Per Capita	10.956	0.409	10.164	12.013	168
Industrial added value	9.114	0.796	7.018	10.697	168
Treatment of waste gas	11.441	1.038	7.513	13.782	168
Treatment of waste water	9.610	1.305	3.951	12.013	168
Population	8.328	0.626	6.528	9.443	168
Secondary industry share	3.678	0.213	2.760	3.921	168
Tertiary industry share	3.916	0.151	3.659	4.430	168
R&D	−5.446	0.528	−6.498	−4.265	168
Cars	−5.348	0.751	−6.457	−3.374	168
Afforestation area	12.006	1.212	7.838	13.487	168

$$SO2_{i,t}\ or\ NOx_{i,t} = a_0 + a_1 BSP2018 + a_2 ESG_{i,t} + a_3 BSP2018 \times ESG_{i,t} + \mathbf{X\beta} + \eta_i + \tau_t + \varepsilon_{i,t} \tag{3}$$

where $SO2_{i,t}$ or $NOx_{i,t}$ denotes sulfur dioxide or nitrogen oxide emissions in a province i in year t. $\mathbf{X}$ represents the vector of control variables. Here, we reconstruct our ESG data to match the provincial level panel data. Specifically, we calculate the provincial level ESG investment intensity by adding up and standardizing the ESG score of listed companies in each province. According to Ai et al. (2021), Yang et al. (2020), and Zhang et al. (2019), our control variables included thermal power generation, power consumption, GDP per capita, industrial added value, treatment of waste gas, treatment of wastewater, population, secondary industry share, tertiary industry share, R&D, cars, and the affected area. η_i and τ_t refer to provincial and time-fixed effects, respectively.

4 Empirical results

In this section, we first study whether steel companies' ESG investment affects their financial performance and explore the impact of the "Blue Sky Plan" on the relationship between corporate ESG investment and profitability. We then examine the policy effect of the "Blue Sky Plan" on steel companies' ESG investment decisions; finally, we examine whether the "Blue Sky Plan" reduces air pollutant emissions.

Table 3 reports the empirical results of Eq. 1. For comparison, we also provide conventional panel regression analysis. Case (1) shows that the ESG investment of steel companies will significantly reduce their financial performance. A 1% increase in the company's ESG investment will reduce the stock return by 0.378%, indicating that the ESG investment of steel companies will not bring immediate benefits. On the contrary, the cost of R&D investment related to emission reduction and fixed asset investment will cause significant losses to the enterprise.

Then, following Lins et al. (2017), we quartile the ESG scores before introducing them into the model. Specifically, we divide the annual ESG investment status of steel companies into four equal parts, from high to low. Case (2) shows that the top 50% of companies in the steel industry for ESG investment suffer significant losses in their financial performance. However, the marginal ESG investment loss for Q1 companies is 0.232%, which is much smaller than that for Q2 companies, suggesting that companies with the most ESG investments may already be reaping the benefits.

TABLE 3 Policy effects of the "Blue Sky Plan" on the financial performance of China's steel industry.

Dependent variable: Annual holding period stock return

	Case (1)	Case (2)	Case (3)	Case (4)	Case (5)	Case (6)	Case (7)	Case (8)	Case (9)	Case (10)	Case (11)	Case (12)
ESG	– 0.378**				– 0.556**				– 0.388*			
	(– 2.06)				(– 2.40)				(– 1.97)			
ESGQ1		– 0.232**				– 0.258**				– 0.225**		
		(– 2.36)				(– 2.33)				(– 2.21)		
ESGQ2		– 0.330**				– 0.385**				– 0.317**		
		(– 2.43)				(– 2.36)				(– 2.21)		
ESGQ3		0.077				0.028				0.091		
		(0.36)				(0.11)				(0.39)		
Environment			– 0.377**				– 0.522**				– 0.384**	
			(– 2.38)				(– 2.66)				(– 2.28)	
EnvironmentQ1				– 0.190**				– 0.218**				– 0.187*
				(– 2.18)				(– 2.17)				(– 2.01)
EnvironmentQ2				– 0.226*				– 0.274				– 0.221
				(– 1.79)				(– 1.63)				(– 1.47)
EnvironmentQ3				– 0.030				– 0.080				– 0.025
				(– 0.18)				(– 0.42)				(– 0.14)
BSP2018					0.180	0.109	0.164	0.106				
					(1.24)	(0.70)	(1.16)	(0.71)				
BSP2019									0.020	– 0.052	0.017	– 0.221
									(0.15)	(– 0.36)	(0.12)	(– 0.16)
Market cap	0.777**	0.800**	0.775**	0.795**	0.772**	0.801**	0.769**	0.793**	0.778**	0.796**	0.776**	0.793**
	(2.56)	(2.66)	(2.56)	(2.60)	(2.59)	(2.68)	(2.58)	(2.61)	(2.53)	(2.60)	(2.53)	(2.55)
Other control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R square	0.278	0.286	0.279	0.273	0.276	0.283	0.277	0.270	0.274	0.282	0.274	0.269

Values in parentheses are t-values. *, **, and *** represent for significance at 10%, 5%, and 1%, respectively. Q1, Q2, and Q3 refer to dummy variables for the first, second, and third quarters of ESG, or environmental investment intensity. BSP2018 is the policy effect of the "Blue Sky Plan."

We then replaced the ESG scores with environmental scores and arrived at similar conclusions. Case (3) shows that a firm's environmental investment, such as ESG investment, significantly reduces stock returns. The coefficients of the parameters are very similar to those in Case (1), which indicates that the ESG investments of these steel companies are mainly environmental investments rather than social and corporate governance investments.

Similarly, Case (4) shows that the top 50% of companies with environmental investment suffer significant financial losses. Q1 companies suffer less than Q2 companies, suggesting that the companies with the largest environmental investments may have already gained from them.

Cases (5–8) perform a heterogeneous timing difference-in-differences analysis to study the policy effect of the "Blue Sky Plan." Case (5) suggests that a 1% increase in ESG investment will reduce the stock return by 0.556%, indicating that the coefficient of – 0.378 in case (1) is underestimated. Actual losses from ESG investments are much higher. After the implementation of the "Blue Sky Plan," companies received compensation for their ESG investments. These compensations include, but are not limited to, the government's ESG investment subsidies: the reduction in pollutant emission taxes: and the benefits of emission allowance trading after companies' emission reductions. Collectively, these gains do not compensate for corporate losses in ESG investment. The average compensation amount is approximately one-third of the losses caused by ESG investment.

Case (6) showed similar results. The marginal losses from ESG investments are much larger than those in Case (2). This is consistent with the results obtained in case (5). However, we also find that Q1 companies suffer fewer financial losses than Q2 companies, suggesting that the ESG investment has already yielded.

TABLE 4 Policy effects of the "Blue Sky Plan" on ESG investment in China's steel industry.

Dependent variables

	Case (1) ESG	Case (2) environment	Case (3) ESG	Case (4) environment	Case (5) ESG	Case (6) environment
BSP2018			0.364***	0.357***		
			(8.31)	(8.04)		
BSP2019					0.323***	0.317***
					(8.50)	(7.83)
Market cap	5.462**	5.043*	2.536	2.174	6.456***	6.022***
	(2.07)	(1.93)	(1.37)	(1.26)	(3.50)	(3.38)
Cash holdings	27.996	19.339	4.068	4.125	27.365	18.719
	(1.22)	(0.86)	(0.32)	(− 0.32)	(1.40)	(0.97)
Short-Term Debt	− 16.965	− 16.050	− 8.881	− 8.122	− 14.443	− 13.567
	(− 1.15)	(− 0.98)	(− 1.09)	(− 0.83)	(− 1.27)	(− 1.03)
Long-Term Debt	− 42.960	− 37.329	− 7.870	− 2.918	− 21.25	− 15.966
	(− 1.18)	(− 1.04)	(− 0.25)	(− 0.10)	(− 0.64)	(− 0.49)
Profitability	− 4.333	− 5.030	− 1.245	− 2.003	− 0.921	− 1.674
	(− 0.54)	(− 0.58)	(− 0.18)	(− 0.25)	(− 0.13)	(− 0.22)
Book to market	− 4.029	− 5.398	− 2.890	− 4.281	− 3.321	− 4.701
	(− 1.14)	(− 1.45)	(− 0.87)	(− 1.17)	(− 0.97)	(− 1.28)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R square	0.624	0.592	0.757	0.719	0.682	0.648

Values in parentheses are t-values. *, **, and *** represent for significance at 10%, 5%, and 1%, respectively. BSP2018 is the policy effect of the "Blue Sky Plan."

From case (7), it can be seen that each 1% increase in environmental investment reduces the stock return by 0.552%. First, this indicates that the coefficient of the variable Environmental in case (3) − 0.377 is underestimated. Second, through the closeness of the coefficients in cases (7, 5), it is confirmed that the main part of the ESG investment of steel companies is environmental investment, which is consistent with the comparison results from cases (1, 3). Case (8) shows that Q1 companies suffer significant losses from environmental investment. A 1% increase in environmental investment reduces the stock return by 0.218%, which is larger than that in case (4).

Overall, from the comparison of cases (5–8), (1–4), we find that the "Blue Sky Plan" cannot significantly change the status quo of the decline in corporate financial performance caused by the ESG investment of steel companies. Corporate ESG investments cause significant declines in stock returns. After the implementation of the "Blue Sky Plan," companies that invested heavily in ESG achieved certain benefits through subsidies, emission taxes, and emissions allowance trading. Therefore, we conclude that the "Blue Sky Plan" may play a role in promoting corporate ESG investment and green transformation.

One may suspect that there should be a time-lag between the implementation of the policy and its impact occurred. Since the time-lag of policy effect may lead to endogeneity, we delay the effect of the "Blue Sky Plan" to 2019, and report these results in case (9–12). Similarly, ESG investment significantly reduce the stock returns of steel companies. However, these estimates are much closer to case (1–4) than case (5–8), suggesting that the impact of the "Blue Sky Plan" has been quickly absorbed, and the steel industry rebalanced production and environmental protection in a short time.

We then investigate whether the "Blue Sky Plan" stimulates ESG investments. Table 4 presents the results of Eq. 2. Case (1) shows that the larger the market cap of a company, the more ESG investments it has made, indicating that large steel companies are more willing to make ESG investments. On the one hand, large enterprises have sufficient capital to invest in fixed assets and R&D. On the other hand, large enterprises are more likely to obtain emission reduction subsidies and tax relief and are more likely to benefit from emissions trading. In case (2), we substituted environmental scores for ESG scores and obtained similar results to case (1).

Case (3) shows that the "Blue Sky Plan" significantly affects enterprises' ESG investment. After the introduction of policy effects, the coefficient of the market cap no longer becomes significant, indicating that after the implementation of the policy, companies started to make ESG investments regardless of their size. Combining case (1), we can argue that the policy played a

TABLE 5 Provincial-level policy effects of the "Blue Sky Plan" on air pollutants emissions.

	Dependent variables							
	(1) SO_2	(2) NOx	(3) SO_2	(4) NOx	(5) SO_2	(6) NOx	(7) SO_2	(8) NOx
ESG	0.29***	− 0.11			0.22**	− 0.09		
	(2.68)	(− 1.61)			(2.14)	(− 1.39)		
Environment			0.304***	− 0.112			0.23**	− 0.09
			(2.70)	(− 1.64)			(2.16)	(− 1.43)
BSP2018	− 2.31***	− 1.41***	− 2.30***	− 1.41***				
	(− 6.31)	(− 3.54)	(-6.30)	(− 3.56)				
BSP2019					− 2.42***	− 1.38***	− 2.41***	− 1.38***
					(− 5.89)	(− 3.53)	(− 5.87)	(− 3.54)
ESG×BSP2018	− 0.17***	0.04						
	(− 3.11)	(1.25)						
ESG×BSP2019					− 0.10**	0.02		
					(− 2.06)	(0.49)		
Environment×BSP2018			− 0.17***	0.04				
			(− 3.13)	(1.26)				
Environment×BSP2019							− 0.10**	0.02
							(− 2.08)	(0.53)
Other control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Provincial fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj.R square	0.894	0.516	0.895	0.516	0.888	0.513	0.888	0.513

Values in parentheses are t-values. *, **, and *** represent for significance at 10%, 5%, and 1%, respectively. BSP2018 is the policy effect of the "Blue Sky Plan."

significant role in promoting ESG investment in small firms. Similar to Case (3), Case (4) shows that the policy has a significant effect on stimulating the environmental investment of enterprises. In general, the "Blue Sky Plan" has a significant positive impact on ESG and environmental investment, especially for relatively small-scale enterprises. In case (5, 6), the impact of the policy is supposed to be delayed. Obviously, the "Blue Sky Plan" still has significantly impact on corporate ESG investment.

Finally, we examined whether the "Blue Sky Plan" could reduce air pollutant emissions. Table 5 presents the results of Eq. 3. Case (1) shows that ESG investment positively related to SO_2 emission, since both of them are positively correlated with industrial level. However, the estimates of the "Blue Sky Plan" and its product with ESG investment are significantly negative, indicating that the implementation of the "Blue Sky Plan" has a significant inhibitory effect on SO_2 emissions. Similarly, case (2) shows that the "Blue Sky Plan" also significantly reduced NOx emissions. We replace ESG by environmental investment in case (3, 4), and obtain similar results. In case (5–8), the policy effect of the "Blue Sky Plan" is supposed to be delayed. Similarly, we still find that SO_2 and NOx emissions are significantly reduced after the implementation of the "Blue Sky Plan". Overall, our results suggest that the "Blue Sky Plan" has significantly alleviated China's air pollution problems and gradually achieved the policy goals.

5 Conclusion

With the rapid development of China's economy, environmental pollution, especially air pollution, has seriously affected the quality of life of Chinese residents, arousing government concern. As the world's largest producer and exporter of crude steel, the pollution generated by China's steel industry has surpassed that of the power industry, ranking first among China's highly polluting industries. In this context, the Chinese government launched the Three-Year Action Plan to Win the "Blue Sky War," which aims to solve problems such as promoting the green transformation of high-polluting industries and curbing air pollution. This study is the first to examine the policy effects of the "Blue Sky Plan" on China's steel industry. We first analyze the impact of the "Blue Sky Plan" on steel companies' ESG investment and financial performance. We then examine the effects of the "Blue Sky Plan" on air pollution.

From the perspective of the ESG investment of steel enterprises, the ESG-related investment of listed steel enterprises has a significant negative impact on their financial performance, especially for those companies that heavily invest in ESG. This is because these investments cost a large amount of capital in R&D and fixed assets. The "Blue Sky Plan" has compensated for the ESG investment losses of steel companies to a certain extent, with an average rate of about one-third. Additionally, we found that the "Blue Sky Plan" significantly stimulated steel companies' ESG investments. Finally, the "Blue Sky Plan" has significantly reduced emissions of sulfur dioxide and nitrogen oxides, which has played a positive role in improving air pollution problems.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/Supplementary Material.

Author contributions

PL conducted the empirical analysis and wrote the paper. Conceptual design is performed by PL, SH, and ST.

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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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Supplementary material

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Urban digital economy development, enterprise innovation, and ESG performance in China

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This study analyzes the influence of urban digital economy development on enterprise ESG performance in China and its enterprise innovation channels. Based on matching micro-level data of enterprises and macro-level data of prefecture-level cities from 2012 to 2020, this study uses OLS to conduct empirical estimation and uses a multiple mediation effect model to test the influencing mechanism. Our findings demonstrate that the development of an urban digital economy significantly improves enterprise ESG performance in China. Additionally, the development of the digital economy can boost enterprise ESG performance by enhancing innovation input intensity, improving innovation output capacity, and enhancing innovation input intensity to improve innovation output capacity. Furthermore, we find that the development of the digital economy in eastern and northeastern China significantly improves enterprise ESG performance, urban agglomerations play a central role in the process of digital economy development improving enterprise ESG performance, and the development of the digital economy significantly enhances enterprise ESG performance in younger enterprises. Overall, our findings improve and enrich the research on the digital economy and enterprise development from the perspective of micro-enterprises and macro development. Moreover, they provide theoretical support and empirical evidence for the development of the digital economy and the realization of enterprises' sustainable development.

KEYWORDS

ESG performance, digital economy, innovation input, innovation output, Chain multiple mediation effect

1 Introduction

Environmental, social, and governance (ESG) performance is an important dimension of enterprises' sustainable development. For example, ESG progress for digital infrastructure vendors is predicted by the market research firm IDC to become mandatory by 2024 (IDC, 2022). Technology is key to implementing an ESG strategy. For an enterprise undergoing digital transformation, ESG should be part of its development process to ensure that new technology systems are integrated into ESG (Hodge, 2021).

The global economy has entered a new stage of digital economy development, and the technological revolution is developing rapidly, having a profound impact on firm development and transformation. Currently, China's economy faces new characteristics and requirements in the high-quality development stage, and Chinese enterprises are urged to constantly adjust their development concepts to cater to green and responsible investment. This is a relevant context for further study on the impact of digital economy development on ESG performance.

Tapscott (1996) first proposed the concept of the "digital economy" in 1996, pointing out that it was an economic system with extensive use of information and communications technology (ICT). Since then, the meaning of the term "digital economy" has been considered and extended by the Organization for Economic Cooperation and Development, Bureau of Economic Analysis, G20, China Academy of Information and Communication Technology, and Chinese National Bureau of Statistics, among others. There are three primary digital economy measurement methods. First, in the direct estimation method (Machlup, 1962; Porat, 1977), the measurement range and method of value-added of the digital economy are not unified, resulting in significant differences in the measurement results and disputes over the measurement details. The second method involves building a digital economy satellite account. Research on this approach is still being refined and the method has not yet been fully developed. The third method involves establishing a multidimensional digital economy evaluation index system and constructing a digital economy index. In terms of measuring the index systems of the digital economy at home and abroad, international organizations, government agencies, and scholars have proposed different index systems based on defining the concept and scope of the digital economy. Digital infrastructure refers mainly to information infrastructure. Digital industrialization refers to the ICT industry as the foundation for digital economy development, including computer communication and other electronic equipment manufacturing, software, and information technology services (Chinese National Bureau of Statistics, 2021). Industrial digitalization, the integration of exponential technology, and the real economy mainly manifest in e-commerce (OECD, 2014), digital inclusive finance (Zhao et al., 2020), and other aspects. The developmental environment of the digital economy is reflected in its governance and innovation environments (Wang et al., 2021).

Research on ESG has primarily focused on the following aspects. First, the related literature mainly focuses on the actual performance and information disclosure of ESG. Notably, ESG performance is not completely equivalent to ESG disclosure. What is the relationship between ESG performance and ESG information disclosure? Some scholars find no correlation between actual ESG performance and ESG information disclosure (Wiseman, 1982). However, other studies have found evidence of a correlation. For example, Clarkson et al. (2008) found a positive correlation between corporate environmental performance and voluntary environmental information disclosure for 191 companies in the five most polluting industries in the United States. Bewley and Li (2000) showed that Canadian manufacturing enterprises with higher pollution levels were more inclined to disclose conventional environmental information. Shen et al. (2014) found a significant U-shaped nonlinear relationship between corporate environmental performance and environmental information disclosure. Second, there are two main approaches to calculating ESG scores. On the one hand, some scholars constructed an ESG index system based on ESG core connotation and market development, and used principal component analysis to measure the ESG index (Bai et al., 2005; Qiu and Yin, 2019; Chen et al., 2022). On the other hand, some professional institutions issued ESG rating databases, such as the ESG rating system of Sino-Securities and the ESG database of Hexun.com. Third, a few studies have analyzed the factors that influence ESG performance. Farooq et al. (2015) used a sample of 247 United States companies from 2007 to 2011 to explore the impact of company size on social responsibility and found that large companies paid more attention to external market reputation than did small ones. Corporate social responsibility investment may have a significant positive correlation with corporate image. The literature directly related to this study discusses the impact of digital economy development on enterprise development, mainly focusing on the impact of digital economy development on energy use, pollutant emissions, and other environmental aspects (Moyer and Hughes, 2012; Ishida, 2015; Li et al., 2021), the impact of digital economy development on employment structure, employment quality, and other labor market aspects (Qi et al., 2020b), and the impact of the development of the digital economy on corporate governance (Qi et al, 2020a). However, digital economy development is not systematically linked to enterprise ESG performance.

There is a lack of research on the impact of digital economy development on ESG. What impact does urban digital economy development have on enterprise ESG performance in China? What is its action mechanism? The practical significance of these problems has not been effectively resolved. This study constructs an enterprise ESG performance index through environmental (E), social responsibility (S), and corporate governance (G) variables, and constructs an urban digital economy index with Internet development and digital financial inclusion dimensions based on the micro-level data of enterprises and macro-level data of prefecture-level cities in China from 2012 to 2020. Furthermore, this study examines the impact of urban digital economy development on enterprise ESG performance in China and its mechanism and expands the heterogeneity analysis based on matching micro and macro data. We hope that the results of this study can be used to promote the development of the urban digital economy, improve the ESG performance of enterprises, and ultimately realize the digital transformation and sustainable development of enterprises.

The contributions of this study are as follows. First, neither theoretical nor empirical studies exist on the relationship between urban digital economy development and enterprise ESG performance. This study discusses the relationship between digital economy development and enterprise ESG performance using both theoretical and empirical analyses. Second, existing research lacks an exploration of the influencing mechanism of how the digital economy improves enterprise ESG performance. This study proposes the influencing mechanism based on innovation input and output paths. The existence of the influencing mechanism is verified by using a multiple mediation effect model. Finally, this study focuses on the heterogeneity analysis of the four economic regions, urban agglomerations, and enterprise development stages.

The remainder of this paper is organized as follows. Section 2 presents the hypothesis development. Section 3 discusses the data source, variable selection and measurement, and specification of the econometric models. Section 4 presents the empirical results and a discussion. Section 5 discusses influencing mechanism. Section 6 expands on the analysis of heterogeneity. Section 7 presents the robustness test. Section 8 concludes the paper with policy directions.

2 Hypothesis development

2.1 Digital economy development and ESG performance

With the wide application of digital technology in various industries and rapid development of the digital economy, the production efficiency of enterprises has significantly improved, and the development mode of enterprises has undergone significant changes. Technology has become the key to ESG strategy implementation (Hodge, 2021). From a broad perspective, the development of the digital economy significantly improves total factor productivity, economic structure, and social welfare while reducing ecological and environmental pollution and promoting China's high-quality economic development (Zhang et al., 2021; Wang et al., 2022). First, in terms of the environment, the development of the digital economy is closely related to the environment. Internet technology has gradually been applied to energy and environmental protection, directly affecting energy consumption and pollutant emissions. Overall, digital economy development is conducive to improving environmental quality, and the impact of the digital economy on pollutant emissions has a threshold effect (Li et al., 2021). Many studies have shown that digital technology represented by ICT can improve energy efficiency and reduce energy consumption to a certain extent to achieve environmental protection (Moyer and Hughes, 2012; Ishida, 2015). Second, in terms of social responsibility, the implementation of digital reform inevitably impacts the rights and interests of shareholders, employees, consumers, and others. The digital economy enables enterprises to transform from being product-oriented to focusing on users' experience to meet their needs and experience (Jiao, 2020). The development of the digital economy can significantly improve enterprise economic efficiency and effectively improve workers' rights and interests, such as the employment environment, labor remuneration, and labor protection (Qi et al., 2020b). Third, in terms of corporate governance, digital technology improves its level by broadening the depth and breadth of enterprises' access to information, improving information transparency, and reducing the irrational degree of managers' decision-making (Qi et al, 2020a).

Considering the impact of the digital economy development on the environment, social responsibility, and corporate governance, digital technology supports high-quality economic growth and helps enterprises achieve sustainable development. Therefore, this study proposes the following hypothesis:

Hypothesis 1. Overall, the development of the digital economy positively affects enterprise ESG performance.

Meanwhile, given the complexity of the impact of the digital economy on enterprise ESG performance, there are bound to be differences among the various enterprise groups. In summary, this study further explores the heterogeneous impact of the digital economy on ESG performance based on regional and firm characteristics, including the differentiation of four economic regions, urban agglomerations, and the development stage of enterprises.

2.2 Digital economy development, enterprise innovation, and ESG performance

The digital economy has brought profound changes to enterprise production and other fields, encouraging enterprises to engage in economic behavior having a positive impact on environmental protection, social responsibility, and corporate governance. The development of the digital economy can improve enterprises' ESG performance by influencing their economic activity innovation.

The development of the digital economy has accelerated the coupling of digital technology and research and development (R&D) systems and can significantly improve innovation efficiency (Wang and Cen, 2022). First, the development of the digital economy positively affects enterprise innovation input. The digital economy simplifies the channels for multiple innovation subjects to obtain information, and digital platforms provide technological sources and a knowledge base for innovation (Su et al., 2021). The development of the digital economy improves the efficiency of resource allocation and utilization by enterprises, improves their profitability, releases more resources within enterprises (Thompson et al., 2013), and encourages the input of innovation resources. The digital economy aims to achieve innovative development by increasing R&D and human capital investments in enterprises (Dai et al., 2022). Second, the development of the digital economy positively affects enterprise innovation output. The digital economy has a feedback effect. The widespread use of digital technology pushes enterprises to update and upgrade products, learn and use new technologies, and promote periodic technological innovation (Su et al., 2021). The development of the digital economy encourages enterprises to conduct R&D activities, improve the output level of innovation patents, and raise the quality and diversification of new products.

To clarify enterprise innovation's mediating role on the influence of digital economy development on ESG performance, we comprehensively consider how enterprise innovation affects ESG performance. The direction of enterprise innovation is often financial performance and value creation, which is important in improving enterprise competitiveness and profitability (Michelino et al., 2014; Chouaibi et al., 2021). Innovation is essential for pursuing ESG (Esposito De Falco et al., 2021). First, innovation is an important way to solve environmental problems (Kivimaa, 2008). Innovation in this domain improves environmental performance (Ghisetti and Quatraro, 2017). Innovation reduces enterprise pollutant emissions and pollution through technology, configuration, and structural effects (Shi et al., 2018). The development of Internet technology has accelerated declining energy consumption intensity through innovative R&D investment and human capital (Ren et al., 2021). Second, innovation should be considered a valid argument for corporate social responsibility (Asongu, 2007). Enterprises can meet stakeholders' needs and offer advantages for firm development through innovation. With fierce market competition, social consciousness and innovation are key to enterprises' survival (Ullah and Sun, 2021). Asongu (2007), taking DuPont as an example, pointed out that it keeps innovating, reduces production costs, improves product lines, and actively responds to climate change challenges to fulfil corporate social responsibility commitments. Third, innovation has a positive impact on corporate governance. Innovation includes not only the innovation of the business model (content) and business structure (organization) but also the innovation of business governance (Zott and Amit, 2010; Qi et al, 2020a).

In summary, the digital economy can achieve innovative development by increasing innovation input and innovation output, and encourage enterprises to comprehensively improve ESG performance, including environmental protection, social responsibility, and corporate governance through innovation. Accordingly, this study proposes the following hypothesis:

Hypothesis 2. Development of the digital economy improves enterprise ESG performance by enhancing their innovation input.

Hypothesis 3. Development of the digital economy improves enterprise ESG performance by improving their innovation output.

Additionally, this study considers that innovation input affects innovation output. The effectiveness of the National Innovation Systems (NIS) mainly covers the efficiency evaluation of the input–output system, that is, the transformation from innovation input to innovation output (Wang et al., 2016). Increasing R&D investment stimulates firms to conduct R&D activities, thereby increasing the output of their R&D activities. This study considers that innovation input plays a mediating role in digital economy development and innovation output, because it affects the latter. Innovation output mediates the relationship between innovation input and ESG performance. Therefore, innovation input and output have a chain multiple mediation effect on digital economy development and enterprise ESG performance.

Accordingly, this study proposes that:

Hypothesis 4. Development of the digital economy improves enterprise ESG performance by enhancing innovation input intensity to improve innovation output capacity.

This study preliminarily proposes influencing mechanism between digital economy development and enterprise ESG performance through innovation input and output, as shown in Figure 1.

3 Data, variables, and methodology

3.1 Data sources

A-share listed companies from 2012 to 2020 were selected as samples. We conducted the following data-processing steps in this study: eliminated financial industry samples; eliminated stocks that used to be ST, *ST, PT; and excluded abnormal samples of financial indicators, such as net profit rate greater than 1 and asset–liability ratio not in the range of 0–1 (Liu et al., 2020). After sorting, the final sample contained 16,203 observations covering 3,085 listed enterprises distributed in 242 prefecture-level cities over nine years.[1] The data of the listed companies

1 In December 2018, Laiwu City was revoked and the area under its jurisdiction was placed under the jurisdiction of Jinan City. Therefore, this study combines the data of Jinan and Laiwu in the study period.

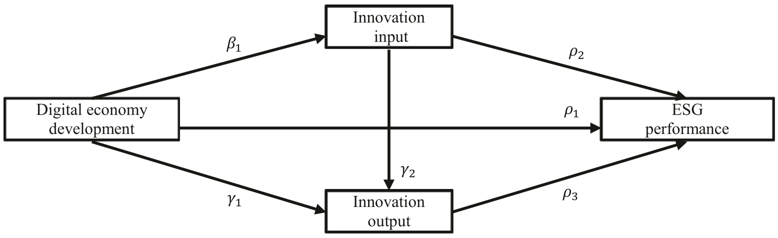

FIGURE 1
How does digital economy development affect enterprise ESG performance through innovation input and output?.

utilized here were obtained from the China Stock Market and Accounting Research database. For continuous variables, we conducted a 1% winsorization to reduce the influence of extreme values. The data on prefecture-level cities come from the China City Statistical Yearbook, Peking University Digital Financial Inclusion Index, some prefecture-level cities' statistical yearbooks and bulletins, and China Entrepreneur Investment Club database.

3.2 Variables

3.2.1 Explained variables

ESG performance includes three aspects: environment, social responsibility, and corporate governance. Specifically, the environment refers to enterprises' emissions from resource management and others. Social responsibility refers to firm's responsibility to stakeholders, such as shareholders, employees, customers, and consumers; it comprehensively considers the enterprise's internal and external economic, ecological, and social environment to ensure its sustainable development. Corporate governance is an institutional arrangement that balances stakeholders, such as shareholders, the board of directors, and management (Alda, 2021; Ullah and Sun, 2021).

First, for the environmental variable (E), we referred to Long et al. (2015) and Qiu and Yin (2019). Specifically, we selected indicators based on whether the company is a key monitoring unit, the discharge of pollutants is up to standard, there is a major environmental pollution incident, there is an environmental illegal event, there is an environmental petition letter event, it has ISO9001 environmental management system certification, and it has developed an environmental management system.

Second, for the social variable (S), this study refers to Qiu and Yin (2019) and basic information based on social responsibility reports. We select indicators based on the design of the shareholders' rights and interests protection, creditors' rights and interests protection, staff's rights and interests protection, safety production, suppliers' rights and interests protection, consumers' rights and interests protection, the GRI's Sustainability Reporting Guidelines, environmental and sustainable development, public relations and social public welfare undertakings, and social responsibility system construction and improvement measures.

Third, for the governance variable (G), this study refers to Bai et al. (2005) and Qiu and Yin (2019) and selects the nature of the controlling shareholders, integration of two key positions (whether the chair and general manager are the same person), proportion of independent directors, sum of squares of the shareholding ratio of the top 10 major company shareholders (concentration), and the management's shareholding ratio.

Finally, for the ESG comprehensive variable, the ESG comprehensive score was calculated with equal weights according to the three-dimensional variables of the environment, social responsibility, and corporate governance.

3.2.2 Core explanatory variable

Development of the digital economy. (1) Index Selection. Based on the core content of the meaning of the digital economy, this study uses Huang et al. (2019) and Zhao et al. (2020) as references and combines relevant data availability at the city level to measure the comprehensive digital economy development level from the two dimensions of Internet development and digital financial inclusion. First, the dimension of Internet development covers the digital infrastructure and the development of related digital industries. Indicators are adopted from four aspects: mobile phone penetration rate, Internet penetration rate, output of related industries, and employees of related industries. The specific corresponding indicators were as follows: the number of mobile phone users among 100 people, number of Internet broadband access users among 100 people, per capita income of telecom services, and number of computer services and software employees that account for the proportion of urban employees. Second, the development dimension of digital finance reflects the integration of the digital industry, and adopts the China Digital Inclusive Finance Index. (2) Measurement methods. In this study, a combined weighting method was adopted to determine the weight. Specifically, the entropy method of the objective weighting method is used to assign weights to specific evaluation indicators of internet development. The time

TABLE 1 Variable definitions.

Variables	Variable description
Explained variables	
ESG	The equal weight sum of E, S, and G dimensions
E	Whether it is a key monitoring unit, whether the discharge of pollutants is up to standard, whether there is a sudden major environmental pollution event, whether there is an environmental illegal event, whether there is an environmental petition letter event, whether to pass the ISO14001 environmental management system certification, whether to develop environmental management system
S	Whether to formulate shareholders' rights and interests protection, whether to formulate creditors' rights and interests protection, whether to formulate staff's rights and interests protection, whether to formulate safety production, whether to formulate suppliers' rights and interests protection, whether to formulate consumers' rights and interests protection, whether to refer to the GRI's Sustainable Development Report Guide, whether there is environmental and sustainable development, whether there are public relations and social welfare undertakings, whether there are social responsibility system construction and improvement measures
G	Nature of controlling shareholders, combination of two positions (whether the chair and general manager are the same person), proportion of independent directors, square sum of shareholding ratio of the top 10 major shareholders of the company (concentration degree), shareholding ratio of management (ratio of the number of directors, supervisors, and senior management of the company to the total number of shares)
Core explanatory variable	
Digital	Development of urban digital economy
Intermediary variables	
InnoIn	Enterprise innovation input: percentage of R&D investment in operating revenue
InnoOut	Enterprise innovation output: the logarithm of (number of patent applications granted in the year add one)[a]
Enterprise characteristic variables	
Size	Company size: Logarithm of total assets
ROA	Profitability: Return on assets
Leverage	Corporate risk: Asset liability ratio
Growth	(Total assets ending value of current period - Total assets ending value of last year period)/(Total assets ending value of last year period)
Regional characteristic variables	
PerGDP	Logarithm of real GDP per capita
Ind	Industrial structure upgrading: The proportion of output value of primary, secondary, and tertiary industries in GDP is calculated by multiplying by 1, 2, and 3, respectively, and adding together
Gover	Expressed in terms of the proportion of local fiscal expenditure in GDP, reflecting the size of the government
Pop	Population size: Logarithm of the registered population at the end of the year
Capital	The value of the provincial capital is 1; otherwise, it is 0

Note: The price variables of total assets and per capita GDP, are deflated using the GDP deflator of prefecture-level cities, taking 2011 as the base year.
[a]Avoid the number of patent applications granted in the year for some enterprises from being zero for which the logarithm cannot be taken.

variable was added by referring to an improved entropy weight method (Yang and Sun, 2015). The two dimensions of Internet development and digital inclusive finance have equal granted value of 0.5.

3.2.3 Intermediary variables

Enterprise innovation includes both innovation input and output. It is generally measured by R&D investment, number of patents, and output value of new products (Hagedoorn and Cloodt, 2003). In this study, the percentage of R&D investment in operating revenue is used to measure enterprise innovation input. The number of patent applications granted in the year was used to measure enterprise innovation output.

3.2.4 Control variables

This study selects enterprise and regional variables. At the enterprise level, company size, profitability, corporate risk, and development ability were selected based on Qiu and Yin (2019), Alda (2021), and Chang et al. (2021). At the city level, this study also selected the logarithm of per capita gross domestic product (GDP), industrial structure upgrading, government size, population size, and city administrative rank (provincial capital) indicators. In addition, we controlled for province, industry, and time effects. The definitions of these variables are listed in Table 1. The descriptive statistics for each variable are shown in Table 2.

TABLE 2 Descriptive statistics.

Variables	Observations	Mean	Std. Dev	Min	Max	Quantile		
						25%	50%	75%
ESG	16,203	−0.0000	0.3917	−9.3946	1.3346	−0.2236	0.0089	0.2372
E	16,203	−0.0000	0.5837	−28.6952	0.1586	−0.0241	0.1586	0.1586
S	16,203	−0.0000	0.8336	−1.4180	1.8714	−0.5982	0.2152	0.6294
G	16,203	−0.0000	0.7157	−1.2163	3.0120	−0.5924	−0.1367	0.4622
Digital	16,203	0.3974	0.1495	0.0243	0.7044	0.2898	0.4014	0.5004
Size	16,203	21.8630	1.2640	19.4824	25.7726	20.9596	21.6954	22.5895
ROA	16,203	0.0490	0.0386	0.0000	0.1869	0.0199	0.0400	0.0680
Leverage	16,203	0.4164	0.2022	0.0518	0.8696	0.2522	0.4070	0.5714
Growth	16,203	0.2038	0.3714	−0.2581	2.5712	0.0314	0.1088	0.2340
TAR	16,203	0.9229	0.0930	0.5099	1.0000	0.9096	0.9544	0.9781
CurrentRatio	16,203	2.5090	2.5369	0.3308	16.5412	1.1836	1.6980	2.7818
Age	16,203	9.9759	7.0586	1.0000	29.0000	4.0000	8.0000	16.0000
PE	16,203	86.6128	156.5995	5.6347	1,093.9960	21.8835	37.9460	77.1568
TobinQ	16,203	2.0223	1.2428	0.8811	8.1098	1.2443	1.6100	2.3215
PerGDP	1,846	10.9507	0.4610	8.9100	12.0016	10.6471	11.0736	11.3401
Ind	1,846	2.4888	0.1677	1.9327	2.8320	2.3750	2.4802	2.5982
Gover	1,846	0.1571	0.0575	0.0439	0.6929	0.1138	0.1382	0.2030
Pop	1,846	6.4437	0.6453	2.9704	8.1362	5.9925	6.4965	6.8950
Capital	1,846	0.2823	0.4501	0.0000	1.0000	0.0000	0.0000	1.0000
Loan	1,846	1.5405	0.6206	0.1322	4.2399	1.0402	1.5433	1.9899
Sch	1,846	5.7230	0.8916	0.0000	7.1795	5.2866	5.8718	6.3263
Pat	1,846	8.4882	1.5867	1.6292	10.8143	7.5172	8.8568	9.7052
InnoIn	8,549	4.4499	4.0090	0.0400	23.8700	2.1700	3.5700	5.2900
InnoOut	8,549	1.6780	1.4190	0.0000	5.6419	0.0000	1.6094	2.6391

3.3 Model setting

3.3.1 Basic empirical model

Ordinary least-squares (OLS) regression was adopted in this study. We constructed the following model to test the overall effect of urban digital economy development on enterprise ESG performance:

$$\boldsymbol{ESG_{i,j,t}\big/E_{i,j,t}\big/S_{i,j,t}\big/G_{i,j,t} = \alpha_0 + \alpha_1 Digital_{j,t-1} + \alpha_2 Control_{i,j,t-1} + \mu_p + \theta_k + \tau_t + \varepsilon_{i,j,t}} \tag{1}$$

where *ESG* represents enterprise ESG performance; *E*, *S*, *G* represent environmental, social, and governance, respectively; *Digital* represents the development of the urban digital economy; *Control* represents a series of control variables; and ε represents a random error term. The subscripts i, j, and t represent enterprise, city, and time, respectively. μ, θ, and τ represent the effects of the province, industry, and time, respectively. To address endogeneity, all explanatory variables were lagged by one period.

To test Hypothesis 1, we performed a regression on Eq. 1. In the equation with ESG as the explained variable, if the estimation coefficient $\boldsymbol{\alpha}_1$ of digital economy development is significantly positive, Hypothesis 1 is valid.

3.3.2 Constructing the multiple mediation effect model

Based on Liu and Ling (2009) and Dong et al. (2020), this study further constructs the following multiple mediation effect model to test the mediation channel of urban digital economy development on enterprise ESG performance, that is, the influencing mechanism test model:

$$\boldsymbol{InnoIn_{i,j,t} = \beta_0 + \beta_1 Digital_{j,t} + \beta_2 Control_{i,j,t} + \mu_p + \theta_k + \tau_t + \varepsilon_{i,j,t}} \tag{2}$$

$$\boldsymbol{InnoOut_{i,j,t} = \gamma_0 + \gamma_1 Digital_{j,t} + \gamma_2 InnoIn_{i,j,t} + \gamma_3 Control_{i,j,t} + \mu_p + \theta_k + \tau_t + \varepsilon_{i,j,t}} \tag{3}$$

$$\boldsymbol{ESG_{i,j,t} = \rho_0 + \rho_1 Digital_{j,t-1} + \rho_2 InnoIn_{i,j,t-1} + \rho_3 InnoOut_{i,j,t-1} + \rho_3 Control_{i,j,t-1} + \mu_p + \theta_k + \tau_t + \varepsilon_{i,j,t}} \tag{4}$$

TABLE 3 Regression results of the impact of urban digital economy development on enterprise ESG performance.

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	**ESG**	**ESG**	**ESG**	**E**	**S**	**G**
Digital	0.1475***	0.1475***	0.2020**	−0.1507	−0.1666	0.9233***
	(0.0488)	(0.0485)	(0.0879)	(0.1193)	(0.1834)	(0.1616)
Size		0.0514***	0.0514***	−0.0373***	0.2581***	−0.0666***
		(0.0032)	(0.0032)	(0.0051)	(0.0061)	(0.0055)
ROA		0.5870***	0.5914***	−0.0808	0.9394***	0.9156***
		(0.0857)	(0.0857)	(0.1135)	(0.1706)	(0.1639)
Leverage		−0.1681***	−0.1690***	−0.0375	−0.1053**	−0.3642***
		(0.0202)	(0.0202)	(0.0277)	(0.0422)	(0.0366)
Growth		0.0147*	0.0143*	0.0431***	−0.0811***	0.0809***
		(0.0077)	(0.0077)	(0.0083)	(0.0161)	(0.0150)
PerGDP			0.0310*	0.0173	0.0961***	-0.0205
			(0.0171)	(0.0262)	(0.0350)	(0.0308)
Ind			−0.0824	0.1680*	−0.4772***	0.0619
			(0.0628)	(0.1005)	(0.1220)	(0.1077)
Gover			0.1649*	0.4348***	0.0827	−0.0228
			(0.0878)	(0.1257)	(0.1840)	(0.1654)
Pop			0.0547***	0.0172	0.1315***	0.0153
			(0.0102)	(0.0179)	(0.0204)	(0.0179)
Capital			−0.0459***	−0.0209	−0.0334	−0.0833***
			(0.0125)	(0.0204)	(0.0252)	(0.0225)
Constant	−0.1115***	−1.2047***	−1.7866***	0.0942	−6.7393***	1.2853***
	(0.0423)	(0.0786)	(0.2362)	(0.3058)	(0.5051)	(0.4503)
Province FE	YES	YES	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Observations	16,203	16,203	16,203	16,203	16,203	16,203
Adjusted R-squared	0.0820	0.1026	0.1045	0.0378	0.2181	0.1522

Note: Robust standard errors are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

where *InnoIn* represents enterprise innovation input and *InnoOut* represents enterprise innovation output. The other settings are the same as those in Eq. 1 [2]. Eq. 2 tests the influence of digital economy development on the first intermediary variable, innovation input. Eq. 3 tests the influence of digital economy development on the second intermediary variable, innovation output, and the influence of the first intermediary variable, innovation input, on the second intermediary variable, innovation output. Eq. 4 tests the influence of digital economy development, the first intermediary variable, and the second intermediary variable on ESG performance respectively. Multiple mediation effects test conditions were run accordingly. The specific path of the multiple mediation effect model is shown in Figure 1; the mediation effect includes parallel and chain mediation effects. In this study, the two parallel mediation effects refer to "digital economy development → enhancing innovation input intensity → improving ESG performance" (Hypothesis 2) and "digital economy development → improving innovation output capacity → improving ESG performance" (Hypothesis 3). The chain mediation effect refers to "digital economy development → enhancing innovation input intensity → improving innovation output capacity → improving ESG performance" (Hypothesis 4).

2 This study does not consider the time lags between digital economy development and enterprise innovation, which are reflected as technological progress. Therefore, Eqs 2, 3 are not treated with time lags.

4 Empirical results and discussion

Eq. 1 was used to estimate the results presented in Table 3, which reports the benchmark test results vis-à-vis the impact of urban digital economy development on enterprise ESG performance. Columns (1)–(3) show the regression results of the impact of digital economy development on total ESG performance, and Columns (4)–(6) show the regression results of the impact of digital economy development on environment (E), social responsibility (S), and corporate governance (G), respectively. Column (1) reports the estimation results without adding control variables. The estimation coefficient of the digital economy development (Digital) is positive and significant at the 1% significance level. Column (2) shows the estimation results for the addition of the enterprise characteristic control variables. The estimation coefficient of the digital economy development (Digital) is 0.1475, which is significantly positive at the 1% significance level. In Column (3), the estimated results of the enterprise and regional characteristic control variables are added. The estimated coefficient of digital economy development (Digital) is 0.2020, which is still significantly positive. This indicates that the development of the urban digital economy significantly improves enterprise ESG performance, which supports Hypothesis 1.

The regression results for the control variables are basically in line with our expectations. Company size (Size), profitability (ROA), and development ability (Growth) all play significant roles in promoting ESG performance, while corporate risk (Leverage) is not conducive to the improvement of ESG performance. The level of economic development (PerGDP), government size (Gover), and population size (Pop) all have significant positive effects on ESG performance. Provincial capitals (Capital) do not have superior ESG performance.

The regression results for each component of ESG are shown in Columns (4)–(6) of Table 3. The estimated coefficients of digital economy development (Digital) in columns (4) and (5) are all negative, but not significant. The development of the digital economy not only has positive effects, but may also have negative effects. Specifically, there is an inverted U-shaped relationship between digitization and environmental performance; that is, excessive levels of digitization can have a "rebound effect" that increases resource use and leads to higher pollution (Ahmadova et al., 2022). In addition, digital transformation and technological change may damage workers' rights and interests (Stevenson, 2019; Trajtenberg, 2019). This study also finds that digital economy development significantly improves corporate governance (G), which is consistent with the conclusion of Qi et al. (2020a) that digital economization improves corporate governance.

5 Influencing mechanism

According to the above theoretical analysis, the impact of urban digital economy development on enterprise ESG performance is mainly through the enterprise innovation path.

TABLE 4 Mechanism identification of digital economy development's impact on ESG performance.

	(1)	(2)	(3)	(4)
Variables	**ESG**	**InnoIn**	**InnoOut**	**ESG**
Digital	0.4395***	1.9710*	0.9054**	0.4231***
	(0.1226)	(1.0389)	(0.3529)	(0.1229)
InnoIn			0.0126***	0.0028**
			(0.0038)	(0.0013)
InnoOut				0.0119***
				(0.0042)
Constant	−1.3860***	6.0876**	−11.0692***	−1.2724***
	(0.3344)	(2.6190)	(1.0510)	(0.3361)
Control variables	YES	YES	YES	YES
Province FE	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Observations	8,549	8,549	8,549	8,549
Adjusted R-squared	0.0804	0.4224	0.3854	0.0817

Note: Robust standard errors are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

The influencing mechanism includes two aspects: innovation input (InnoIn) and innovation output (InnoOut).

As the sample size changes with the addition of intermediary variables, Eq. 1 is re-estimated. According to the regression results in Column (1) of Table 4, the estimated coefficient of digital economy development (Digital) is 0.4395 and passes the 1% significance level test, which is consistent with the previous baseline regression results. This shows that the overall effect of digital economy development on ESG performance is significantly positive, again supporting Hypothesis 1.

The regression results in Columns (2) and (3) of Table 4 were obtained by estimating Eqs 2, 3, respectively. Column (2) takes innovation input (InnoIn) as the explained variable, and the estimated coefficient of digital economy development (Digital) is significantly positive. This finding shows that development of the digital economy increases enterprises' R&D capital investment intensity. Column (3) takes innovation output (InnoOut) as the explained variable, and the estimated coefficients of digital economy development (Digital) and innovation input (InnoIn) are significantly positive. This result shows that both the development of the digital economy and innovation input significantly increase innovation output.

The regression results in Column (4) of Table 4 were obtained by estimating Eq. 4. Column (4) considers ESG to be the explained variable. Compared with the regression results in Column (1), the estimation coefficient of digital economy development (Digital) on ESG performance is still significantly positive, but the absolute value of the coefficient is smaller. The

TABLE 5 Impact of digital economy development on ESG performance by distinguishing the four economic regions.

	East	Central	West	Northeast
Variables	ESG	ESG	ESG	ESG
Digital	0.3737***	0.4919	0.8004	1.6528**
	(0.1052)	(0.5082)	(0.5383)	(0.7515)
Constant	−1.3079***	−2.2204***	−2.1051***	0.8193
	(0.2903)	(0.7849)	(0.6979)	(1.3955)
Control variables	YES	YES	YES	YES
Province FE	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Observations	11,053	2,278	2,044	828
Adjusted R-squared	0.1070	0.1685	0.1315	0.2617

Note: Robust standard errors are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

estimation coefficients of innovation input (InnoIn) and innovation output (InnoOut) are significantly positive.

In summary, the empirical results in Columns (1)–(4) of Table 4 show that multiple mediation effect test conditions are established, indicating that the overall effect of digital economy development on ESG performance is significant, and that there are parallel and chain mediation effects. Specifically, there is the first parallel mediation effect, namely, "digital economy development → enhancing innovation input intensity → improving ESG performance." Thus, Hypothesis 2 is established. There is the second parallel mediation effect, namely, "digital economy development → improving innovation output capacity → improving ESG performance," and thus, Hypothesis 3 is established. There is chain mediation effect, namely, "digital economy development → enhancing innovation input intensity → improving innovation output capacity → improving ESG performance," and thus, Hypothesis 4 is established.

6 Heterogeneity analysis

6.1 Four economic regions

According to the regression results in Table 5, among the four economic regions, the coefficients of digital economy development (Digital) in the eastern and northeastern regions are significantly positive at the 1% and 5% levels, respectively, indicating that the development of the urban digital economy has a significantly positive impact on ESG performance in the eastern and northeastern regions. Furthermore, the positive impact was greater in the northeastern region than that in the eastern region. However, in the central and western regions, the digital economy effect is not significant.

6.2 Urban agglomerations

This subsection further selects representative urban agglomerations of the Beijing-Tianjin-Hebei, Yangtze River Delta, and Pearl River Delta as research objects to analyze the heterogeneity of urban agglomerations. The regression results in Table 6 show that the estimated coefficients of digital economy development (Digital) of the representative urban agglomeration as a whole and the Yangtze River Delta urban agglomeration are significantly positive at the 5% level. This indicates that the development of the digital economy significantly improves the ESG performance of enterprises in the representative urban agglomeration as a whole and the Yangtze River Delta urban agglomeration. In addition, the estimated coefficients of digital economy development (Digital) of the representative urban agglomeration as a whole and the Yangtze River Delta urban agglomeration (0.3022 and 0.8081, respectively) were much higher than the baseline regression estimation result (0.2020). This indicates that urban agglomerations, as new engines of digital economy development, play a central role in such development, promoting the economic transformation of enterprises. The Yangtze River Delta urban agglomeration, with Shanghai, Hangzhou, Nanjing, and other central cities, performed well.

6.3 Enterprise development stage

The samples were divided into two groups according to the median age of the listed companies: older and younger. According to the descriptive statistics of all the samples of listed companies, the median age of the companies was 8 years. Therefore, the sample group of listed companies whose company age is less than 8 years is defined as the younger age group, and the sample group of listed companies whose company age is greater than or equal to 8 years is defined as the older age group. As the regression results in Table 7 show, the development of the urban digital economy has a significant promotion effect on the ESG performance of enterprises in the younger age group, passing the 1% significance level test. However, the development of the urban digital economy had no significant impact on the ESG performance of enterprises in the older age group. According to enterprise life cycle theory, the development of enterprises shows different characteristics as firms age. In the early stages of development, enterprises must establish core competitiveness to survive. Therefore, the younger a company is, the stronger its desire for innovation, and the stronger its ESG performance to attract more investment.

TABLE 6 Impact of digital economy development on ESG performance by distinguishing urban agglomerations.

	Total	Beijing-Tianjing-hebei	Yangtze river delta	Pearl river delta
Variables	ESG	ESG	ESG	ESG
Digital	0.3022**	0.5383	0.8081**	0.0095
	(0.1241)	(0.5201)	(0.3289)	(0.3879)
Constant	−1.2777***	−3.8549**	−1.4481*	−1.6404
	(0.3812)	(1.7840)	(0.7988)	(1.2352)
Control variables	YES	YES	YES	YES
Province FE	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Observations	9,240	2,107	4,882	2,251
Adjusted R-squared	0.1059	0.2389	0.0852	0.2055

Note: Robust standard errors are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

TABLE 7 Impact of digital economy development on ESG performance by distinguishing company age groups.

	Younger age	Older age
Variables	ESG	ESG
Digital	0.4369***	−0.1356
	(0.1247)	(0.1241)
Constant	−0.8510**	−2.6064***
	(0.3478)	(0.3248)
Control variables	YES	YES
Province FE	YES	YES
Industry FE	YES	YES
Year FE	YES	YES
Observations	7,563	8,640
Adjusted R-squared	0.0997	0.1330

Note: Robust standard errors are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

TABLE 8 Impact of digital economy development on ESG performance: two-stage regression and LIML estimation.

	(1)	(2)	(3)
	First-stage	Second-stage	LIML
Phone	0.0000***		
	(0.0000)		
Post	0.0000***		
	(0.0000)		
Digital		0.3500*	0.3500*
		(0.1937)	(0.1937)
Constant	−1.4285***	−1.5083***	−1.5083***
	(0.0204)	(0.4282)	(0.4282)
Control variables	YES	YES	YES
Province FE	YES	YES	YES
Industry FE	YES	YES	YES
Year FE	YES	YES	YES
Minimum eigenvalue statistic	1933.63		
Observations	15,488	15,488	15,488
Adjusted R-squared	0.9629	0.1063	0.1063

Note: Robust standard errors are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

7 Robustness test

7.1 Endogeneity

On the one hand, there may be a reverse causal relationship between urban digital economy development and enterprise ESG performance. On the other hand, owing to the complexity of the factors influencing ESG performance, it is difficult to prevent the occurrence of missing variables in the current study design. The core explanatory variable is treated as a one-period lag, which can alleviate endogeneity to a certain extent. Furthermore, this study attempts to solve the endogeneity problem using instrumental variables. Therefore, based on the methods of Nunn and Qian (2014), Huang et al. (2019), and Zhao et al. (2020), we construct the interaction terms of the number of fixed-line telephones and post offices per 100 people in each city in 1984 (related to individual change) and the number of Internet users in China in the previous year (related to time) as instrumental variables (Phone and Post) of the urban digital economy development index for the year.

Table 8 reports the results of the two-stage regression and limited information maximum likelihood (LIML) estimation. From the regression results of the first stage in Column (1), the

TABLE 9 Impact of digital economy development on ESG performance: Substitution of core explanatory variable and test of missing variables.

	(1)	(2)
Variables	**ESG**	**ESG**
Pat	0.0260***	
	(0.0073)	
Digital		0.2108**
		(0.0898)
Constant	−1.5124***	−2.0517***
	(0.2537)	(0.2464)
Control variables	YES	YES
Province FE	YES	YES
Industry FE	YES	YES
Year FE	YES	YES
Observations	16,203	16,203
Adjusted R-squared	0.1049	0.1384

Note: Robust standard errors are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

TABLE 10 Impact of digital economy development on ESG performance: Alternative measures.

	(1)	(2)
Variables	**FE**	**RE**
Digital	0.2473*	0.5209***
	(0.1484)	(0.0963)
Constant	−0.3814	−0.2339
	(0.5641)	(0.2170)
Control variables	YES	YES
Year FE	YES	YES
Observations	16,203	16,203
R-squared	0.0257	0.0530

Note: Robust standard errors are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

interaction between the number of fixed-line phones per 100 people in 1984 and the number of Internet users in the last year (Phone), and the interaction between the number of post offices per 100 people and the number of Internet users in the last year (Post) are both significantly positively correlated with the development of the digital economy. It can be seen from the regression results of the second stage in Column (2) that the estimated coefficient of digital economy development (Digital) is significantly positive, which indicates that the conclusions of this study remain robust after considering endogeneity. In addition, we test whether the instruments are weak, and find that the minimum eigenvalue statistic is 1933.63, which is far greater than the critical value of 19.93 of the 10% Wald's test, ruling out the possibility of weak instruments. In this study, the LIML method is used to test the samples, and the results are shown in Table 8. The regression coefficient of LIML is consistent with the coefficient of the two-stage regression of instrumental variables, which is significantly positive, and it also indicates that urban digital economy development is closely positively correlated with enterprise ESG performance. In general, the selected instrumental variables are reasonable.

7.2 Number of patents granted is used to replace the core explanatory variable

As the number of patents granted in the region where the enterprise is located can well reflect the development level of the regional digital economy, we conduct a robustness test from the perspective of regional patent authorization, which is processed as follows: weighted number of patents granted = number of inventions obtained in the year *0.5 + number of utility models obtained in the year *0.3 + number of exterior designs obtained in the year *0.2. The logarithm of the weighted number of patents granted with a one-period lag in the city was taken as the core explanatory variable. The results are shown in Column (1) of Table 9. The number of patents granted (Pat) is significantly positively correlated with enterprise ESG performance and passes the 1% significance level test, indicating that patent grants significantly improve the ESG performance of enterprises, which is consistent with the previous conclusions of this study.

7.3 Test of missing variables

Factors such as enterprise capital structure, enterprise relative value, financial development, and level of human capital in the region may also affect ESG performance. Therefore, relevant factors were further controlled in this study to mitigate the impact of missing variables on the main results. Specifically, this study places the following variables in the regression model: company's age (Age), tangible asset ratio (TAR), price–earnings ratio (PE), current ratio (CurrentRatio), Tobin's Q (TobinQ), ratio of loans of the national banking system at year-end to GDP (Loan), and logarithm of the number of university students per 10,000 people (Sch). According to Column (2) of the regression results in Table 9, the estimation coefficient of digital economy development (Digital) is still significantly positive even after possible missing variables are included. This result is consistent with that of the baseline regression.

7.4 Alternative measures

Because the data are unbalanced panel data, this study uses the fixed effects model and random effects model for an additional test. The regression results of Columns (1) and (2) in Table 10 show that the estimation coefficients of digital economy development (Digital) are still significantly positive, which again highlights the robustness of this study's conclusions.

8 Conclusion and recommendations

Based on the matching of micro-level data of enterprises and macro-level data of prefecture-level cities in China from 2012 to 2020, this study constructs the enterprise ESG performance index and urban digital economy index. This study examines the influence and mechanism of urban digital economy development on the ESG performance of enterprises in China. The conclusions are summarized as follows:

First, it innovatively finds that the development of the urban digital economy significantly improves enterprise ESG performance in China from a general perspective. In addition, certain factors such as company size, profitability, company risk, development capacity, economic development, population size, and government size also affect enterprise ESG performance. Second, this study innovatively proposes and tests influencing mechanism. We find evidence for the two parallel mediating effect channels of "digital economy development → enhancing innovation input intensity → improving ESG performance" and "digital economy development → improving innovation output capacity → improving ESG performance." We also find evidence for the chain mediation effect channel of "digital economy development → enhancing innovation input intensity → improving innovation output capacity → improving ESG performance." Third, a heterogeneity analysis was conducted in terms of the four economic regions, urban agglomerations, and company age. The results show that among the four economic regions, the development of the urban digital economy in eastern and northeastern China significantly improves enterprise ESG performance. The development of the digital economy significantly improves enterprise ESG performance in representative urban agglomerations as a whole and the Yangtze River Delta urban agglomeration. The development of the digital economy significantly improves the ESG performance of enterprises in the younger age cohort. Finally, the main conclusions of this study remain valid after a series of robustness tests such as alleviating endogeneity, replacing the core explanatory variable, testing omitted variables, and alternative measures.

Based on these conclusions, the following suggestions are proposed for the government and enterprises. First, it is important to comprehensively promote the development of digital China. The level of digital economy development varies among the different regions in China, and there is still extensive room for improvement. The government should accelerate the promotion of digital industrialization and industrial digitization, realize the transformation and upgrading of traditional industries, and support the development of emerging industries. Enterprises should seize new opportunities in the digital economy era and realize their digital transformation. Second, the government should accelerate the construction of ESG information disclosure systems, improve ESG rating standards, and create better investment environment. Third, enterprises should consider not only the cost of their input into ESG activities but also ESG performance's sustainability benefits. Finally, it is significant to promote enterprise innovation to improve ESG performance effectively and achieve a path toward firms' sustainable development. Specifically, it includes boosting the intensity of enterprise R&D investment, optimizing the quantity and quality of enterprise patents, and promoting the transformation of the output value of new products to improve the level of enterprise innovation capability.

This study has several limitations. First, due to data limitations, the indicators of urban digital economy development and enterprise ESG performance are not perfect at present. Future research should keep pace with the times and continue to improve relevant measures combined with the new characteristics of digital technology and enterprise reform. Second, as the global digital economy enters a new stage, digital transformation leads to economic and social changes and has a profound impact on enterprises' sustainable development, including countries, regions, and even individuals. This study uses China as an example to analyze the impact of digital economy development on ESG performance. Future research could consider global economic development as a perspective for establishing and improving the ESG system. Achieving sustainable development by promoting the development of the digital economy and enhancing the ESG performance of enterprises is a comprehensive and long-term strategy.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

GC conceived and designed the research method; JH analyzed the data and wrote and finalized the manuscript; and HY collected the data and performed preliminary analysis and writing. All authors have read and agreed to the published version of the manuscript.

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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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Environmental protection tax, corporate ESG performance, and green technological innovation

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Environmental, social, and corporate governance (ESG) performance is an analytical framework for measuring the contribution of enterprises to sustainable development and fulfillment of social responsibility. The introduction of an environmental protection tax in China in 2018, which imposes tax on the pollution emission of enterprises, helps enterprises improve their ESG performance and raise their environmental awareness, thus effectively promoting their green technological innovation to achieve sustainable development. This study examines the effect of China's environmental protection tax on corporate ESG performance and green technology innovation. The findings showed that the environmental protection tax in China can vastly improve the ESG performance and green technological innovation, with the ESG performance exhibiting a partial mediating effect in promoting corporate green technological innovation. The mediating effect in enhancing ESG performance and green technological innovation varies with the nature of firms' property rights and regions.

KEYWORDS

environmental protection tax, green technological innovation, mediating effects, ESG, taxable pollutants

Introduction

Rapid economic growth has caused serious damage to global resources and the ecological environment. Environmental, social and corporate governance (ESG) was first introduced in the "Who Cares Wins" initiative released by the UN Global Compact in 2004. In 2006, the UN Principles for Responsible Investment (UNPRI) incorporated ESG into investment decisions, with the aim of promoting sustainable corporate development and enabling investors to focus more on the performance of companies in terms of environmental friendliness, social responsibility, and corporate governance, rather than on their financial performance. With the widespread recognition of ESG in society, third-party organizations in various countries have devised their own ESG rating systems to measure enterprises' ESG performance in three dimensions: environmental, social, and corporate governance responsibilities.

China introduced the environmental protection tax on January 1, 2018, the first tax to address environmental protection in China. China's environmental protection tax is levied on air pollutants, water pollutants, solid waste, and noise. Taxes for air and water pollutants are determined by the people's governments of each province, municipalities directly under the Central Government, and autonomous regions in China. These are based on the tax range specified in the Environmental Protection Tax Law of the People's Republic of China: the tax for solid waste is RMB5–1,000 per ton[1] and noise is taxed at RMB350–1,200 per month[2] based on six noise levels. The Chinese environmental protection tax directly levies taxes on taxable pollutants emitted by enterprises with the aim of reducing the emission of pollutants by transforming the external environmental costs of enterprises into their internal production costs. At the policy level, the environmental protection tax has a "double dividend" effect, as it can reduce the emission of pollutants by enterprises and effectively improve environmental quality, thus realizing an environmental dividend. Although the environmental protection tax will increase the costs of the enterprises, the technological innovation of the enterprises will have an innovative compensation effect which will improve their productivity and boost their financial performance. The improvement of enterprise production efficiency and transformation of green production will also have a sound effect on the green development of the economy and realize the social dividend of the environmental protection tax. To save the cost of the tax and gain sound political affinity, enterprises will optimize their production process by green transformation, which may improve the environmental and social performance of companies. Therefore, China's environmental protection tax may help firms improve ESG performance (Chen et al., 2022).

However, there are few studies on the impact of China's environmental protection tax on corporate ESG performance. Based on this background, this study selected the data of A-shares listed enterprises from 2016 to 2020 as the research sample. Additionally, a difference-in-differences model was used to test the effect of the environmental protection tax on corporate ESG performance and green technological innovation. We conducted various robustness tests, including alternative variables, placebo test, and random sample censoring. The findings showed that the environmental protection tax in China can vastly improve the ESG performance and green technological innovation. We also found that China's environmental protection tax had a partial mediating effect on improving corporate green technological innovation through corporate ESG performance.

1 Coal gangue: RMB5/tonne; tailings: RMB15/tonne; hazardous waste: RMB1000/tonne, including smelting slag, fly ash, slag, other solid waste (e.g., semi-solid, liquid waste).

2 A monthly tax of RMB350 is levied on industrial noise exceeding the standard by 1–3 decibels; a monthly tax of RMB700 is levied on industrial noise exceeding the standard by 4–6 decibels; a monthly tax of RMB1,400 is levied on industrial noise exceeding the standard by 7–9 decibels; a monthly tax of RMB2,800 is levied on industrial noise exceeding the standard by 10–12 decibels; a monthly tax of RMB5,600 is levied on industrial noise exceeding the standard by 13–15 decibels; and a monthly tax of RMB11,200 is levied on industrial noise exceeding the standard by 16 + decibels.

Literature review and research hypothesis

Literature review

Environmental tax and double dividend

Pigou argued that the root cause of negative externalities for firms was the gap between private and social costs, and that tax policy could correct negative externalities and improve overall social welfare. Tullock (1967) was the first to propose the multiple dividends effects of environmental taxes, and Pearce (1991) was the first to use the term "double dividend," arguing that environmental taxes can help improve environmental quality while promoting economic development and social equity. The environmental dividend of environmental taxes has been generally recognized in academic circles, while the social dividend has remained a controversial topic. For example, Baumol and Oates. (1988)argued that environmental taxes helped reduce carbon emissions. In a study of the Indian cement industry, Sabuj (2010) found that environmental regulation could improve energy use efficiency and reduce pollution emissions. A study of environmental taxes implemented in Finland and Malaysia by He, (2019)found that both environmental and social dividends could be realized in the long run. Chinese scholars also argued that the "environmental dividend" and "social dividend" could be achieved within a certain tax rate range (He, 2021; Sun et al., 2021). However, Liu and Zhou (2010) argued that environmental taxes had a negative impact on employment and economic growth. Similarly, Dai et al. (2021)found that environmental regulations affected trade. Adopting a CGE model to test, Carbon taxation could achieve a "double dividend" and encourage investment (Orlov and Grethe, 2012).

Environmental protection tax and firm performance

Neoclassical economic theory suggests that environmental protection tax increases the tax burden of enterprises: when revenue remains unchanged, the operating income is reduced and the business and financial performance is impaired. Gary (1987) found that environmental regulations increased firms' costs and reduced their financial performance. Barbera (1990) argued that firms' rising pollution abatement costs would result in reduced productivity in some industries. "The Porter hypothesis" is a break with traditional economics. To maximize profits, firms have to reduce the tax burden arising from the environmental protection tax by engaging in technological innovation or improving productivity. Thus, "The Porter hypothesis" suggests that appropriate environmental regulations improve the productivity and product quality of enterprises and enhance their financial performance. Berman and Bui (2001) confirmed this view through a study of oil refining in Los Angeles. Lin (2013) confirmed that under environmental regulation, technological innovation helped firms reduce emissions and sell their products, and that appropriate environmental regulation could also achieve the "triple effect" of environment, firm financial performance, and economic growth. Sun et al. (2021) found that the promotion of green technological innovation helped improve the utilization of natural resources, and green technological innovation helped reduce production costs. Measuring the competitiveness of enterprises in three dimensions (i.e., enterprises' operational capacity, development capacity, and external linkage capacity), Bi and Yu, (2019) concluded that environmental taxes had a positive effect on the competitiveness of enterprises. Wei and Hu (2021) argued that administrative and market-based environmental policies had a positive effect on the long-term performance of firms with their salient contribution to corporate social responsibility.

Environmental tax and green technological innovation

Weitzman (1974) was the first to theoretically argue that tax instruments have a stronger effect on technological innovation than administrative orders alone. Acemoglu et al. (2012) found that tax policies and research subsidies are helpful for green technological innovation and emission reduction. The relationship between political affiliation and corporate innovation performance was analyzed by Yang and Yu (2014), showing that political affiliation serves to enhance the outcomes of corporate patent efforts. Bi et al. (2019) found that environmental taxes could promote green investments by firms and was conducive to environmental governance and improvement. According to Schumpeter's innovation theory, R&D investment can promote the enhancement of firms' technological innovation and competitiveness. Bai and Chen. (2022) theoretically confirmed that environmental regulation stimulated firms' intrinsic motivation for environmental governance and had a catalytic effect on firms' innovation investment and improvement of governance technology. In their study of the shift from the pollutant discharge fee to environmental protection tax in China in 2018, Yu et al. (2021) found that the shift had a significant promotion effect on the green transformation of heavy-polluting enterprises, albeit with differences among enterprises with various characteristics. Huang et al. (2022) also argued that the environmental protection tax could promote technological innovation of enterprises, but the degree of impact varied for enterprises of different property rights and different sizes.

ESG performance and corporate behavior

With the increasing emphasis on environmental protection, a growing number of scholars are linking corporate ESG performance to corporate behavior. Fatemi et al. (2017) found that sound corporate ESG performance could enhance corporate financial performance. However, Ruhaya et al. (2018) suggested the converse. Bowenand and Gond. (2013) stated that social responsibility motivated businessmen to make decisions based on social values and government wishes. Tan and Zhu, (2022) argued that sound ESG performance of firms could reduce financing constraints, helping them to attract investment and engage in technological innovation. Tian (2020) adopted a game theory approach and found that the role of social responsibility on the performance of corporate technological innovation was more salient in regions with lower environmental tax rates. Using a large cross-sectional dataset, Li et al. (2018) found ESG discourse has a positive impact on firm value. Francesco et al. (2021) also argued that ESG pillars could help improve firms' behavior, particularly highlighting the impact of the governance pillar.

Research hypothesis

Environmental protection tax and corporate ESG performance

Environmental protection tax in the broad sense refers to the emission of pollutants, resource use, and management, that is, all taxes related to resource use and resource bonding. The environmental protection tax in the narrow sense refers only to the tax that came into effect in China in 2018. The environmental protection tax analyzed in this study is limited to the concept of environmental protection tax in the narrow sense.

China's environmental protection tax takes the emissions of pollutants from enterprises as the basis for taxation and aims to achieve environmental protection. The introduction of an environmental protection tax reflects the Chinese government's intention for green development, and guides the society in enhancing environmental protection awareness, attracting greater attention to environmental protection to achieve sustainable social development. In order to reduce the costs of environmental protection tax, enterprises optimize their production process, improve their utilization rate of resources, reduce energy consumption, and choose more environmentally friendly packaging, which indirectly reduces the emission of pollutants. In the production process, enterprises directly reduce the emission of pollutants by improving the pollution treatment process and the end treatment technology, which improves their environmental performance. The stakeholder theory holds that the development of enterprises is related to the quality of their response to stakeholder demands. The implementation of environmental protection tax enables society to pay greater attention to the environmental protection actions and sustainable development strategies of enterprises, thus enhancing consumers' willingness to purchase the products of enterprises with sound environmental protection behaviors and a strong sense of social responsibility. Companies also improve their social performance to gain a closer political affinity. However, the adjustment of corporate strategies and change in business awareness of corporate shareholders requires time. Thus environmental protection tax may not have a significant impact on corporate governance performance of companies in the short term. However, the implementation of environmental protection tax in China can improve corporate ESG performance in terms of the combined effect. Based on the above analysis, this study proposed Hypothesis 1 as follows:

H1: China's environmental protection tax improves the ESG performance of firms.

Environmental protection tax and green technological innovation

China's environmental protection tax is one of the key tools used by the government to manage the environment. The "Porter hypothesis" suggests that appropriate environmental regulation is conducive to corporate green technological innovation. China's environmental protection tax is an incentive-based environmental management system. Although the environmental protection tax has a dampening effect on the operating profit of enterprises, it stimulates enterprises to achieve green innovation. The environmental protection tax follows the ancient "polluter pays" principle, and the amount of tax costs borne by enterprises hinges on the amount of pollutants emitted. The development of green products, including those that are recyclable and reusable, and production of goods that are more in line with sustainable development reduces the pressure of production on the environment, leading to the compensatory effect of innovation, thus increasing firms' enthusiasm for green technological innovation. In addition, the environmental protection tax introduced in China in 2018 produced stronger enforcement with less administrative intervention from local governments than the previous administrative fees. Owing to the mandatory nature of the tax and the monitoring of pollution emissions by environmental protection departments, enterprises have less bargaining power with the government, which also reduces the government's rent-seeking behavior (Lv and Cao, 2019). Therefore, the institutional advantages of China's environmental protection tax induces rational firms to improve their green technological innovation capabilities and reduce the potential environmental protection tax costs. Therefore, Hypothesis 2 is proposed.

H2: China's environmental protection tax significantly promotes firms' green technological innovation.

The mediating effect of corporate ESG performance on green technological innovation

Green technological innovation refers to the use of green products, green technologies, and green processes to achieve the alignment of the economic, social, and ecological performance of enterprises. Green technological innovation not only refers to the improvement of production processes, but also includes the research and development (R&D) of green products and the use of new tools or new methods. The green technological innovation of enterprises is closely related to R&D investment, and Song and Du. (2017) found that the investment of R&D funds has a positive effect on green technological innovation. The improvement of corporate ESG performance can effectively reduce the financing constraints of enterprises and attract more institutional investors following corporate ESG performance, which is conducive to corporate green technological innovation. Good environmental performance of firms is in line with the rising environmental awareness of society and promotes political affinity. To maintain sound environmental performance, enterprises need to improve their green technological innovation capabilities by continuously improving their production processes, pollution treatment technologies, and resource utilization. Sound social performance of enterprises improves the relationship between enterprises and stakeholders. By taking more social responsibility, enterprises can more easily obtain technical support and government procurement, reduce the information asymmetry of external investors, and gain access to more investment to advance their green technological innovation. The management teams of companies with better corporate governance performance tend to have a more precise understanding of national policies and pay greater attention to environmental protection, as well as to long-term corporate development and value enhancement. Green technology innovation not only promotes the green transition of enterprises, but also has a better promotion effect on the improvement of enterprise value. Therefore, the improvement of corporate ESG performance contributes to the improvement of corporate green technological innovation capability. Thus, Hypothesis 3 is proposed.

H3: Corporate ESG performance has a mediating effect on the relationship between environmental protection tax and corporate green technological innovation in China.

Research design

Model setting

The environmental protection tax introduced in China in 2018 is viewed as a quasi-natural experiment exogenous to the economic system, and the difference-in-differences model is considered a relatively mature method to test the net effect of policy adjustments. This study constructed a difference-in-differences model.

$$GTI = \alpha_0 + \alpha_1 treated_i{*}post_t + \beta X_{i,t} + \lambda_i + \mu_t + \varepsilon_{i,t} \quad (1)$$

In Eq. 1, i and t represent the firm and year. GTI, representing the green technology innovation, is the explained variable. We searched the number of green patent applications of enterprises on the Chinese Research Data Services (CNRDS) based on the green technology classification list provided by the OECD and World Intellectual Property Office (WIPO), and selected the logarithm as the mediating variable (GTI) by adding 1 to the number of applications.

The core explanatory variable is the dummy variable $treated_i{*}post_t$, which is used to indicate the excess impact of China's environmental protection tax on heavy polluting enterprises.

Referring to Yu et al.'s (2021) and Bai and Chen, (2022) selection of variables, we use the control variables Xi,t, including firm size (Size), leverage ratio (Lev), return on assets (Roa), regional economic level (Gdp), nature of equity (state), firm year (Age), and the degree of equity concentration (share). λi is the individual fixed effect, μt is the time fixed effect, and Ɛi,t is the random error.

To test whether corporate ESG performance has a mediating effect on the role of environmental protection tax in promoting corporate green technology innovation, the mediating effect is incorporated into the difference-in-differences model and the following models are constructed.

$$ESG = \gamma_0 + \gamma_1 treated_i{*}post_t + \beta X_{i,t} + \lambda_i + \mu_t + \varepsilon_{i,t} \quad (2)$$

$$GTI = \theta_0 + \theta_1 treated_i{*}post_t + \theta_2 ESG_{i,t} + \beta X_{i,t} + \lambda_i + \mu_t + \varepsilon_{i,t} \quad (3)$$

ESG represents corporate ESG performance, which is the mediating variable. The mediating effects of environmental (E), social (S), and corporate governance (G) dimensions on the relationship between the environmental protection tax and corporate green technological innovation in China was also examined and the other variables are defined in the same way as in Eq. 1.

Data source

This study selected heavy polluters as the treatment group and non-heavy polluters as the control group. Based on the definition of heavily polluting industries in the Guidelines for Environmental Information Disclosure by Listed Companies (Consultation Draft) issued by the Ministry of Ecology and Environment of the People's Republic of China and the Guidelines for the Industry Classification of Listed Companies (2012 Revision) issued by the China Securities Regulatory Commission, this study selected 16 heavily polluting industries such as steel, cement, coal, and metallurgy as the treatment group samples, and the cultural and entertainment, transportation, wholesale, retail and leasing services as the control group samples.

TABLE 1 Descriptive statistics results of the main variables.

Variables	Sample	Mean	Std. Dev	Min	Max
GTI	4,560	1.4059	1.4583	0	7.3627
treat	4,560	0.3197	0.4664	0	1
post	4,560	0.6	0.4900	0	1
Lev	4,560	0.4783	0.1979	0.01	1.7
Size	4,560	23.3788	1.2098	19.73	28.42
Roa	4,560	0.0483	0.0718	−0.9560	0.478
lnGDP	4,560	11.2738	0.4227	10.2300	12.01
State	4,560	0.4886	0.4999	0	1
Age	4,560	14.9616	6.6126	0	30
Roe	4,560	0.0806	0.2369	−8.2200	2.09
Share	4,560	0.5931	0.1516	0.1460	0.9510
ESG	4,560	22.0939	6.8657	6.6604	64.0749
E	4,555	11.5472	8.1375	0.0075	65.2011
S	4,560	24.7707	9.3725	3.3595	77.3600
G	4,560	46.5281	5.0244	3.5700	84.08

TABLE 2 Results of difference-in-differences regression.

	(1)	(2)	(3)	(4)	(5)
	GTI	GTI	RD	GTI	GTI
Treat*post	0.107**	—	0.183***	0.132***	0.063
	(2.52)	—	(9.49)	(2.93)	(1.21)
pre2	—	0.126	—	—	—
	—	(0.169)	—	—	—
pre1	—	0.271	—	—	—
	—	(0.171)	—	—	—
Current	—	0.319*	—	—	—
	—	(0.172)	—	—	—
post1	—	0.417	—	—	—
	—	(0.172)**	—	—	—
post2	—	0.203	—	—	—
	—	(0.170)	—	—	—
control variables	Y	Y	Y	Y	Y
_cons	−4.2**	−10.295***	−0.436	−2.842	−4.216
	(−2.32)	(1.704)	(−0.52)	(−1.46)	(−1.09)
Individual fixed effects	Control	Control	Control	Control	Control
Time fixed effects	Control	Control	Control	Control	Control
N	4560	4560	4560	4104	4560
R2	0.1198	0.1242	0.0256	0.1191	0.1188

Notes: t-statistic values in parentheses, $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

Our initial sample consisted of the A-shares listed companies of China from 2016 to 2020, excluding the samples containing ST, ST*, and missing key data during the sample period, and excluding the special enterprise samples such as financial and insurance industries and comprehensive enterprises. We used Bloomberg database ESG scores of A-share listed companies to measure corporate ESG performance. All the control variables were from the WIND database. To avoid the influence of extreme values on the empirical results, observations below the 1st and above the 99th percentile of the continuous variable data were excluded, and the final sample data of 4560 were obtained. Table 1 shows the descriptive statistics results of the main variables.

Empirical results

Basic regression results

The results of the regression for treat*post is shown in Column 1 (Table 2), which shows the results of Model 1; the regression coefficient is significant at the 5% level. This result indicates that the implementation of an environmental protection tax in China effectively promotes the improvement of green technological innovation in Chinese enterprises. In other words, the green technological innovation of heavy polluting enterprises is more effective than that of non-heavy polluting enterprises (Yu et al., 2021; Huang et al., 2022).

The use of a DID model must satisfy the parallel trend assumption. Thus, to verify whether the parallel trend hypothesis holds, the following dynamic effect model of the impact of environmental protection tax on corporate green technological innovation in China is constructed thus:

$$GTI = \alpha_0 + \alpha_1 pre_2 + \alpha_2 pre_1 + \alpha_3 current + \alpha_4 post_1 + \alpha_5 post_2 + \beta X_{i,t} + \lambda_i + \mu_t + \varepsilon_{i,t} \tag{4}$$

where pre2, pre1, current, post1, and post2 are the cross multiplication terms of the time dummy variables and the heavily polluting polluters from 2016 to 2020, respectively. The specific results are shown in Column 2 (Table 2), revealing that the results for pre2 and pre1 do not reach the 10% level of significance. Thus, there was no significance gap in China before the implementation of the environmental protection tax policy. In other words, the control and experimental groups satisfy the parallel trend hypothesis, and the DID model is adopted.

To further test whether the above results are all robust, we conducted the following tests. First, to reduce the error of variable selection, we measured enterprise green technological innovation (GTI) by replacing the number of green patent applications with the ratio of environmental protection input (RD) in Column 3. Second, to exclude the bias of sample selection, 10% of the original sample was randomly censored and DID regression was performed again, as shown in Column 4. Third, to exclude the interference of other policies on the empirical results, this study conducted a placebo test, assuming that the implementation time of environmental protection tax policy was 2019, in Column 5. The results of Columns 3 and 4 show that the coefficients of treat*post are positive at 1% level of significance, supporting our main findings. The result shown in Column 5 does not reach significance, which indirectly confirms that firms are able to implement green technological innovation because of the environmental protection tax rather than the other policies.

Mediating effects

To analyze the mediating effect of ESG performance on the relationship between environmental protection tax and green technological innovation in China, a DID analysis was performed on models 2 and 3. Table 3 presents the regression results. As shown in Column 1, the treat*post coefficient is significant at the 5% level, indicating that the implementation of China's environmental protection tax can improve the overall ESG performance of enterprises. This result is similar to that of Chen et al. (2022). The regression coefficient of treat*post in Column 2 is 0.103, significant at the 5% level, while the regression coefficient of ESG in Column 2 is 0.010, significant at the 1% level, indicating that ESG performance has a partial mediating effect. As ESG consists of three dimensions (i.e., environmental (E), social (S), and corporate governance (G)), we conducted a regression analysis of E, S, and G on models 2 and 3 to analyze the impact of China's environmental protection tax on E, S, and G and the mediating effect of E, S, and G on corporate green technology innovation. The results, shown in Columns 3, 5, and 7 of the table, indicate that the environmental protection tax can improve the environmental and social performance of firms, but has no significant effect on improving the corporate governance performance of firms. In other words, China's environmental protection tax can enhance corporate ESG performance, but this is mainly due to enhanced environmental performance and social performance of firms. From the regression results in Columns 4, 6, and 8 of the table, it can be deduced that environment and society play a partial mediating role in corporate green technological innovation, and have no significant effect on corporate governance. Thus, the mediating effect of ESG performance on corporate green technological innovation is the result of the company's environmental and social performance.

TABLE 3 Mediating effects.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	ESG	GTI	E	GTI	S	GTI	G	GTI
Treat*post	0.410**	0.103**	0.582**	0.104**	0.696**	0.103**	-0.080	0.108**
	(2.14)	(2.43)	(2.31)	(2.45)	(2.43)	(2.41)	(-0.53)	(2.53)
ESG	—	0.010***	—	—	—	—	—	—
	—	(2.64)	—	—	—	—	—	—
E	—	—	—	0.006**	—	—	—	—
	—	—	—	(2.01)	—	—	—	—
S	—	—	—	—	—	0.007***	—	—
	—	—	—	—	—	(2.88)	—	—
G	—	—	—	—	—	—	—	0.003
	—	—	—	—	—	—	—	(0.64)
control variables	Y	Y	Y	Y	Y	Y	Y	Y
_cons	−13.989*	−4.139**	−1.862	−4.389**	−43.603***	−3.966**	44.181***	−4.409**
	(−1.69)	(−2.25)	(−0.17)	(−2.38)	(−3.52)	(−2.15)	(6.82)	(−2.38)
Individual fixed effects	Control	Control	Control	Control	Control	Control	Control	Control
Time fixed effects	Control	Control	Control	Control	Control	Control	Control	Control
N	4560	4560	4560	4560	4560	4560	4560	4560
R2	0.0990	0.1215	0.0655	0.1213	0.0539	0.1218	0.0285	0.1199

Note: t-statistic values in parentheses, $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

TABLE 4 Heterogeneity in the nature of property rights.

	(1)	(2)	(3)	(4)
	ESG	GTI	ESG	GTI
Treat*post	−0.049	0.137**	0.931***	0.075
	(−0.18)	(2.35)	(3.34)	(1.18)
ESG	—	0.014***	—	0.007
	—	(2.64)	—	(1.41)
control variables	Y	Y	Y	Y
_cons	−0.172	−5.555**	−41.281***	−3.819
	(−0.02)	(−2.37)	(-3.01)	(−1.23)
Individual fixed effects	Control	Control	Control	Control
Time fixed effects	Control	Control	Control	Control
Nature of sample	SOEs	SOEs	Non-SOEs	Non-SOEs
N	2228	2228	2332	2332
R2	0.0905	0.1647	0.1149	0.0967

Note: t-statistic values in parentheses, $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Heterogeneity analysis

The regression analysis was performed by grouping by the nature of enterprise property rights (Table 4). The coefficient of treat*post in Column 1 is non-significant, while the coefficient of treat*post in Column 3 is significant at the 1% level, indicating that China's environmental protection tax improves the ESG performance of non-state-owned enterprises (non-SOEs). The results in Columns 2 and 4 indicate that China's environmental protection tax promotes green technological innovation in SOEs, which is contrary to Huang et al. (2022). This is probably because SOEs, with less financial pressure, advantageous resource endowment, closer relationship with government departments, and stronger government bargaining power, do not need to obtain external investment and government policies by improving corporate ESG performance. In addition, SOEs have had a greater social responsibility and better relationship with stakeholders since their inception and raised their environmental standards before the implementation of China's environmental protection tax. Thus, the implementation of China's environmental protection tax has no significant effect on the ESG performance of SOEs. However, SOEs have easier access to financial and technical support, and thus the Chinese environmental protection tax has a significant impact on improving green technological innovation in SOEs. Contrariwise, non-SOEs are more motivated to improve their ESG performance to secure better government relations, attract more investment, and reduce financing constraints. However, access to financing has a lag effect;

TABLE 5 Regional heterogeneity analysis.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	ESG	GTI	ESG	GTI	ESG	GTI	ESG	GTI
Treat*post	0.685***	0.063	−0.027	0.325***	0.509	−0.007	−0.785	0.488**
	(2.63)	(1.08)	(−0.05)	(3.27)	(1.17)	(−0.08)	(−1.25)	(2.39)
ESG	—	0.013***	—	0.010	—	−0.003	—	−0.014
	—	(2.80)	—	(1.16)	—	(−0.28)	—	(−0.51)
control variables	Y	Y	Y	Y	Y	Y	Y	Y
_cons	4.444	3.022	41.421	−8.289	−58.111**	7.323	1.080	−9.650
	(0.32)	(0.96)	(1.22)	(−1.22)	(−2.42)	(1.40)	(0.03)	(−0.95)
Individual fixed effects	Control	Control	Control	Control	Control	Control	Control	Control
Time fixed effects	Control	Control	Control	Control	Control	Control	Control	Control
Regional Classification	Eastern Region	Eastern Region	Central Region	Central Region	Western Region	Western Region	Northeast Region	Northeast Region
N	2928	2928	721	721	710	710	201	201
R2	0.0985	0.1074	0.0816	0.1974	0.1739	0.1157	0.1915	0.2414

Note: t-statistic values in parentheses, $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

as most non-SOEs have a weak foundation, they are thus unable to immediately improve their green technological innovation capability.

The China Statistical Yearbook divides China into four regions[3]: central, eastern, western, and northeastern. The regression analysis is done for models 2 and 3 (Table 5). The regression coefficients of ESG performance in eastern China are significant at the 1% level, while the regression coefficients of GTI are non-significant, indicating that the environmental protection tax improves the ESG performance of enterprises in the eastern region, and ESG performance has a complete mediation effect in improving the green technological innovation of enterprises. For central and northeastern China, environmental protection tax can enhance firms' green technological innovation, but has no significant effect on the ESG performance of firms in central, western, and northeastern China. A possible reason is that the general tax standard is higher in eastern China and enterprises bear high tax costs. Enterprises aim to reduce financing constraints and attract investment by improving ESG performance; they also have an incentive to reduce tax costs by improving their green technological innovation capabilities. In addition, the eastern region has a higher concentration of talents, a higher degree of marketization, and a more mature financing mechanism than other regions, implying a more powerful driver for technological innovation. This result is consistent with that of Lu and Dang (2014). Therefore, the ESG performance of enterprises in eastern China has a complete mediation effect on the relationship between environmental protection tax and corporate green technological innovation.

Conclusion and policy suggestions

With increasing awareness of environmental protection, analyses of long-term corporate value and development potential are no longer limited to financial indicators, and experts and scholars are increasingly incorporating ESG concepts into investment practices. Therefore, studying the intrinsic relationship and operational mechanism of environmental protection tax, green technological innovation, and corporate ESG performance can help improve corporate ESG performance, attract favorable investors, and enhance corporate green technological innovation capability. Based on this, the sample data of A-share Chinese listed companies from 2016 to 2020 was used to establish a difference-in-differences model to test the impact of the introduction of the environmental protection tax in China on corporate green technological innovation and ESG performance. Additionally, the role of corporate ESG performance in environmental protection tax and corporate green technological innovation was verified, and a heterogeneity analysis was conducted. We find that China's environmental protection tax has a significant effect

3 The eastern region includes 10 provinces (cities): Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan; the central region includes 6 provinces: Shanxi, Anhui, Jiangxi, Henan, Hubei, and Hunan; the western region includes 12 provinces (regions, cities): Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang; and the northeast region includes Liaoning, Jilin, and Heilongjiang.

on the improvement of corporate green technological innovation and ESG performance, and the improvement of ESG performance is observed in two aspects, namely, environmental performance and social performance. In addition, China's environmental protection tax has a partial mediation effect on improving corporate green technological innovation through corporate ESG performance; that is, corporate ESG performance is partially mediated by environmental performance and social performance of the three dimensions, with no significant effect on corporate governance. Moreover, China's environmental protection tax has different effects on firms with different types of property rights and in different regions. The environmental protection tax aims to improve the technological innovation capacity of SOEs and enterprises in central, eastern, and northeastern regions, but it can only improve the ESG performance of non-SOEs and enterprises in eastern region. Finally, the ESG performance of enterprises in the eastern region has a complete mediation effect. Based on the analysis results, the following policy insights are derived:

First, appropriately raise the tax standards. The cost of environmental management varies across regions, and thus differential taxation standards needs to be implemented in different regions. With the continuous development of China's economic level and the maturity of environmental protection technology, tax standards need to be raised in some regions at an appropriate time. Therefore, given the improvement of China's economy and environmental technology, the rate for environmental protection tax must be appropriately increased in some regions. However, the increase must be in line with the actual requirements of China's economic development, and be gradual: the tax rate for pollutants with more serious pollution hazards must be the first to be raised, followed by other pollutants, based on the economic growth.

Second, gradually expand the scope of taxation. The purpose of the environmental protection tax in China is to reduce the pollution of the environment and improve the ecological environment by taxing pollutants. However, some of the pollution is still not included in the scope of taxation. Thus, the effect of environmental protection tax on green technological innovation and ESG performance in some regions or industries is not salient. For example, while volatile organic compounds include 12 major categories, only some of the volatile organic compounds in air pollution are taxed, such as benzene, toluene, and formaldehyde. Thus, all volatile organic compounds should be gradually included in the taxation scope in the future. In addition, noise pollution only includes industrial noise, but construction and aircraft noise, which have a greater impact on residents, should also be included in the scope of taxation. China's environmental protection tax should not be limited to the current four categories of pollutants, but should also gradually include light pollution, household waste, and thermal pollution into the scope of environmental protection tax.

Third, industry disparities should be reflected in China's environmental protection tax. Owing to the differences in technology base, pollution level, and major pollutants of each industry, differential taxation is implemented by industry. This avoids regional tax competition and improves the targeting and flexibility of the environmental protection tax. According to the survey by the Ministry of Environment of China, sulfur dioxide and nitrogen oxides are the main pollutants. However, currently, differential taxes for different pollutants are adopted in less than half of the cities in China. Thus, in the future, slightly higher tax rates should be set for sulfur dioxide and nitrogen oxides in air pollutants and chemical aerobics in water pollutants based on the industry tax gap. Solid waste is currently taxed in four classes by category and a differential tax rate should be set for each type of waste by quantity in the future. Such a differential tax rate by industry and different emissions helps guide society toward the green concept and enterprises toward enhancing environmental efficiency, fulfilling social responsibility, and improving ESG performance.

The main contribution of this study is that we focus on corporate ESG performance from the perspective of China's environmental protection tax, and study the intermediary effect of ESG performance between environmental protection tax and green technology innovation of enterprises. A signification limitation of our study is its use of A-share listed firms in China for the data of ESG performance, ignoring the small and medium-size enterprises. In future research, we will establish an ESG index evaluation system and use data from multiple countries.

Data availability statement

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

Author contributions

JL led the conceptual design of the manuscript, SL wrote the initial drafts and built the model, all authors reviewed the manuscript and provided comments and feedback.

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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Carbon neutrality vs. neutralité carbone: A comparative study on French and English users' perceptions and social capital on Twitter

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Carbon neutrality is one of the most critical global concerns at present. As one of the largest social media, Twitter is used widely by individuals, organisations, and government agencies to share their comments and perceptions on carbon neutrality. This study collected 26425 English and 20331 French tweets to compare the differences between French and English tweets. Social network analysis found that users in the French social networks interacted more frequently than the English ones. The geodesic analysis evidenced that the connection of any two users required about five intermediate users on average in French networks, while English ones required seven intermediate users. The modularity metrics of the English network were higher, indicating that users in English networks did not communicate with different clusters and people in carbon neutrality issues. In addition, the French network of carbon neutrality activists comprised politicians, government agencies, journalists, NGOs, and companies, while those in the English network mainly included companies, media, and politicians. Sentiment analysis and independent samples t-test have confirmed that despite the types of activists and the interactions between clusters being different, negative Tweets were more than positive ones in English and French networks, especially in French networks. It may be caused by people's dissatisfaction with the government's current carbon neutrality policy. By analysing the social pattern on Twitter, the research results allow people to know more about the means to enhance carbon-neutral knowledge sharing, which has the policy and social significance for addressing climate change.

KEYWORDS

carbon neutrality, Twitter, social network analysis, sentiment analysis, social capital

Introduction

Global warming impacts society, the economy, the environment, and other aspects (Rabaey and Ragauskas, 2014; Hoang and Kanemoto, 2021). Since the industrial revolution, greenhouse gas emissions caused by human activities have been the leading cause of global warming. It is one of the critical factors that restrict sustainable development. Energy issue has been at the core of United Nations Sustainable Development Goals. To lay a solid foundation for prosperity, scholars pointed out that countries should balance three critical aspects of the energy trilemma: environmental sustainability, energy security, access and affordability (Khan et al., 2022). In 2015, the "Paris Agreement" reached a consensus that the global temperature increase should not exceed 2°C by the 21st century (Shao X. et al., 2021). The special report from the Intergovernmental Panel on Climate Change released in 2018 highlighted that limiting global warming to 1.5°C can significantly reduce the impact of climate change. Thus, countries worldwide must reduce their emissions to achieve carbon neutrality. The US government promised that greenhouse gas emissions in 2030 will be reduced by 50%–52% compared with 2005 and reach carbon neutrality by no later than 2050 (Whitehouse, 2021). The EU claims that by 2050, more than 80% of the electricity will come from renewable energy, on top of about 15% of nuclear power, which will be the pillar of Europe's carbon-free power system. As one of the important member states of the European Union, the French National Assembly incorporated net-zero emission into law on 27 June 2019. The High Council on Climate of France suggested that the government triple the emission reduction rate to achieve the carbon neutrality goal in 2050 (Gouvernement, 2017).

To achieve carbon neutrality and sustainably support human activities, reducing carbon emissions from fossil fuels and promoting carbon sequestrations in terrestrial and marine ecosystems are essential. For example, India has been using biomass energy to overcome the current energy crisis (Irfan et al., 2022). However, the existing technologies, policies, and people's living habits challenge reaching the goal of net-zero carbon emissions (Cheng, 2020). Although many countries have implemented laws requiring enterprises, organisations, and industries to use carbon-neutral technology gradually and publish their carbon emission data (Attia et al., 2021), carbon neutrality remains a non-mandatory activity at the individual level. Reaching this target mainly depends on personal environmental awareness and perception of climate change (Wan et al., 2021). Yangka et al. (2019) pointed out that carbon neutrality relies not only on the nation's policy but people's willingness, which is the premise for reaching the goal of carbon neutrality.

With the development of information communication technology, social media enables people to share their views and change how they communicate (Song et al., 2022). It eliminates time and space constraints and facilitates knowledge dissemination and sharing (Yao et al., 2022). Previous studies have confirmed the potential of using social media such as Twitter to share expert knowledge and increase user interest in specific topics (Etemadi et al., 2021; Yao et al., 2021). However, few studies highlighted the public attitudes and information flow on carbon neutrality in social networks despite this topic being on many governments' agendas. Besides, understanding the public's views and opinions on carbon neutrality may ease governments' policy implementation, provide suggestions that lead to a low carbon society, relieve climate change and achieve sustainability goals. This research selects the French-speaking population and the English ones for several reasons: while English is the most popular language used by all nations, the Paris Agreement imposes a significant impact on carbon emission globally, and the government in France has just implemented carbon emission legislation (Légifrance, 2021; Ministère De La Transition Écologique Et De La Cohésuin Des Territoire. and Ministère De La Transistion Énergique, 2022), and there are high-profile protests on environmental issues in France (Garric, 2022, Ouest France., 2022; Le Deley, 2022; Monin, 2022). These three reasons indicate a high interest in carbon emission and environmental issues in the French-speaking community. Using carbon neutrality and neutralité carbone as keywords, this study collected English and French tweets to study the following research questions:

1) What are the users' perceptions of carbon neutrality on Twitter?
2) Who influences more on Twitter?
3) Do English and French social networks differ on carbon neutrality issues?

Acknowledging the importance of individual willingness on the issue, the literature review introduces the idea of social capital in social media, establishing a theoretical, and methodological framework for this study. Following the introduction, the literature review section first identifies the concept of carbon neutrality and three key factors that influence carbon neutrality. Section 3 illustrates the research methods: social network analysis, sentiment analysis and theory of computational communication to study English and French Twitter users' views and opinions on carbon neutrality. The conclusion offers insights to individuals who wish to share related carbon neutrality knowledge and raise awareness of people's environmental responsibility. It throws light on policy and social contribution of this research that address climate change.

Literature review

Carbon neutrality and influential factors

Many places worldwide advocate the carbon neutrality goal to alleviate the problems of climate change. Carbon neutrality refers to the environmental protection behaviour of reducing carbon dioxide emissions. It offsets the carbon dioxide produced by people through afforestation or by using green products and energy (Dhanda and Hartman, 2011; Bento et al., 2015). Carbon emissions are related to multiple factors such as population size (Ribeiro et al., 2019), industrial and energy structure (Wu et al., 2022), urbanisation (Xu et al., 2018), foreign trade (Zhang, 2012), sustainable use of material resources (Xie et al., 2022) etc., Among these factors, there are three foci in academia. Regarding technology and management, Prabu and Geeta (2015) proposed an underground coal gasification technology, which could use carbon dioxide as a gasification medium, combined with carbon capture and storage technology to increase net thermal efficiency and reduce carbon emissions significantly. Some scholars also concurred that realisation of village carbon neutrality should start with design and village infrastructure modification, adjusting the regional energy mode of operation, and adopting an appropriate biomass energy compensation mechanism to achieve carbon neutrality (Goodfield et al., 2014).

From the perspective of policies and regulations, the government needs to implement related policies and offer enterprises guidelines to reduce carbon emissions by improving the incentive and restraint mechanism to achieve carbon neutrality. For example, instead of giving subsidies, which will lead companies to maintain the status quo of non-market activities (Shao X.-F. et al., 2021), Zhang H. et al. (2021) suggested using carbon, energy, and other taxes to increase energy consumption or emission cost. These are the primary tools to regulate the cost of energy production. Jia and Lin (2020) discussed the different impacts of a carbon tax and trading mechanism on the environment, energy, and economy. They found that carbon tax is more potent in emission reduction than carbon trading (Zhang S.-C. et al., 2021; Carroll and Stevens, 2021). However, Povitkina et al. (2021) pointed out that the carbon tax is unfair due to a lack of trust in the government and high oil prices.

At present, there are many difficulties in achieving carbon neutrality. Ojha et al. (2020) showed that although carbon tax effectively reduces carbon emissions, it lowers GDP. Khastar et al. (2020) analysed the impact of a carbon tax on social welfare and emission reduction rate through a general equilibrium model. The result showed that although Finland's carbon tax policy successfully reduced carbon dioxide emissions, it harmed Finnish's social welfare. In addition, different people's willingness to pay for carbon offset projects was also an obstacle that hindered carbon neutrality. Rehman et al. (2021) found that carbon emissions from transportation affected Pakistan's economic development *via* econometric analysis. Mclennan et al. (2014) revealed that air passengers from the United Kingdom and Europe were more willing to pay for carbon offset projects than in Asia. Masood et al. (2015) stated that income, education level, and awareness of climate change heavily influenced the willingness to pay for carbon offset projects (Figure 1). Although studies have studied carbon neutrality in various fields and perspectives, people's perceptions and attitudes towards carbon neutrality on Twitter remain unclear.

Social capital in social media

Zhang et al. (2022) examined the role of information and communication technology (ICT) in environmental quality in developing countries during 1996–2019. It recommended that policymakers should invest more in ICT infrastructure and develop modern information systems to reduce unsustainable practices and increase public awareness of environmental quality. Lu and Wang (2018) found that appropriate media promotion changed people's perception of carbon neutrality and their behaviours. Social media, such as Twitter, has become a prosperous source of data to investigate people's behaviour in the physical world (Singh et al., 2020). Thus, we might consider a social network as a kind of social capital, that is, the connection to resources people have accessed to a social network (Lin, 2002). These resources consist of the strength of the network, people's relationships, and how people access information (Coleman, 1988).

There are two kinds of social capital: bridging and bonding. Bridging social capital refers to the weak ties that individuals with heterogeneous limited interactions form. Bridging social capital is more likely to provide valuable new information (Moshkovitz and Hayat, 2021). Bonding social capital refers to strong ties: the intimate relationships people feel close to and trust (Lu and Lee, 2021; Le, 2022). With the development of social media, users obtain a significant volume of information. Thus, online social capital is more effective than offline social capital, and previous research examined how people develop their online social networks through different uses (Ellison et al., 2007). De Zúñiga et al. (2017) found that online social capital exhibited different behaviour patterns.

As one of the most popular and influential social media, Twitter requires no reciprocity to follow or be followed by other users (Marwick and Boyd, 2010). This feature gives the Twitter user more social capital (Hofer and Aubert, 2013). Previous studies have investigated the strategies of what to post and share on social media. These strategies facilitate the management of users' self-image and help users accumulate social capital from social networks (Huvila et al., 2014). Moreover, Twitter enables connections with a wide range of people, and the information they reach can broaden their horizons, which increases their online bridging social capital (Hofer and Aubert, 2013). Thus, to understand the users with higher social capital and influence on Twitter and their characteristics in the carbon neutrality discussion networks,

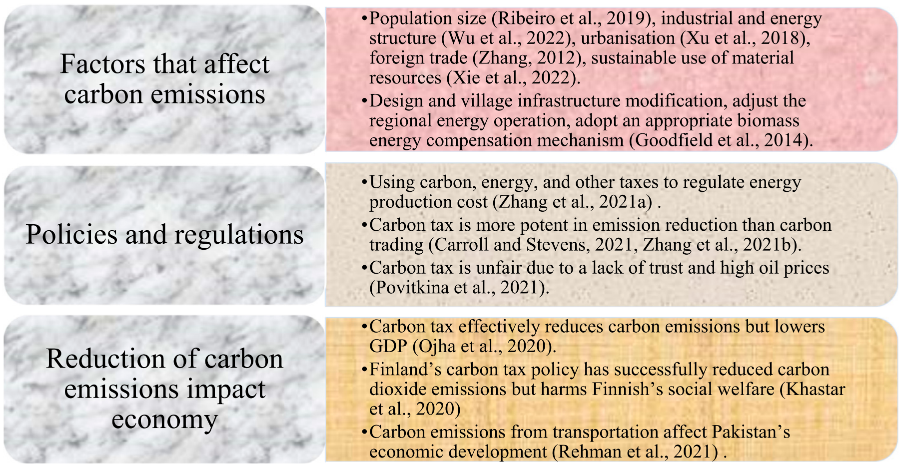

FIGURE 1
An overview of carbon-related research (authors' figure).

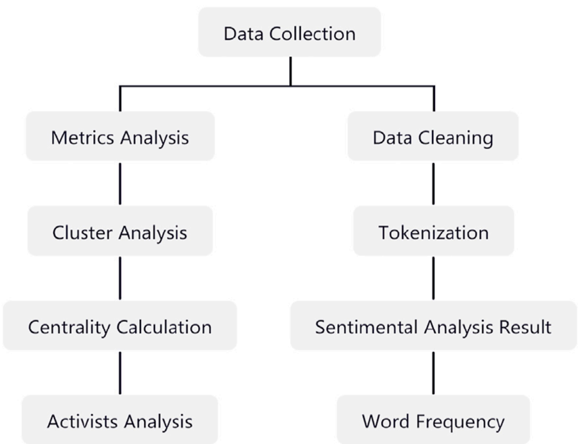

FIGURE 2
Methods applied in this study.

this study applied data mining, social network analysis and sentiment analysis.

Data collection and analysis

Social network analysis of English and French tweets

In the past two decades, the rise of social media has led to massive communication data, allowing academia to investigate social networks from a broader scope (Hayat et al., 2017). Social media also enables the non-disruptive data collection from various social platforms such as Facebook, Twitter, YouTube, etc., (Yao et al., 2021). One method for analysing social network data is social network analysis (SNA). SNA is used to present the logical structure of the two-dimensionally data visually. More importantly, researchers can visualise meaningful results to offer insights in the form of graphs for further study (Song et al., 2022). Another advantage of SNA is that it can process many social ties and describe the comprehensive relational network structure (Yao et al., 2022).

Moreover, clusters, relations, and positions of social media users can be manifestly characterised by analysing nodes (Suratnoaji et al., 2020). This study analysed both networks' activists, sentiment, and word frequency. The methods applied in this study is shown in Figure 2.

In order to have enough data that can be filtered or sampled, previous studies suggested using the keywords that return all potentially relevant tweets (Shelton et al., 2014; Grace et al., 2019). Thus, this study chose two keywords, namely "carbon neutrality" and "neutralité carbone", to collect sparse metadata. The data was collected from 1 January to 31 March 2022 *via* Twitter API. The data was then saved in the "vertices" and "edges" worksheets. Vertex is a node, referring to an individual, organisation, institution, or team (Hansen et al., 2010; Nodexl, 2022), and this study refers to the Twitter user. As shown in Table 1 English and 8647 French users were included. Edge is the link or connection that exchanges information between two vertices (Nodexl, 2022). This study collected 26425 English and 20331 French tweets separately. Average geodesic distance refers to the average number of paths connecting two vertices. It measures how many intermediate users may be required between any two users (Yao et al., 2022). The average geodesic distance between the English and French Twitter network was 7.150551 and 4.705047, respectively. This result indicated that the distances between any two users in the English

TABLE 1 Graph metric of English and French networks.

Graph metric	Value (English)	Value (French)
Vertices	17521	8647
Total Edges	26425	20331
Average Geodesic Distance	7.150551	4.705047
Modularity	0.749081	0.643406

network were more significant than that of the French network. The relationship between users in the English network was less intimate.

When investigating the social capital in Twitter, one of the critical metrics is modularity. Modularity examines the fitness of the groups in a network (Park et al., 2020) and quantifies the actual community structure in a network corresponding to a statistical arrangement of edges. Modularity can be positive or negative, and positive ones indicate the possible presence of community structure (Newman, 2006; Ouest France, 2022). If the modularity metrics are high, the connections within a group are dense, but the connections to other groups are sparse (Park et al., 2020). In this study, the modularity of the English network is higher than French, indicating that when discussing carbon neutrality issues, users in English networks tended to discuss, and interact in their clusters rather than others. On the other hand, the French users preferred to discuss with various clusters and different people. In this study, both English and French modularity were positive, evidenced the existence of the online community and English (0.75) was stronger than French (0.64).

This study clustered the vertices and analysed the characteristics of both networks *via* the Clauset-Newman-Moore (CNM) algorithm, which is suitable for extensive network analysis (Ahmed et al., 2020). The result was then visualised by Harel-Koren Fast Multiscale layout algorithms (as shown in Figure 3).

3627 English clusters and 903 French clusters were found. Although there were more clusters in the English network, most users only interacted in their own "small circles", the information flow between clusters was limited (this result was consistent with the modularity analysis), and their social capital was relatively low. On the contrary, the number of French networks was small, but the users were willing to go to other circles to discuss carbon neutrality issues. In other words, although the number of users and clusters was not as large as in the English network, the French network had more social capital and was likely to exert more influence than other users.

Activists of English and French networks

Recuero et al. (2019) stated that in-degree centrality manifests the number of mentions or retweets received by a vertex and is also an essential metric measuring social capital. This study selected nodes with the highest in-degree centrality in the top 10 clusters to study the attributes of the activists with more social capital. It analysed the role they play in carbon neutrality discussions on Twitter.

As shown in Table 2, among the top 10 activists, three were government officials, three were media, three were companies or company representatives, and only one was an individual. The activists with the most followers were the media; two came from China (despite this study only covered English and French Tweets). The nodes with the most social capital mainly used Twitter to spread carbon neutrality-related policies, plans, and progress. Politicians call for environmental protection and the realisation of carbon neutrality, and Twitter is a tool for publicity. Companies or company representatives use Twitter to advertise their products. Therefore, we can conclude that those with high social capital only used Twitter to send information in the English network. There were not many incentives in individual users' discussions. That is, to say, the activists

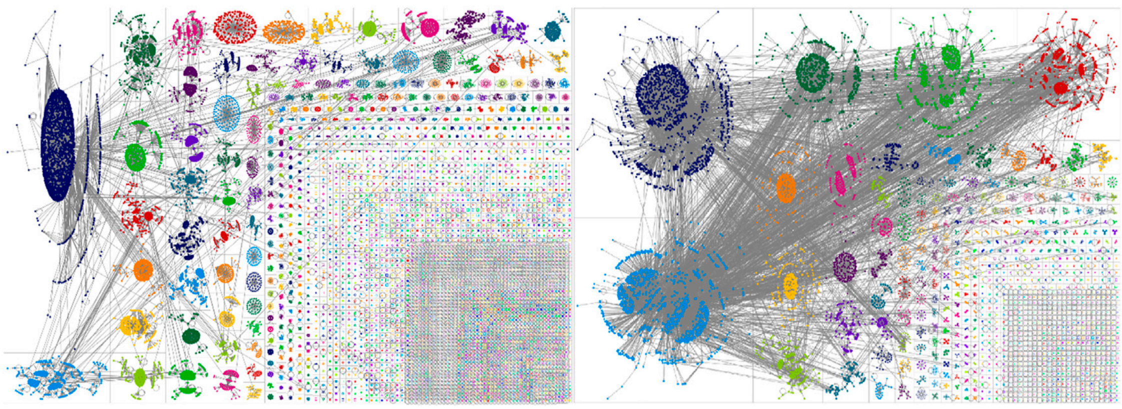

FIGURE 3
Characteristics of English (left) and French (right) networks.

TABLE 2 Top 10 activists in the English network.

ID	Followers	Attribute	Companies/individuals
antonioguterres	1677289	Secretary-General of the UN	Individual (global organisation)
xhnews	12308687	China state-affiliated media	Private company
kallemets	1928	CEO of an energy company	Individual (senior management, businessman)
huaweisolar	58980	Solar energy company	Private company
pdchina	6861898	China state-affiliated media	Organisation (government related, news)
mrkrudd	1579412	Former Prime Minister of Australia	Individual (politician)
phantasmachain	43822	NFT and gaming company	Private company
Afp	2294364	Agence France-Presse	Organisation (news)
timmermanseu	198811	Executive Vice-President for the European Green Deal	Individual (EU)
buweekulaprody	8495	Individual	Individual

TABLE 3 Top 10 activists in the French network.

ID	Followers	Attribute
emmanuelmacron	8143200	The President of France
Ademe	128532	The French Agency for Ecological Transition
audreygarric	57515	Journalist of Le Monde
bonpote	41656	Independent media
goldbergnic	15715	Senior manager of an energy consulting company
laydgeur	27974	Individual
maxcordiez	17635	Energy engineer
Cnrs	201152	French National Centre for Scientific Research
olivierdavid_ec	11014	Head of Directorate General of Energy and Climate
clemsenechal	20520	Spokesman of Greenpeace France (NGO)

in the English network did not consider carbon neutrality a general topic. There were not many active interactions between clusters. Scattered clusters decreased weak ties and interaction between groups, limiting people's access to different opinions and reducing the influence of activists (Wojcieszak and Mutz, 2009).

It can be seen from Table 3 that the activists in the French network with the highest number of followers were mainly government departments (or politicians) and companies (or company representatives), journalists and NGOs who diverted the discussion topics. Like activists in the English network, government departments (or politicians) promoted carbon neutrality policies and invited people to participate in carbon neutrality. Companies (or company representatives) promoted their technology and questioned the government's current policies. Journalists, NGOs, and individuals criticised the government's carbon neutrality actions and fossil energy companies. Because of these individual activists, the interaction between clusters in the French network was high. These activists with higher social capital can also better attract the attention of other users. Table 3 lists the top 10 activists in the French network.

Sentiment comparison of English and French tweets

This study conducted sentiment analysis to examine users' sentiments about carbon neutrality issues and whether there were differences between English and French networks. Sentiment analysis is often applied to identify opinions, feelings and attitudes in unstructured written texts such as Twitter comments (Soo-Guan Khoo et al., 2012). SentiStrength, which was used in this study, is a lexicon-based sentiment analysis tool. After analysing each word, SentiStrength can generate positive and negative scores for texts written in English, French, Portuguese, etc., (Yao et al., 2021). The scores range from +5 (extremely positive) to −5 (extremely negative).

After deleting tweets that could not be processed (containing only emojis or web links), 26243 English and 20198 French tweets were analysed. Among all the English tweets, 5815 (22.2%) were positive, 12013 (45.7%) were neutral, and 8415 (32.1%) were negative. Meanwhile, in the French network, 1930 (9.6%) were positive, 9365 (46.3%) were neutral, and 8903 (44.1%) were

TABLE 4 Independent samples t-test result.

		Levene's test for equality of variances		t-test for equality of means				
		F	Sig	T	df	Sig. (2-Tailed)	Mean difference	Std. Error difference
Sentiment Distribution	Equal variances assumed	0.003	0.958	−0.418	14	0.682	−755.62500	1808.80642
	Equal variances not assumed			−0.418	13.677	0.683	−755.62500	1808.80642

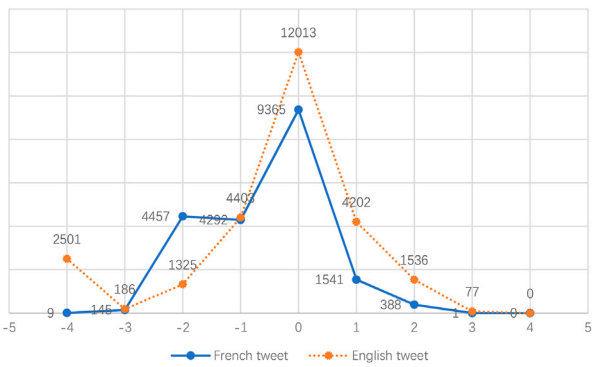

FIGURE 4
Sentiment distribution of English and French networks.

negative. As shown in Figure 4, most of the tweets in both English and French networks were neutral. The two networks also showed that negative sentiments exceeded the number of positive ones. In the French network, negative sentiments were almost five times that of positive sentiments. Previous studies shared similar findings: Peeters (2021) found that the French often shared their standpoints rather than kept them private. Song et al. (2022) also found that French speakers inclined to express their thoughts in a more extreme way.

As mentioned above, journalists and NGO spokespersons in the French network criticised the government's or certain enterprises' carbon neutrality policies and actions. However, most activists in the two networks were positively calling for and supporting the implementation of carbon neutrality. However, pessimistic tweets were more than positive ones in the two networks. An independent samples t-test was performed to compare sentiment distribution between English and French tweet networks. The result in Table 4 showed that there was not a significant difference in sentiment distribution between English and French tweets network; t (14) = −0.418, p = 0.682. In other words, despite the types of activists and the interactions between clusters being different, people's attitudes towards carbon neutrality were statistically the same.

To understand the detail of users' discussions on carbon neutrality, this study studied the word frequency of all the tweets. As shown in Figure 5, essential timetables (as explained in Introduction) 2030 and 2050 were frequently mentioned in English and French networks, and "goal" and "ambition" also reflected the importance of carbon emission reduction targets. Words such as "catastrophe" and "devastating" emphasised the urgency of carbon neutrality. Unlike the English network, many "nucléaire" appeared in the French network, which was related to the current situation of French nuclear power plants. Studies have shown that France has many nuclear power plants to make it resilient in energy security (Krikštolaitis et al., 2022). However, as half of the nuclear power plants are approaching the end of their design life, the energy problem in France is becoming increasingly prominent. Since 2022, energy prices in France have been rising. According to a report from Le Parisien (2022), half of the nuclear reactors in France have been shut down or suspended. Affected by this, the total power generation in France has decreased sharply, and the local energy prices have continued to rise.

In addition, many "@" existed in the French network. On Twitter, "@" is used to mention or remind someone. Users can use @username in tweets to attract attention. "@" calls out usernames in Tweets by sending a message or link (Twitter, 2022). The users mentioned in the French network were environmental protection organisations (@greenpeacefr), non-profit associations (@notreaffaire) and politicians (@emmanuelmacron). This proved that users have high social capital. Other users tended to send their ideas about carbon neutrality to them. "Justice" and "greenwashing" also showed people's dissatisfaction with the status quo of carbon neutrality.

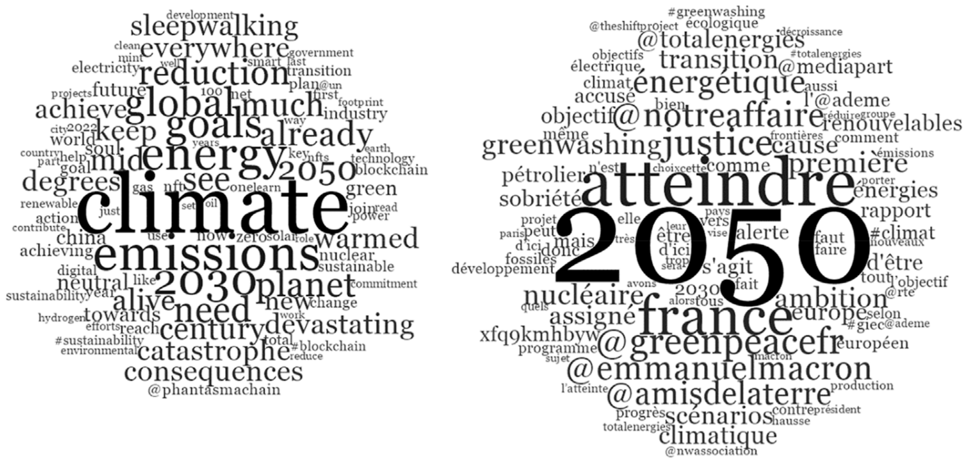

FIGURE 5
Word cloud of English (left) and French (right) networks.

Discussion and conclusion

This study emphasised individual perception and involvement in carbon neutrality on Twitter. Through social network analysis, this study attempted to find activists with high social capital. Coupled with the sentiment analysis of tweets, this study provided suggestions to raise public carbon neutrality awareness and knowledge sharing.

For the first research question, sentiment analysis revealed that many tweets were neutral and negative sentiments were more than positive ones in English and French networks, which was contrary to previous similar studies (Song et al., 2022). Negative sentiments came from users' concern about environmental damage, building new nuclear power plants and dissatisfaction with the government's existing carbon neutrality policy. The analysis indicated that most users expressed their views on carbon neutrality from an individual standpoint through Twitter, and their discussions mainly criticised the government's measures and expressed dissatisfaction with energy enterprises.

As per the second research question, after analysing the activists in the two networks, this study found that the activists in the English network mainly comprised government officials, media, and enterprises. They regarded Twitter as a publicity tool. Based on graph metrics, the activists in the French network had more social capital and influence. To answer the third research question, the analysis showed that although there were more users and clusters in the English network, users in French social networks interacted more frequently than in English ones, with various clusters.

To sum up, besides the efforts of governments and enterprises, social media might enhance people's awareness of environmental protection and turn the green concept into action to achieve carbon neutrality. Individual willingness is critical when dealing with carbon emissions and climate change. In addition to the general public through traditional media, the government, related organisations, and social media users with high social capital should share their knowledge *via* social media. Knowing the keywords that were shared more and the sentiment will be beneficial for successful knowledge sharing. Therefore, this research further reinforces that the carbon neutrality initiative has a broad social foundation and will be prosperous in the future, even though global warming is a universal challenge to humankind which is a long-term and complex process requiring systematic solutions.

This study has certain limitations. Abbreviations, words, and ambiguities in tweets may affect the accuracy of sentiment analysis. Implicit language, such as humour and irony, is sometimes complex for even real people to be detected; however, the implied meaning of a sentence might make it completely different from literal. Moreover, although SentiStrength is reliable, one of its disadvantages is that it does not use grammatical parsing to eliminate the ambiguity between different word meanings. Little words in the lexicon dictionary are also restricted to the value assignment of each word in the tweet. To widen observation of carbon neutrality issues, this study unavoidably used simplistic keywords, which might miss some subtle data when quantifying users' perceptions.

Besides, this study did not conduct a manual content analysis of tweets. There may be new and innovative findings if we go into detail for all tweets like Regona et al. (2022). Moreover, this study only focused on two languages, meaning there is room to expand the scope to other languages. Lastly, this study mainly utilised a qualitative method to compare the French and English contents. Modelling the tweets data might be another research gap.

In the future, sentiment analysis can convert qualitative texts into quantitative scores, which enables more innovative research designs. Follow-up research should collect more tweets from languages such as Thai and Chinese in a more extended time range. In addition to positive and negative sentiment detection, future studies might also identify a new direction, such as the perception of carbon neutrality compliance. Using the PRISMA approach to remove the irrelevant ones, different topics of carbon neutrality could then be analysed. The problem of the implicit meaning of Tweets might also be identified in this process. For example, people may write that this policy is "excellent". Computer algorithms may consider this a positive word because excellent has a positive meaning. Humans might realise that the quotation marks imply a negative meaning by reading all the contents. To investigate motivations and perceptions behind social network structure, a combination with other quantitative econometrics, statistical modelling and machine learning approaches might be used to study carbon neutrality from other angles.

Data availability statement

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

Author contributions

QY: Original writing and conceptualization, research method. RL: Writing and revise paper, conceptualization, data curation. LS: Literature review, research method, data curation.

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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Does the enterprise's choice of intangible capital help to promote its ESG score?

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Digital transformation, as an important way to optimize the existing resources of enterprises, is a driving force to achieve their high-quality development. Intangible capital is used to reflect the status of digital transformation of enterprises, so as to explore the relationship between the decision of enterprises on digital transformation and the ESG scoring effect of enterprises under financing constraints. The results show that when enterprises are faced with strong financing constraints, the management's decision on digital transformation tends to be conventional. Although maintaining the traditional business model is more beneficial, it is not conducive to the improvement of ESG score. To further analyze the digital transformation mechanism of enterprises, this paper examines the decision-making behavior of enterprises under financing constraints from the perspective of intermediary mechanism. The results show that the decision of increasing intangible capital of enterprises promotes the improvement of enterprise performance, and then drives the promotion of the enterprise ESG score. This study enriches the research achievements in the field of digital transformation of enterprises, and provides reference for heterogeneous enterprises to select digital transformation decisions.

KEYWORDS

intangible capital, ESG score, decision-making behavior, enterprise performance, digital transformation

1 Introduction

The input with information technology and data as key elements has become an important way for the transformation, upgrade and leapfrog development of enterprises. Since the Fifth Plenary Session of the 18th CPC Central Committee put forward the "implementation of the national big data strategy", relevant departments have issued

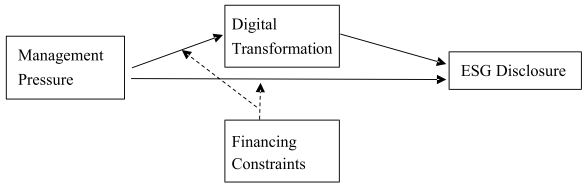

FIGURE 1
Enterprise digital decision-making process.

corresponding support policies to promote the digital transformation of enterprises. By the end of 2020, the digitalization rate of production equipment of industrial enterprises above designated size has reached 49.4%[1]. To realize digital transformation, enterprises need to invest more resources in IT, digital transformation and talents (Li et al., 2020). General Purpose Technologies input in digital transformation often need a lot of other complementary investments, such as business process redesign, new product and business model development and related human capital investment (Brynjolfsson et al., 2021). These complementary investments are often invisible and difficult to measure, and it is difficult to fully reflect their business performance and enterprise value. Accounting methods failing to reflect intangible capital significantly reduce the vitality of enterprises and markets (Farhi and Gourio, 2018; Autor et al., 2020; Crouzet and Eberly, 2021). However, according to the major ESG evaluation systems in the world, all ESG evaluation systems include information technology related options. Therefore, is there a correlation between the increase of intangible capital brought by digital transformation and the ESG score? The existing research rarely deals with this topic.

ESG involves a wide range of contents in Environmental, Social and Governance. In order to accurately obtain the evaluation of E, S, and G, corresponding digital transformation is also required, such as adding corresponding software and information systems, etc (Jun et al., 2022). Emerging technologies such as artificial intelligence have driven society into the era of digital economy, and its foothold lies in the transformation and application of enterprise digitalization. The disclosure of digitization-related information is a form of intellectual capital disclosure that can provide investors with potentially value-related information (Ricci et al., 2020), especially contributing to the improvement of ESG scores. In an era where society attaches great importance to ESG, poor performance of ESG means that companies do not pay enough attention to environmental and social responsibility, and corporate governance needs to be further improved at all stages (Thomas, 1995). The ESG score obviously represents its market prospects, and with the advancement of the digitalization process, the flow of internal resources within the enterprise is smoother and the information is more transparent (Wang Xiaohong et al., 2022), and the ESG score is correspondingly higher. From the perspective of the social responsibility of economic entities, digital transformation will also deeply empower enterprises to fulfill their social responsibilities, thereby generating social spillover effects through more and better corporate social responsibility. Digital transformation can not only enhance the willingness of enterprises to fulfill their social responsibilities, but also improve the ability of an enterprise to fulfill its social responsibilities and to enhance the fulfillment of corporate social responsibilities by improving the enterprise management mechanism, improving the production methods of the enterprise, and improving the external relations of the enterprise (Shen Minghao, 2022).

Will the large amount of unaccounted intangible capital invested in the process of digital transformation affect the enterprise ESG score? How to measure the intangible capital invested in the process of enterprise digital transformation? Whether intangible capital has synergy with tangible capital and its influence on the enterprise ESG score has become the focus of academic circles. To analyze the above problems, the academic circles have carried out relevant research, which mainly focuses on the measurement of intangible capital, the influence of intangible capital on enterprise performance and the choice of intangible capital.

First, the meaning and measurement of intangible capital. Intangible capital is usually defined as the intangible resources that enter the production process (Yang and Shi, 2018), mainly including software, intellectual property, brand and innovative business processes (Crouzet and Eberly, 2019). It is highly correlated with tangible capital (McGrattan and Prescott, 2014) and is one of the important driving forces of business activities. In the process of enterprise digital transformation, in addition to the equipment related to digital equipment, enterprises also need intangible resources such as management and training, business process transformation, information network and corporate culture, which have increased intangible capital after accounting treatment (Xiang and Tian, 2014). Therefore, the intangible capital discussed in this paper refers to the result of accounting treatment of intangible resources invested by enterprises in the period of digital transformation. It is used to depict the underestimation of the potential enterprise ESG score due to the failure to accurately reflect the value of intangible capital in financial statements.

1 This article is a general OLS measurement model. Of course, the core explanatory variable in the measurement model is the interaction term of the logarithm of intangible capital and the logarithm of fixed assets. The setting condition of this interaction variable is the effect of the explanatory variable intangible capital on the explained variable. When potentially affected by fixed assets, we need to consider using regression with interaction terms.

According to the traditional accounting standards, the balance sheet cannot reflect the value brought by new business processes or other types of intangible capital. Intangible capital has been considered to be particularly elusive, and its depreciation rate is unknown, so it is difficult to adopt the traditional methods for evaluating capital stock (Tambe et al., 2020). How to measure intangible capital is one of the core issues concerned by academic circles. Throughout the existing research, the main methods to measure intangible capital are: adopting enterprise knowledge capital and organizational capital (Peters and Taylor, 2017), Tobin Q (Brynjolfsson et al., 2021), IT investment measurement (Tambe et al., 2020), and input-output (McGrattan, 2020). The above methods are mainly based on the sources of intangible capital, and measured from two dimensions including input and output (Xu et al., 2018). Although these two methods of measuring intangible capital complement each other and improve the accuracy of intangible capital assessment, it is difficult to reflect the various intangible complementary investments invested by enterprises in the process of digital transformation in the three major statements. For example, Peters and Taylor (2017) measured intangible capital in the fields of R&D, management, sales, etc. Although it can be found in financial statements, the measurement involving other intangible investments still needs further study.

Second, the influence of intangible capital on enterprise performance. Intangible capital, such as software and information systems, is becoming increasingly important to the profits of enterprises, and the expansibility of intangible capital makes it easier for enterprises to gain competitive advantage (Autor et al., 2020; Akcigit and Ates, 2021). The influence of intangible capital on enterprise performance can be summarized from two aspects. On the one hand, intangible capital can improve enterprise productivity by increasing industry concentration and market forces (Crouzet and Eberly, 2018; Crouzet and Eberly, 2019); on the other hand, enterprises adopt more intangible capital and scale-biased technology brought by the progress of information technology, which forms the "superstar" effect (Autor et al., 2020), and realizes the steady growth of profits. Intangible capital not only affects the business performance of enterprises, but also affects the macroeconomic quality. It is an important source of productivity and economic growth (Yang and Shi, 2018). According to the research of Crouzet and Eberly (2021), intangible capital affects the accuracy of total factor productivity in the United States, especially when the wrong measurement of intangible capital and the increase of bonus rate together cause a downward deviation of one-third to two-thirds of total factor productivity growth in the United States. Based on this, intangible capital investment affects enterprise performance, and more resources can be invested in the process of enterprise ESG construction when enterprise performance is improved, thus improving enterprise ESG score.

Third, the choice of intangible capital investment of enterprises. Although some studies have shown that the input of intangible capital can help enterprises improve their performance, not all types of intangible assets can achieve enterprise performance improvement (Chappell and Jaffe, 2018). The existing research on the choice of intangible capital of enterprises mainly focuses on two aspects. On the one hand, it is considered that the intangible assets of enterprises are puzzled by financing constraints, because under the financial constraints, enterprises can obtain additional cost bonus through intangible capital, thus distorting the decision of enterprises on investment in intangible capital (Altomonte et al., 2021). The availability of financing is the key factor for enterprises to invest in intangible capital; On the other hand, the choice of intangible capital is faced with the opportunity cost of balancing with tangible capital. As the intangible investment of enterprises is as important as the tangible investment (Corrado et al., 2009), the study of American companies by McGrattan & Prescott (2014) confirms that intangible investment is highly correlated with tangible investment. Therefore, in the face of uncertain external environment, the management of enterprises is faced with certain choices of the intangible capital investment required for digital transformation.

To sum up, the existing researches mainly focus on the problems of intangible capital and business performance. Although some researches begin to involve the choice of intangible capital investment, there is a lack of consideration on the choice of intangible capital investment, the synergy between intangible capital and tangible capital, and even less research on the choice of intangible capital investment from the level of business pressure. Therefore, compared with the existing literature, the marginal contribution of this paper may lie in: First, analyzing the influence of digital transformation and enterprise ESG score from the perspective of the choice of intangible capital investment of enterprises. Especially, considering the influence of the decision of enterprises on digital transformation on the enterprise ESG score under the background of financing constraints; Secondly, using the interaction between intangible capital and fixed assets to express the synergy between them after the enterprise makes decision on digital transformation, and measuring the influence of digital transformation on the enterprise ESG score from the perspective of capital synergy after the digital transformation of enterprises. Using the interaction between intangible capital and fixed assets to measure the effect of digital transformation of enterprises. Compared with that using a single intangible capital, it can better reflect the collaborative transportation result of intangible capital and fixed assets after decision-making of digital transformation made by enterprise management, and its conclusion may be more convincing. Thirdly, using the ratio of intangible capital to fixed assets to measure the decision-making behavior of enterprises in digital transformation. The ratio of intangible capital to fixed assets is divided into three quantile groups according to 25, 50, and 75%, which are multiplied by the financing constraints of enterprises, respectively, to depict the dynamic changes of intangible capital selection of heterogeneous enterprises, and to show the influence of the changing state of intangible capital on the ESG score of enterprise performance in the process of digital transformation.

2 Theoretical model

To describe the decision of enterprises on digital transformation, this study adopts the general equilibrium model, integrates the operating pressure, financing constraints and choices of intangible capital investment into the model, and discusses the effects of operating pressure, financing constraints and intangible capital investment choices on enterprise performance. To analyze this problem, this paper studies the three-sector model, as follows:

2.1 Family sector

Drawing lessons from Altamonte et al. (2021) to describe the consumer behavior pattern. It is assumed that the representative household consumption income is y. In a given case, the combination of different kinds of commodity i can be expressed as $\{p_i\}_{i\in M}$. Then, the consumption function of representative families can be expressed as:

$$c_i \equiv C(p_i, P, Q) = QD(p_i/P) \tag{1}$$

Where, $D(p/P)$ is a second-order continuously differentiable function, and $D'_{p/P} < 0$.

2.2 Enterprise sector

As far as enterprise sector is concerned, its decisions on production are made as follows: 1) The enterprise keeps the traditional technology at the ratio of $1-\varphi(0<\varphi\leq 1)$ to continue production; 2) The enterprise chooses digital transformation at the ratio of $\varphi(0<\varphi\leq 1)$, that is, investing in new technologies represented by intangible capital (hereinafter referred to as new technologies). Supposing that s_i represents the marginal cost reduction brought by the application of new technology, $s_i \subset [0,1)$. With given new technology investment, the cost function with new technology is considered as $f(s_i)$. Assuming that the cost function with new technology investment meets the monotonic increasing feature, it is similar to the function of the total enterprise cost. The function of the enterprise cost is shown in the following equation:

$$TC(q_i) = \varphi \cdot [f(s_i) + (1-s_i)q_i] + (1-\varphi)\cdot q_i \tag{2}$$

In terms of the decision on maintaining traditional technology or making investment in new technology, the enterprise management needs to consider the business pressure. Under the pressure of operation, enterprises are more likely to choose leverage financing. Studies have shown that the management's choice of leverage ratio is based on the judgment of the enterprise's future development. If there are good projects, the enterprise needs to raise funds externally (Harris and Raviv, 1991). Generally speaking, the greater the business pressure faced by an enterprise, the greater the possibility that the management will consider investing in new technologies, and the greater the possibility of financing through financial institutions. Assuming that the cost function of an enterprise is expressed as:

$$TC(q_i) = \varphi \cdot [f(s_i) + (1-s_i)q_i] + (1-\varphi)\cdot q_i \tag{3}$$

In addition to business pressure, which will affect the management's decision-making, corporate financing constraint itself is also an important factor affecting management's choice of new technology investment. Generally speaking, the weaker the corporate financing constraint, the easier it is for the management to raise funds to invest in new technologies. Let τ represent the constraint state of enterprise financing, and let it be an exogenous variable. If its value satisfies $\tau > 0$, it obeys the cumulative probability distribution $G(\tau)$, and the value is within $[\tau, \infty)$. Under the financing constraints, the financing scale of new technology investment decided by the management should meet the following conditions: $g(s,\tau) = (1+\frac{1}{\tau})f(s)$.

2.3 Bank sector

Faced with financing constraints, to increase investment in new technologies, enterprises can raise funds from the financial sector through mortgage. Assuming that the initial investment assets of an enterprise are f_e (such as fixed assets at the beginning of the period) and the assets are used as collateral, and assuming that the mortgage rates of the initial investment assets are ϑ and $\vartheta \in (0,1)$. If ϑ is lower, the mortgaged assets of the enterprise will be fewer. To meet the capital demand of new technology investment, it is necessary to raise more funds from the bank, and the enterprise will have to bear more interest expenses. When an enterprise is faced with operating pressure and financing constraints, assuming that the probability of the enterprise choosing to perform the contract is λ, the expected interest income that the bank can get at this time is $\lambda R(s,\tau)$. If the enterprise defaults, the bank can only recover the principal $(1-\lambda)\vartheta f_e$. It can be seen that, in the face of operating pressure and financing constraints, the balanced loan and income of the enterprise and the bank can be expressed by the following equation:

$$-g(s,\tau) + [\lambda R(s,\tau) + (1-\lambda)\vartheta f_e] \geq 0 \tag{4}$$

2.4 Maximizing the profits of enterprises

According to the principle of supply and demand of family sector, bank sector and enterprise sector, the conditions for profit maximization of enterprise sector can be expressed as follows:

$$\max_{p,s} (p-1+s)q(p/P,Q) - [\lambda R(s,\tau) + (1-\lambda)\vartheta f_e]$$
$$s.t.\ q(p/P,Q) = QD(p/P) \tag{5}$$

$$(p - 1 + s)q(p/P, Q) \geq R(s, \tau) \tag{6}$$

$$-g(s, \tau) + [\lambda R(s, \tau) + (1 - \lambda)\vartheta f]_e \geq 0 \tag{7}$$

According to the profit maximization function of enterprises,

$$\max_{p,s} (p - 1 + s)q(p/P, Q) - g(s, \tau) \tag{8}$$

On both sides of Eq. 8, the derivative of s is obtained, and $QD(p/P) = g'(s, \tau) = (1 + \frac{1}{\tau})f'(s)$ is obtained. Because $\tau > 0$ and the cost function of enterprises' choice of new technology investment' meets the monotonic increasing feature ($f'(s) > 0$), $QD(p/P) = g'(s, \tau) > 0$. This indicates that enterprises choose the optimal financing scale for intangible asset investment under the operating pressure and financing constraints to achieve the maximum output. According to this feature, inference 1 is drawn.

Inference 1: the weaker the financing constraint τ of an enterprise, the larger the financing scale of the enterprise's output and investment in new technologies, which means that the enterprise is more motivated to carry out digital transformation. In other words, the management has more courage to "cut off all means of retreat" to carry out digital transformation, namely the increases in intangible capital investment, thus promoting the ESG information disclosure of enterprise.

Deriving from both sides of Eq. 8 about p, $\frac{q}{q'} = \varphi(1 - s)$. To analyze the problem in a simple manner, it is assumed that the marginal cost reduction s brought by the new technology is constant. Because the enterprise's choice of technology investment is $0 < \varphi \leq 1$ and $0 \leq s < 1$, $\frac{q}{q'} > 0$. That is, the contribution of marginal product to the total output is greater than 0. To make the $\frac{q}{q'}$ on the left side of the equation larger, on the right side of the equation, the proportion of intangible capital investment should be higher or the cost of new technology should be reduced faster. Because the cost reduction of new technology investment is difficult to measure, this study will not consider the cost reduction s for the time being. Based on this, this study puts forward the following inference:

Inference 2: considering that other conditions remain unchanged, the greater the intangible capital investment ratio caused by the decision of enterprises on digital transformation, the more conducive it is to promote the ESG information disclosure of enterprises.

2.5 Enterprise digital decision-making process

In a volatile, uncertain, complex and ambiguous digital environment, unplanned digital initiatives are infeasible, and the lack of clear strategic goals and practical paths will lead to unsatisfactory digital transformation of enterprises (Amit & Han, 2017; Lichtenthaler, 2020). However, considering the high frequency of unexpected events in the process of digital transformation (Nambisan et al., 2017), it is not feasible to strictly follow the strategic plan and achieve digital transformation by avoiding risks. Especially when the management plays the role of an agent, on the one hand, the management is hired and assessed by the principal, and has the motivation to improve the company's ESG through digital means and achieve the improvement of the company's performance; on the other hand, when the company faces financing constraints, The digital transformation of the management is faced with the "dilemma" of choosing, that is to "break the boat" to carry out digital transformation or maintain the original model? In summary, the digital decision-making process for management is shown as Figure 1.

3 Data, variables and statistical description

3.1 Data description

The research objects of this paper are A-share listed companies. The data comes from Wind Information Financial Terminal Database, covering the period from 2017 to 2020. To avoid data interference to the accuracy of research conclusions, according to the usual practice of existing research, the data processing methods of this paper are as follows: 1) Delete ST, *ST and the stocks to be delisted; 2) Delete financial listed companies; 3) Delete listed companies with a listing period of less than 1 year. Due to the significant heterogeneity among listed companies, especially the quite different financial indicators of some listed companies, to avoid the interference of the outliers of individual indicators on the sample data, this paper adopts 1% truncated processing for all data.

3.2 Description of measurement model and variables

3.2.1 Model building

To construct and depict the decision of enterprises on digital transformation, measure the digital transformation of enterprises with intangible capital, and consider the synergy between intangible capital and fixed assets (the interaction between intangible capital and fixed assets), the following measurement models are considered:

$$\ln esg_{it} = \alpha + \beta_1 \ln \mathrm{int}\, an\_cap_{it} \times \ln fix_{it} + \beta_2 X_{it} + \varepsilon \tag{9}$$

$\ln esg_{it}$ in Eq. 9 is the explained variable, which represents the logarithm of the ESG information disclosure score of company i in t, and is used to describe the ESG information disclosure status of the enterprise; both intangible capital and tangible capital (fixed assets) are a kind of capital. To describe the mutual promotion between intangible capital and tangible capital (fixed assets) after the choice of intangible capital investment, the interaction term ($\ln intan\_cap_{it} \times \ln fix_{it}$) between the intangible capital logarithm and the fixed asset logarithm is introduced as an explanatory variable[1]. X_{it} indicates control variables, mainly including ending cash flow logarithm (lncash), Tobin Q (tobin_q), asset-liability ratio logarithm (lndebt), the shareholding ratio of the top ten shareholders (lnshare_holder) and business performance (lnincome).

According to Eq. 9, the expected β_1 sign is positive, which indicates that the choice of intangible capital investment and the promotion of fixed assets are helpful to improve the performance of enterprises.

3.2.2 Description of main variables

ESG information disclosure of explained variables. ESG disclosure data of A shares began in 2017, and the collection range of equity research data is A shares non-ST shares from 2017 to 2020. ESG refers to the score of corporate social responsibility. This study mainly adopts the A-share Wind score standard and FTSE Russell score standard.

Explaining the interaction between the logarithm of variable intangible capital and the fixed asset logarithm. In the process of digital transformation, with the increase of intangible capital investment, the cooperation between intangible capital and fixed assets is helpful to improve enterprise performance. In this study, intangible capital investment mainly includes intellectual capital and organizational capital (Eisfeldt and Papanikolaou, 2014; Peters and Taylor, 2017). Intellectual capital is measured by R&D input and expenditure, and sales, general and administrative expenditures (SG&A for short) are accounted into intangible capital by using perpetual inventory method. This study draws on Peters and Taylor's (2017) method for intangible capital accounting. To analyze the problem in a simple manner, see the choice of intangible capital investment below as the digital transformation decision-making of enterprises.

In this study, intangible capital is not used alone, but expressed by the interaction between intangible capital and fixed assets. There are two reasons: First, in the digital transformation of enterprises, with the input of intangible capital, intangible capital still needs to rely on fixed assets and other equipment to achieve mass production, and there is certain mutual synergy between intangible capital and fixed assets; secondly, to describe the decision of enterprises on digital transformation, it can be measured by the ratio of intangible capital to fixed assets, and the influence of the interaction between intangible capital and fixed assets on enterprise performance can be measured by the change of the ratio of intangible capital to fixed assets.

Business performance (income). The existing indicators of enterprise performance measurement mainly include return on assets (Brown and Kimbrough, 2011; Zhang et al., 2015; Dai and Li, 2021; Zheng and Huang, 2021), return on equity (Zhang et al., 2015; Dai and Li, 2021), sales profit rate (Zhang et al., 2015), operating income growth (Liu M. et al., 2021), per capita operating income (Zhang and Pan, 2019), and Tobin's Q (Abernethy et al., 2019). To implement digital transformation, enterprises often need to invest more in digital resources and organizations (Wang and Wang, 2021), and realize product and service innovation to meet customer needs (Luo and Jiang, 2021). To catch the change of enterprise management caused by the choice of intangible capital investment in the digital transformation of enterprises, the method put forward by Zhang and Pan (2019) is used for reference, and the operating income indicator is used to measure enterprise performance. At this time, compared with other indicators, operating income can more directly reflect the change of output caused by the digital transformation of enterprises.

Financing constraints. The existing indicators for measuring the financing constraints faced by enterprises mainly include SA (Lu and Chen, 2017; Jiang et al., 2019; Zhou et al., 2021), KZ index (Jiang et al., 2019) and WW index. In this study, SA method is adopted for financing constraints.

Other control variables. To avoid the possible collinearity between the control variables and the explained variables, the control variables in this study mainly include ending cash flow logarithm (*lncash*), Tobin Q (*tobin_q*), asset-liability ratio logarithm (*lndebt*) and the top ten shareholders' shareholding ratio (*lnshare_holder*) by referring to the design methods of Jiang et al. (2019) and Zhou et al. (2021). The logarithm of cash flow at the end of the period (*lncash*) is mainly measured by the ending balance of cash and cash equivalents in the financial report of the listed company; Tobin's Q (*tobin_q*) is measured by the ratio of the company's market value to replacement cost.

3.2.3 Statistical description

Logarithmic transformation is adopted for dependent variables, in which the related variables such as final cash flow, operating pressure, and financing constraint variables may have negative values and will be treated according to the digital-to-analog conversion equation. To reduce the interference to the accuracy of the model caused by the possible abnormal values of related variables, all variables are truncated by 1%.

See Table 1 for statistical description of main variables. As shown in Table 1, the minimum and maximum scores of ESG information disclosure scores of listed companies are

1 This article is a general OLS measurement model. Of course, the core explanatory variable in the measurement model is the interaction term of the logarithm of intangible capital and the logarithm of fixed assets. The setting condition of this interaction variable is the effect of the explanatory variable intangible capital on the explained variable. When potentially affected by fixed assets, we need to consider using regression with interaction terms.

TABLE 1 Statistical description of main variables.

Variable	Obs	Mean	Std.Dev	Min	Max
lnesg	5,146	1.82	0.16	0.77	2.27
lncap_fix	11,985	2.64	1.70	−1.72	7.12
lnincome	15,356	3.05	1.43	0.30	7.27
lncash	15,351	1.53	1.46	−1.83	5.63
tobin_q	13,940	1.82	1.71	0	9.91
lndebt	15,358	−1.33	0.18	−1.81	0.18
lnshare_holder	13,760	4.08	0.27	3.26	4.56
lnsa	15,358	−1.33	0.18	−1.81	0.18

Note: The data comes from Wind information, and the relevant data is self-made.

0.77 and 2.27, respectively, indicating that there is a big gap among listed companies. The logarithmic minimum and maximum values of operating income of listed companies are 0.30 and 7.27, respectively, which leads to such great differences among listed companies. On the one hand, it may be related to the status of the industry in which the enterprises are located, and on the other hand, it may be related to the ESG information disclosure decision of enterprise management. Furthermore, the minimum value and maximum value of the interaction term (*lncap_fix*) between variable intangible capital logarithm and fixed asset logarithm are −1.73 and 7.12, respectively, which indicates that there is a big difference in heterogeneity among enterprises. On the one hand, it is the heterogeneity of the company itself; on the other hand, it is mainly reflected in the difference caused by the choice of intangible assets of enterprises in the process of digital transformation.

4 Empirical analysis and results

4.1 Benchmark regression results

Equation 9 reflects the impact of the interaction between intangible capital and fixed assets on enterprise performance, as shown in Table 2. According to Table 2, Column (1) indicates the cash flow logarithm (*lncash*), Tobin Q (*tobin_q*), asset-liability ratio logarithm (*lndebt*), the top ten shareholders' shareholding ratio (*lnshare_holder*), business performance (lnincome), time and industry fixed effect at the end of the control period. Without considering the financing constraints, the interaction between the intangible capital logarithm and the fixed asset logarithm is helpful to improve the enterprise ESG score. The performance interaction item *lncap_fix* is increased by 1%, and the enterprise ESG score is increased by 0.014%; Column (2), on the basis of Column (1), considers the influence of the interactive item *lncap_fix* on the enterprise ESG score under the financing constraints faced by the enterprise. The results show that the influence of interactive item *lncap_fix* on enterprise ESG score is 0.004% higher than that of Column (1), indicating that the digital transformation of management is more helpful to improve enterprise ESG score under financing constraints.

Furthermore, to test the robustness of Columns (1) and (2) in Table 2, this paper intends to adopt FTSE Russell scoring standard. Column (3) of Table 2 considers the regression result of FTSE Russell score, and the result shows that the interaction between the intangible capital logarithm and the fixed asset logarithm can promote the improvement of enterprise ESG score, which is reflected by every 1% increase of interaction *lncap_fix* contributing to every 0.11%increase of enterprise ESG score. The effect of FTSE Russell score is obviously better than that of Wind ESG score; similarly, on the basis of Column (3), Column 4) considers the influence of the

TABLE 2 Benchmark regression results.

	lnesg	lnesg	lnfs_esg	lnfs_esg
	(1)	(2)	(3)	(4)
lncap_fix	0.014*** (0.003)	0.018*** (0.003)	0.11*** (0.0015)	0.11*** (0.014)
lnincome	0.01** (0.004)	0.01*** (0.004)	−0.004 (0.02)	−0.02 (0.02)
lncash	0.02*** (0.003)	0.02*** (0.003)	0.05*** (0.01)	0.04*** (0.01)
tobin_q	0.005*** (0.001)	0.0002 (0.001)	−0.02** (0.006)	−0.016** (0.006)
lndebt	−0.02*** (0.006)	−0.02*** (0.006)	−0.03 (0.03)	−0.04*** (0.04)
lnshare_holder	−0.05*** (0.01)	−0.04*** (0.01)	−0.01 (0.05)	−0.02** (0.01)
lnsa		0.06* (0.03)		0.001 (0.05)
Industry-level fixed effect	Yes	Yes	Yes	Yes
Year-level fixed effect	Yes	Yes	Yes	Yes
Adj-R^2	0.22	0.26	0.40	0.40
Observed value	4,856	4,856	1,240	1,240

Note: * * *, * * and * represent the significance level of 1, 5 and 10% respectively; The values in brackets are standard errors.

TABLE 3 Choice of intangible capital of enterprises under financing constraints.

	lnesg	lnesg
	OLS	GMM
	(1)	(2)
lncap_fix	0.021*** (0.003)	0.019*** (0.003)
lnincome	0.002 (0.005)	0.006 (0.004)
lncash	0.01*** (0.003)	0.02*** (0.003)
tobin_q	−0.002 (0.0015)	0.003** (0.001)
lndebt	−0.03*** (0.01)	−0.02*** (0.006)
lnshare_holder	−0.02* (0.01)	−0.05*** (0.01)
$intan\_cap \times CF_1$	0.05 (0.03)	0.02** (0.01)
$intan\_cap \times CF_2$	0.008** (0.004)	0.03 (0.03)
$intan\_cap \times CF_3$	0.007** (0.003)	0.005* (0.003)
Control of business pressure	是 Yes	是 Yes
Industry-level fixed effect	是 Yes	是 Yes
Year-level fixed effect	是 Yes	是 Yes
Adj-R^2 (within-R^2)	0.26	
Observed value	3,511	3,511

Note: * * *, * * and * represent the significance level of 1, 5 and 10% respectively; the values in brackets are standard errors.

interactive item *lncap_fix* on the enterprise ESG score under the financing constraints faced by enterprises. The results show that the interactive item *lncap_fix* contributes to the improvement of enterprise ESG score.

The above results show that under the financing constraint, the interaction between the intangible asset logarithm and the fixed asset logarithm is helpful to promote the enterprise ESG score. To get rid of the financing constraint, the management is motivated to change the ratio of intangible capital to fixed assets, that is, to promote the structural transformation of enterprises, so as to achieve the purpose of improving business performance.

4.2 Financing constraints and enterprises' choice of intangible capital of

Column (2) of Table 2 shows that the financing constraint makes the interactive item *lncap_fix* promote the improvement of enterprise ESG score. How does financing constraint reduce the impact of interactive item *lncap_fix* on the enterprise ESG score? To analyze this problem, with other conditions unchanged, this paper reveals how the financing constraints faced by enterprises affect the decision of enterprises on digital transformation, and then depicts its impact on enterprise ESG score.

The financing constraint SA is divided into three dimensions according to the 25 and 75% quantiles, and the SA value with quantile less than 25% is defined as the group with strong financing constraint; the SA value with quantile between 25 and 75% is defined as the group with strong financing constraints; the SA value with quantile greater than 75% is defined as the group with weak financing constraints. Therefore, CF_1, CF_2 and CF_3 are respectively used to represent three virtual variables: strong financing constraint, relatively strong financing constraint and weak financing constraint.

The three virtual variables showing the strength of financial constraints faced by enterprises are multiplied by the intangible capital logarithm, respectively, to describe the influence of digital transformation decision on enterprise performance under the financial constraints faced by enterprises. The results are shown in Table 3. According to Table 3, the Column (1) of Table 3 shows that when the interactive item *lncap_fix* is increased by 1%, the enterprise ESG score is increased by 0.021%, which is consistent with the conclusion of Column (2) of Table 2. The process of financing constraints affecting the influence of digital transformation decision-making on enterprise ESG score can be expressed as follows: under strong financing constraints, increasing intangible capital investment will increase enterprise ESG score by 0.007%; however, in the face of weak financing constraints, increasing intangible capital investment will not improve the enterprise ESG score; faced with weak financing constraints, increasing intangible capital investment will increase the enterprise ESG score by 0.008%. Compared with the enterprises not under financing constrains, increasing intangible capital investment helps to improve the enterprise ESG score under financing constraints.

The above results show that, when enterprises are faced with financing constraints, increasing intangible capital investment may not necessarily improve the enterprise ESG score, but will promote enterprises under strong financing constraints to continue to choose to invest in fixed assets, that is, to adopt the conventional decision. With the gradual relaxation of financing constraints on enterprises, the coefficients of interactive terms $intan\_cap \times CF_2$ and $intan\_cap \times CF_3$ increase, indicating that the decision on intangible capital investment is helpful to improve enterprise performance. That is, the management adopts the most dramatic decision on digital transformation, thus promoting the improvement of enterprise ESG score. To check whether the above conclusions are correct, GMM method is adopted, and the results are shown in Column (2) of Table 3, respectively. As shown in Column (2) of Table 3, the results are basically consistent with those in Column (1) of Table 3, indicating that financing constraints restrict the choice of intangible capital investment of enterprises.

Take Mobvista (01860.HK), a digital marketing company, as an example. Mobvista is a technology service company based on the global mobile Internet ecosystem. Its main business is to

TABLE 4 Regression results of intermediary mechanism.

	lnincome	lnesg
	(1)	(2)
lncap_fix	0.34*** (0.005)	0.018*** (0.003)
lnincome		0.01*** (0.004)
lncash	0.26*** (0.006)	0.02*** (0.003)
tobin_q	−0.02*** (0.004)	0.0002 (0.001)
lndebt	0.34*** (0.01)	−0.02*** (0.006)
lnshare_holder	0.15*** (0.02)	−0.04*** (0.01)
lnsa	−2.32*** (0.07)	0.06*** (0.03)
Industry-level fixed effect	Yes	Yes
Year-level fixed effect	Yes	Yes
Adj-R^2 (within-R^2)	0.85	0.26
Observed value	11,795	4,856

Note: * * *, * * and * represent the significance level of 1, 5 and 10% respectively; The values in brackets are standard errors.

provide mobile app developers with marketing technology services and cloud computing technology services. Mobvista was listed on the Hong Kong Stock Exchange in 2018 and is known as "the first stock of intelligent mobile advertising in the new economy in the world". Most of the company's revenue comes from overseas, and it is one of the leading mobile Internet companies going overseas. Its most important product is programmatic advertising platform Mintegral. According to the statistics of AppsFlyer in March 2022, Mintegral ranks fourth in the global all-category retention strength list in both iOS and Android systems. In addition to Mintegral, Mobvista strives to build a SaaS tool ecosystem to empower B-end customers and its own development, and build a shared and win-win growth flywheel.

In the process of Mobvista's investment in digitalization, it is faced with a large financing constraint. According to the company's financial report, from 2017 to 2020, the company's closing balance of cash and cash equivalents at the end of the period was about 300 million yuan on average. In 2017 and 2020, the initial balance of cash and cash equivalents was -200 million yuan. However, in order to survive in the industry, the company attaches great importance to customer privacy, and always regards data supervision as an important lifeline, which has been widely praised by the market. In 2021, the company won the ESG Award Titanium Award from Hong Kong's "The Asset" magazine to Mobvista.

4.3 Mechanism inspection

To test the relationship between intangible capital investment decision and enterprise ESG score, the intermediary mechanism analysis is introduced, and the enterprise performance is selected as the intermediary variable to study the path of enterprise ESG score. See Table 4 for the results of intermediary mechanism analysis. As shown in Table 4, Column (1) of Table 4 shows that the improvement of enterprise performance significantly improves enterprise ESG score; Column (2) of Table 4 shows that after the introduction of intermediary variables, the intermediary effect is 0.006. Although the intermediary effect is not large, the effect is remarkable.

4.4 Heterogeneity analysis

The data description in Table 1 shows that there is great heterogeneity among enterprises. When faced with financing constraints and business pressure, are there differences in the choice of intangible capital investment among different types of enterprises? To analyze this problem, this paper attempts to consider the nature of enterprises (state-owned enterprises and private enterprises), the scientific and technological attributes of enterprises (traditional manufacturing and high-tech enterprises) and the proportion of intangible capital and fixed assets. Among them, enterprises engaged in the top 10 areas specified in "Made in China 2025″ are defined as high-tech enterprises, while others are regarded as traditional manufacturing industries.

The heterogeneity analysis is shown in Table 5. As shown in Table 5, Columns (1) and (2) in Table 5 correspond to the types of enterprises. For the types of state-owned enterprises and private enterprises, the *lnintan_fix* coefficient of the interaction between the intangible capital logarithm and the fixed asset logarithm is significantly positive after the selection of intangible capital. However, the effect of state-owned enterprises is better than that of private enterprises, which indicates that the *lnintan_fix* coefficient of state-owned enterprises is higher than that of private enterprises; for the heterogeneous enterprises with scientific and technological attributes, the intangible capital selection of traditional manufacturing enterprises is better than that of high-tech enterprises, which is reflected as their *lnintan_fix* coefficient of interaction term being higher than that of high-tech enterprises.

For the groups with intangible capital accounting for 25, 50, and 75%, the lower the proportion of intangible capital, the higher the interactive item *lnintan_fix* coefficient, and the stronger the willingness of enterprises to maintain fixed assets, as shown in Columns (5), (6) and (7) of Table 5.

5 Main conclusions and policy recommendations

5.1 Main conclusions

Not all enterprises have the genes of digital transformation, and the management of heterogeneous enterprises is restricted by operating pressure and financing constraints. Through the

TABLE 5 Heterogeneity differences of intangible capital choice of enterprises.

	Lnincome		Lnincome		Lnincome		
	State-owned enterprise	Private enterprise	Traditional manufacturing industry	High-tech enterprise	φ_25	φ_50	φ_75
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
lnintan_fix	0.22*** (0.003)	0.02*** (0.003)	0.022*** (0.002)	0.021*** (0.005)	0.03*** (0.005)	0.03*** (0.003)	0.007* (0.0036)
lncash	0.02*** (0.004)	0.018*** (0.00)	0.023*** (0.003)	0.013*** (0.006)	0.03*** (0.005)	0.014*** (0.004)	0.01*** (0.005)
tobin_q	−0.004 (0.003)	0.002 (0.001)	−0.001*** (0.002)	0.001 (0.003)	0.013*** (0.005)	−0.0036* (0.002)	−0.003 (0.002)
lndebt	−0.014 (0.01)	−0.02*** (0.006)	−0.01*** (0.006)	−0.041*** (0.01)	0.01 (0.01)	−0.04*** (0.007)	−0.01 (0.01)
lnshare_holder	0.03*** (0.01)	−0.10*** (0.01)	−0.04*** (0.01)	−0.04** (0.02)	−0.03* (0.016)	−0.05** (0.012)	−0.04*** (0.02)
lnsa	0.12*** (0.06)	0.06 (0.04)	0.035 (0.0035)	0.03 (0.07)	−0.03 (0.07)	0.09** (0.04)	−0.10* (0.06)
Industry-level fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-level fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj-R^2	0.37	0.29	0.27	0.20	0.40	0.30	0.28
Observed value	2053	2,803	4,080	776	1,653	2,307	996

Note: * * *, * * and * represent the significance level of 1, 5 and 10% respectively; The values in brackets are standard errors.

investment of general-purpose technologies in enterprise digital transformation, this paper measures the enterprise digital transformation from the perspective of intangible capital, and measures the degree of enterprise digital transformation by the ratio of intangible capital to fixed assets. According to the mutual cooperation between intangible capital and fixed assets, it captures the influence and effect of digital transformation on enterprise ESG score. The results show that: 1) The digital transformation of enterprises is helpful to improve the enterprise ESG score. The product of the intangible capital logarithm and the fixed asset logarithm significantly improves the enterprise ESG score. However, under financing constraints, the product of the intangible capital logarithm and the fixed asset logarithm improves the enterprise ESG score. 2) When enterprises are faced with strong financing constraints, the management's decision on digital transformation is more "radical", which is more conducive to the improvement of enterprise ESG score, and may be more beneficial to increase the process of digital transformation.

5.2 Policy recommendations

Combined with the research conclusion, the suggestions for heterogeneous enterprises to carry out digital transformation mainly include:

First of all, revitalizing the assets, easing the financing constraints of enterprises, and providing financing guarantee for the digital transformation of enterprises. The conclusion of this study shows that, faced with the double constraints of business pressure and financing constraint, the best choice of the management will be conventional. That is, the power of digital transformation is insufficient, but it is beneficial to maintain or increase fixed assets, which is not conducive to the transformation and development of enterprises. Especially in the background of advocating high-quality development, the middle and lower reaches of the industry will face a big development dilemma in the future if enterprises fail to seize the opportunity to catch up. Especially for the traditional manufacturing industry, digital transformation is imminent. For the traditional manufacturing industry which mainly focuses on fixed assets, activating the fixed assets and increasing the value of the fixed assets will help ease the financing constraints and provide a good financing guarantee for digital transformation. For the traditional manufacturing industry, because the interaction item of the product of the intangible capital logarithm and the fixed asset logarithm has a good effect on enterprise performance, the digital transformation of the traditional manufacturing industry is helpful to improve enterprise performance. For the traditional manufacturing industry with operating pressure, it is not appropriate to adopt short-term assessment alone. By combining short-term assessment with long-term assessment, the management will have the courage to "cut off all means of retreat" to carry out digital transformation.

Secondly, launching special policies at the national level to encourage the digital transformation of private enterprises. Compared with state-owned enterprises, the digital transformation of private enterprises mainly revolves around marketization, without the support of special national policies. Compared with state-owned enterprises, the interaction item of the intangible capital logarithm multiplied by the fixed asset logarithm brought by the digital transformation of private enterprises has less effect on enterprise performance improvement than that of state-owned enterprises. From the marginal effect, there is more room for private enterprises to improve their performance through digital transformation. From the perspective of stimulating market vitality and building a new development pattern, the state encourages the digital transformation of private enterprises through relevant policies, which will help accelerate the development of economy to high quality and promote the pace of digital transformation of private enterprises.

Finally, supporting the digital transformation of enterprises having small proportion of intangible capital and facing financing constraints and operating pressure. The research shows that for enterprises with a small proportion of intangible capital, the management has the courage to "cut off all means of retreat" to carry out digital transformation under the condition of appropriately relaxing the corporate financing constraints. For this reason, enterprises with greater financial constraints can carry out digital transformation with financial support, and the specific measures can be taken from aspect such as expanding the mortgage financing rate and providing green financial support and personnel training support.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

Conceptualization, JG and JL; methodology, JG and YL; validation, JG, JL, and YL; formal analysis, JG, JL, and YL; investigation, JG, JL, and YL; resources, JG, JL, and YL; data curation, JG, JL, and YL; writing—original draft preparation, JG; writing—review and editing, JG, JL, and YL; supervision, YL; project administration, YL; funding acquisition. All authors have read and agreed to the published version of the manuscript.

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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Environmental governance investment and Air Quality: Based on China's provincial panel data

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Ambient air pollution is an important environmental problem that impacts the health and sustainable development of human beings. Many measures have been taken by governments to decrease air pollution. This paper focuses on whether government investment has a positive effect on air quality. Based on China's environmental statistics from 2003 to 2020, the Spatiotemporal Weighted Regression Model is used to observe the spatiotemporal correlation between environmental governance investment and air quality in different provinces in China, finding that there is a negative time-space correlation between environmental governance investment and air quality. In addition, environmental governance investment will not immediately improve air quality, and air pollution has the characteristics of spatial overflow that the pollution between regions affect each other. Then, to further research governments how to deal with environmental protection, configuration analysis has been used, and finds out four high-performance paths for environmental governance of China's provinces. At the end of this research, we put forward four suggestions for air protection. Firstly, government should formulate long-term air governance policies. Secondly, government environmental governance of air pollution should pay attention to the cooperativity of environmental governance between regions. Thirdly, the third sectors, companies and the public should be encouraged in air protection. Fourthly, government should build a whole-process air governance strategy.

KEYWORDS

environmental governance, ESG, spatiotemporal analysis, government investment, China, air quality

1 Introduction

Environmental pollution is a development issue that human beings need to deal with together (Yue et al., 2021). Environmental pollution will have a huge impact on human health and threaten the survival and development of human beings. Some studies found that emissions from human life and industry production not only cause air pollution, such as heavy metal emissions, persistent organic pollutants, spills and hazardous waste sites, but also water pollution that will damage human health after people drink them (René et al., 2010; Wang and Yang, 2016; Ebenstein, 2012). Among many environmental problems, ambient air pollution, as an environmental problem that everyone is familiar with, will have an important impact on human health (Semenova, 2020).

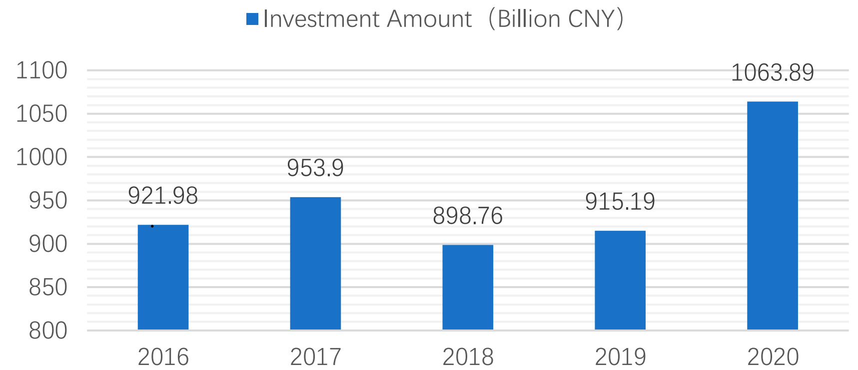
Long-term exposure to air pollution can easily lead to stroke in the older adults (Ma et al., 2022), increase prevalence of rheumatoid arthritis (Alsaber et al., 2020) and even reduce human fertility (Nieuwenhuijsen et al., 2014). It is worth noting that air pollution is strongly associated with mortality. Lung cancer and cardiopulmonary diseases caused by air pollution are important causes of death (Dockery et al., 1993; Jalaludin and Cowie, 2014). Ambient air pollution is a complex environmental problem. Firstly, there are many factors that can lead to air pollution. Both emissions and pollution created by human life and industrial production, such as solid waste, dust, smoke, waste gas, wastewater, sulfur dioxide, nitrogen dioxide, etc. Can trigger air pollution (Bernauer and Koubi, 2013). Secondly, air pollution has a spatial spillover effect. If regional air pollution cannot effectively be controlled, it will spread to other areas and bring new pollution (Chen and Ye, 2019). Thirdly, seasonal variations also affect the level of air pollutant concentration, because seasonal diversity of buildings' energy consumption can affect pollutant emission (Ayoobi et al., 2021).

Regulating Air Quality: The first global assessment of air pollution legislation has been issued by UN in September of 2021 to deal with ambient air pollution. This report acclaimed that Improving air quality is key to tackling the triple planetary crisis of climate change, biodiversity loss, and pollution and waste (United Nations Environment Programme, 2021). And this report recognized that there is no silver bullet to address the air pollution crisis, the role of environmental governance is critical to addressing the pollution crisis (United Nations Environment Programme, 2021). Chinese government also attaches great importance to the ambient air pollution. Environmental Protection Law of the People's Republic of China, The Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution The Law of the People's Republic of China on the Prevention and Control of Atmospheric Pollution, ambient air quality standard (GB3095-2012) have been issued by Chinese government to cope with increasingly ambient air pollution. Factors as the rule of law, regulatory quality and control of corruption were the governance dimensions that contributed to the environmental quality in the long run (Kyriacou and Oriol, 2021). Besides, environmental governance investment from governments is regarded as immediate measure. According to Annual report of China's ecological environment sairtatistics from 2016–2020, the data of 2021 have not issued, the amount of China's environmental governance investment was fluctuating growth (See Table 1). However, there are limited researches on whether government investment in environmental governance will have a positive effect on air pollution. On the contrary, some researchers deemed that government expenditures on environmental protection alone does not play a significant role in contributing to better environmental quality and improvements in quality of governance is the key to deal with environmental protection (Gholipour and Farzanegan, 2018; Moshiri and Daneshmand, 2019).

Data collected from the website of the ministry of Ecology and Environment of the People's Republic of China: https://www.mee.gov.cn/hjzl/sthjzk/sthjtjnb/index.shtml.

The purpose of this paper is to use China's environmental data for 18 consecutive years (from 2003 to 2020) to study whether the environmental governance investment of different provincial governments in China is related to the improvement of air quality. This paper will also find out the differences in different provinces from the spatial distribution. Then, combined with the results of the spatial analysis, further configuration analysis will be carried out to distinguish the different paths presented by the environmental governance of provincial governments. Finally, this paper will analyze the path of government environmental governance and provide theoretical reference for air protection.

TABLE 1 Investment amount of environmental pollution governance in China from 2016 to 2020.



2 Literature review

Governments all over the world have experimented with different approaches to environmental governance, such as enacting public policy (Basoglu, 2019; Zhang et al., 2019), implementing advanced technology (Oberhauser, 2019; Wang and Ye, 2020; Zhao, 2021), and developing integrated governance tools (Abdul Rahman and Alsayegh, 2021; Fitriono, 2019; Pedregal et al., 2020). Among these methods, researchers have paid considerable attention to the direction and magnitude of government spending on environmental pollution. Previously, for instance, researchers applied a regression method to many industrialized nations from 1980 to 2018, including Canada, France, Germany, the United States, and the United Kingdom, with conclusions advocating for higher expenditures on renewable energy as well as energy efficiency to assure a continual improvement in environmental quality (Musibau et al., 2021). Another study recommended that governments in developing countries allocate larger budgets for environmental projects as part of their fiscal reforms, using a generalized method to estimate the impact of government expenditures on environmental quality by measuring sulfur dioxide (SO2), chemical oxygen demand (COD), and ammonia nitrogen emissions (AN) (Zeraibi et al., 2021). In addition, a study examined the effectiveness of the three levels of government's fiscal commitments in reducing CO2 emissions in Nigeria from 2005 to 2020, resulting in increased government spending to address environmental pollution (Onyinyechi and Olasupo, 2022).

However, the government investment could not always benefit the environmental governance in some circumstances. According to research, fiscal pressure reduces the improving effect of vertically applied environmental protection pressure on local government environmental governance (Kou and Han, 2021). Additionally, from 1995 to 2014, a study examined the impact of environmental expenditures on the ecological deficit as a proxy for environmental quality for nine coordinated market economies in Europe, demonstrating that environmental expenditures can increase wellbeing over environmental quality (Basoglu and Uzar, 2019). Moreover, researchers used spatial data from 31 Chinese provinces from 2011 to 2017 to run a spatial econometric model and discovered an inverse U-shaped relationship between environmental expenditures and pollution (Yang et al., 2021). In sum, government investment and other forms of financial assistance could benefit environmental stewardship, but factors such as local economic development and natural systems may limit the effects.

Undeniably, air pollution is a top priority on the international agenda and is generally recognized as a risk to public health and economic prosperity (Dhimal et al., 2021; Shaddick et al., 2020). In China, reform and opening during the past four decades have accomplished not only outstanding achievements but also increased ecological degradation (Ma et al., 2020), with air pollution data in China indicating 1900 ug/m2 of SO2 and 3,200 ug/m2 of NO2 (Xu et al., 2021). According to certain studies, government investment and subsidies benefit air pollution prevention and environmental standards (Bump et al., 2019; Tessum et al., 2019; Li et al., 2015). For example, a study examined data from 77 countries from 1980 to 2000 to examine the impact of government spending on air pollution, finding that more government spending resulted in reduced sulfur dioxide emissions and improved air quality (Halkos paizanos, 2012). Later, a study explored the effect of fiscal policy on air pollution in Pakistan, using the vector autoregressive model on annual data from 1976 to 2018, finding that a budgetary policy scenario has been enacted which boosts government expenditures to mitigate the effects of CO2 emissions (Abbass et al., 2021). Besides, one study suggested that government financing could be the primary source for combating air pollution in the Asia-Pacific area (Husain T. et al., 2021).

Meanwhile, one related study expanded an environmental Kuznets curve framework to analyze the direct and indirect spillover effects of environmental awareness of provincial governments on SO2 emissions using regional econometric models and found that environmental protection expenditures are adversely connected with SO2 pollution (Jiang et al., 2020). Then, according to a study on environmental governance in Taiwan, air pollution control subsidies from the central government can be more effective in improving local air quality than local budget expenditures on environmental protection (Huang, 2021). Also, in Ghana, a study estimated the welfare and environmental effects of imported refined oil subsidies removal with a multi-region computable general equilibrium model, indicating that the removal of subsidies for these imports would lead to the increment of CO2 emissions in this country (Wesseh et al., 2016). Furthermore, several research studies have demonstrated the impact of government investment on the environment of bordering areas. For example, researchers used the data based on China's 30 provinces during one decade, combined with spatial correlation analysis and dynamic panel models, and the results showed that the local government's environmental investment reduces pollution in neighboring regions, demonstrating "free-rider" behavior in positive geographical spillover (Yang, 2021).

As the previous study suggested that changes in the environmental regulations of neighboring regions could hinder the ability of local governments to control haze pollution (Cheng and Zhu, 2021). Thus, long-term cooperation and collaboration in all areas are essential. To investigate the long-term results, a study examined the daily mean of PM10, SO2, and NO2 levels in Beijing from 2006 to 2015, it established a link between the atmospheric indices and government-invested environmental protection funds, demonstrating a direct relationship between the success of

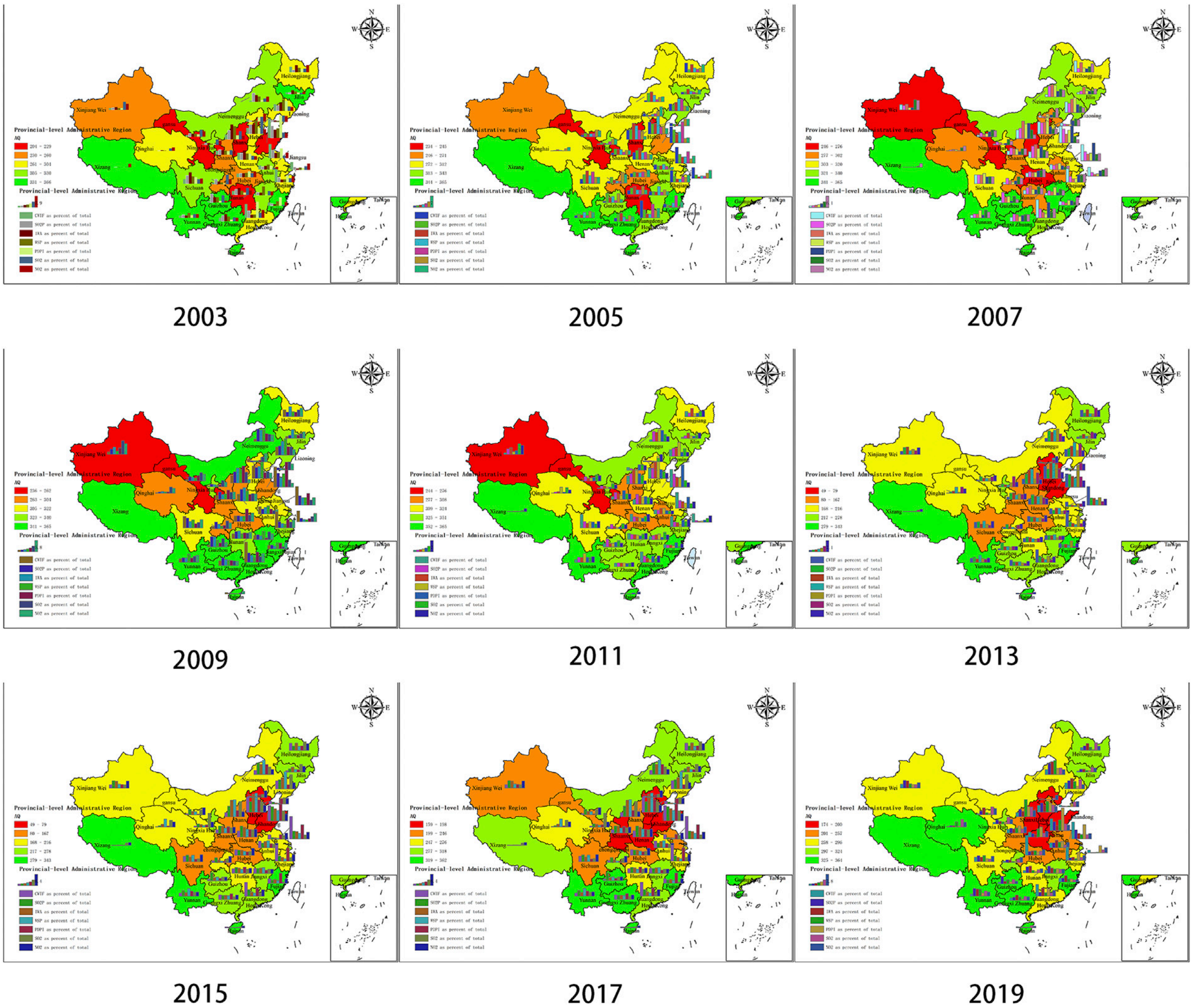


FIGURE 1
Overview of multi-element presentation of environmental indicators by years (2003–2020).

government financial contributions and the promotion of air quality, but during research, it is also discovered that long-term financial investment reduces air quality improvement (Xie and Wang, 2018). Government investment in environmental governance and accompanying financial support has a favorable effect on lowering air pollution. However, the benefit diminishes over time. Furthermore, the spatial impact frequently results in the phenomena of "free-riding." Moreover, these studies typically involve baseline investigations and focus on part geographic regions.

In summary, prior studies have demonstrated positive effects of government investment on environmental governance, particularly the influence on air pollution control. However, despite the researchers' extensive use of models and theories in environmental sciences and econometrics to develop and validate their hypotheses, there are still some limitations to this field of study. Firstly, most studies focused on "time" changes but disregarded "time-space" linkages. Secondly, most studies focused on changes in individual locations and not concentrated on provincial or inter-regional comparisons, as the spatial effect indicates that when environmental protection measures are enacted in a region, the environment in the nearby areas can benefit from it. Thirdly, some advanced research methods, including Moran's Index and configuration analysis, have been combined infrequently on research of air pollution governance. Therefore, the limitations of existing researches provide new direction for further researches. This paper will explore the Spatial-temporal correlation of several air pollution indicators by analyzing environmental data of provincial regions in mainland China from 2003 to 2020, examining whether government investment of various provinces is related to air quality. In addition, this paper will combine Moran's Index and

TABLE 2 Summary of Moran' Index results of provincial distribution in different years (Every 3 years).

Years	Indicators	Moran index	Variance	z-score	*p*-value
2003	AQ	0.0540	0.0141	0.7347	0.4626
	CWTF	0.1611	0.0126	1.7344	0.0829*
	PDPI	0.0512	0.0112	0.7975	0.4252
2006	AQ	0.0972	0.0135	1.1229	0.2615
	CWTF	0.1124	0.0133	1.2631	0.2065
	PDPI	0.0714	0.0126	0.9323	0.3512
2009	AQ	0.1200	0.0135	1.3214	0.1863
	CWTF	0.1205	0.0135	1.3223	0.1861
	PDPI	0.0520	0.0090	0.9109	0.3624
2012	AQ	0.1158	0.0138	1.2698	0.2042
	CWTF	0.1270	0.0118	1.4756	0.1400
	PDPI	0.0886	0.0114	1.1413	0.2538
2015	AQ	0.7281	0.0765	2.7537	0.0059
	CWTF	−0.357	0.0705	−1.2209	0.2221
	PDPI	0.1482	0.0124	1.6290	0.1033
2018	AQ	0.5115	0.0141	4.5860	0.0000***
	CWTF	0.0670	0.0130	0.8829	0.3773
	PDPI	0.0122	0.0119	0.4168	0.6768

*Conceptual of spatial relationship:INVERSE_DISTANCE_SQUARED. Distance method:MANHATTAN_DISTANCE_DISTANCE. Standardization:ROW.

configuration analysis to research the path of governments' air governance.

3 Data analysis

3.1 Methods and data description

3.1.1 Indicators and data description

Air quality is taken as the explained variable in this study. World Health Organization (WHO) has released air quality guidelines (AQG) 2021 for short and long term exposure to various air contaminants, approximately 15 years after the 2005 AQGs, such as particulate matter (PM2.5 and PM10), ozone (O3), nitrogen dioxide (NO2), sulfur dioxide (SO2) and carbon monoxide (CO) (Amini, 2021; Kan, 2022). Air pollution consists of various particles, including sulfur oxides, nitrogen oxides, and carbon monoxide, these particles result from factory emissions, dust, transportation, as well as several other pollutants (Husain T et al., 2021), and is rising due to industrialization, urbanization, rapid population expansion, and other causes (Nagdeve, 2006; Orazbayev et al., 2019). However, air quality is not only related to gas emissions, but also to solid waste production, the indirect determinants of air pollution have also received increased attention. For example, solid, gases and liquid pollutants from industrial production and human actions, like fume and dust (Abdelkader et al., 2015), industrial solid pollutants (Munsif et al., 2021), exhaust gas (Lozhkin et al., 2018), and wastewater contaminants (Devda et al., 2021), have toxicological impacts on the environment. So, we use these related indicators as explanatory variables of air quality.

The statistical data used in this article, comes from the China Statistical Yearbook on Environment which is published annually by Chinese National Bureau of Statistics, and this article will collect 18 years, from 2003 to 2020, data from these yearbooks. These yearbooks were jointly compiled by Chinese National Bureau of Statistics with the Chinese environmental protection department and collects 91 specific indicators related to the environment from 31 provincial-level administrative units (provinces, autonomous regions, and municipalities) in mainland China. The data contained in the yearbook shows status of the end of the last year. Due to the

TABLE 3 GTWR results.

Indicators	GTWR model
Intercept (mean)	2.876,002
p-value (mean)	0.0003
est_lnCWTF (mean)	0.0353
est_lnSO2P (mean)	0.2636
est_lnIWA (mean)	−0.2397
est_lnWSP (mean)	0.0334
est_lnPDPI (mean)	−0.2210
est_lnSO2 (mean)	−0.2250
est_lnNO2 (mean)	−0.3058
Bandwidth	0.114,996
ResidualSquares	1.30476
Sigma	0.049155
AICc	−1,402.25
R^2	0.778,614
R^2 Adjusted	0.775,701
Bandwidth	0.114,996

impact of the COVID-19 pandemic, China's emissions were subject to non-policy restrictions after 2020, so this study did not include the data from China Statistical Yearbook on Environment 2021.

Considering the availability of data, because the provinces do not place environmental governance in the same position in the administrative process, and all these indicators are not mandatory, some indicators are not included in the analysis process.

Therefore, specific indicators involved in this study are as follows:

AQ: days in which the air quality provincial capital cities is or better than Grade II

CWTF: annual operating cost of industrial wastewater treatment facilities.(Due to the availability of the China's data used in this study, there is no direct investment in air pollution control, and previous studies have found that air quality is also related to the discharge of solid waste and wastewater. Therefore, this paper use CWTF to measure the government's investment in air governance).

SO2P: sulfur dioxide emissions total produced (10,000 tons).

IWA: waste smoke and dust emissions total produced (10,000 tons).

CGWAD: the operating cost of the treatment facilities for wasted gas in a year total produced (10,000 yuan).

WSP: industrial waste (solid) generated total produced.

PDPI: the project investment of the pollution decreases in this year.

PM10: PM10 inhalable particulate matter (mg/m^3) total produced.

SO2: sulfur dioxide total produced (mg/m^3).

NO2: nitrogen dioxide (mg/m^3) total produced.

3.1.2 Materials and Methods

In spatial analysis, Moran's Index is usually used to reflect the similarity of the attribute values of adjacent areas in space. Moran's Index is a global measure of spatial autocorrelation (Moran, 1950), this indicator reveals the spatial correlations of the whole region (Li et al., 2014). Moran scatter plot shows the correlation between the observed value vector of a variable and its spatial lag vector. Moran's Index is ranging from −1 (for perfect negative spatial association) to 1 (for perfect positive spatial association). This paper will use the Moran index to reflect the regional correlation of different indicators. This study analyzes major indicators of environmental multi factors in each year by ArcGIS, and finds the results of Moran' Index of provincial distribution. Since the assumption of Moran' Index is that "for a certain index, variables (regions) with similar space do not have correlation." As mentioned before, Moran' Index value is between (0,1), indicating that the distribution pattern of the research object presents an aggregated distribution, and between (−1,0), indicating that the distribution pattern of the research object presents a discrete distribution. The more samples included in the analysis process of Moran's Index, the better the robustness of the results.

To further verify the possible correlation between air quality and explanatory variables, this study adopts the GTWR (Geographically and Temporally Weighted Regression) model designed by Huang et al. (2010) for further analysis. In this study, GWTR is based on the weighting of spatial and temporal dimensions and considers the impact of temporal and spatial heterogeneity on provincial governance investment on environment. Considered the large differences in the measurement units of some indicators, to further standardize the research, indicators in this paper have been logarithmized. The ln AQ (Air Quality, namely, "the number of days when the air quality of the provincial capital city reaches or is better than Grade II") is chose as dependent variable, and the ln CWTF, ln SO2P, ln IWA, ln WSP, ln PDPI, lnSO2, and lnNO2 are chose as explanatory variables.

In addition, this study further carries out a spatial-temporal weighted regression analysis of the relationship between the historical data and the variables. The formula is:

$$\begin{aligned}\ln AQ_i = {} & \beta_0(x_i, y_i, t_i) + \beta_1(x_i, y_i, t_i)\ln CWTF_i \\ & + \beta_2(x_i, y_i, t_i)\ln SO2P_i + \beta_3(x_i, y_i, t_i)\ln IWA_i \\ & + \beta_4(x_i, y_i, t_i)\ln WSP_i + \beta_5(x_i, y_i, t_i)\ln PDPI_i \\ & + \beta_6(x_i, y_i, t_i)\ln SO2_i + \beta_7(x_i, y_i, t_i)\ln NO2_i + \varepsilon_i\end{aligned} \tag{1}$$

3.2 Data analysis

The core dependent variable concerned in this study is the provincial level of air quality. Therefore, the indicator AQ (days in which the air quality provincial capital cities reaches or better than Grade II) is taken as the dependent variable. Taking this

TABLE 4 Calibration anchors for condition variables and result variables.

Variable classification	Name	Indicator description	Complete membership point	Crossing point	No affiliation at all
Result variable	AQ	The number of days (days) when air quality reaches or is better than grade II	920,008.5	178,265.0	26,460.5
Condition variable	CWTP	Annual operating cost of industrial wastewater treatment Facilities (ten thousand yuan)	20.1	10.0	0.6
	IWA	Total soot emission (ten thousand tons)	2,626,092.6	551,171.5	85,165.3
	WSP	Industrial solid waste production amount (ten thousand tons)	34,599.0	9,030.0	1,226.5
	PDPI	Annual completed investment of Pollution Control Project (ten thousand yuan)	512,292.0	98,020.0	2,495.5
	SO2	Unit of sulfur dioxide emissions (mg/m^3)	20.0505	9.98	0.5535
	N02	Unit of nitrogen dioxide emissions (mg/m^3)	365.0	309.0	223.5

indicator as the background color, divided the AQ into five different degrees colors from red to green, indicating that the environment of a province is from poor to good. On this basis, the multi-element presentation of other indicators is showed as bar chart on the figure. The annual data of 2003, 2005, 2007, 2009, 2011, 2013, 2015, 2017, and 2019 are shown in the Figure 1.

From Figure 1, we can clearly see the change of background color during the 18 years, that is, the level of air quality. Compared with the small bar chart in Figure 1, although the values in the bar chart are changing, the air quality in the southern provinces remains relatively stable, while the northern provinces undergo a great transformation. Eastern and central provinces in northern China replaced western provinces as areas with poor air quality.

After calculation with ArcGIS software, the summary of Moran' Index of main indicators in different years is shown in Table 2. It can be seen from Table 2 that under the condition of 90% confidence ($p < 0.1$), not all indicators have passed the significance test. Only CWTF in 2003 and AQ in 2018 have significant spatial autocorrelation effect.

In Eq. 1 of GTWR Model, ln AQ_i refers to the logarithm of the AQ in the spatial-temporal coordinates (x_i, y_i, t_i), $\beta_0(x_i, y_i, t_i)$ represents the spatial-temporal intercept term of province i, $\beta_k(x_i, y_i, t_i)$ represents the spatial-temporal regression coefficient, and K is the number of explanatory variables, ε_i is the residual. Analysis results shown in Table 3.

It can be seen from Table 3 that GTWR shows Adjusted R^2 as an ideal fitting optimization index, with 77.5% explanatory power, indicating that there is a temporal and spatial correlation between AQ and the other seven indicators. Specifically, the parameters corresponding to CWTF, SO2P, IWA, WSP, PDPI, SO2, and NO2 are 0.0353, 0.2636, −0.2397, 0.0334, −0.2210, −0.2250, and −0.3058 respectively, indicating that each 1% increase in CWTF, SO2P, and WSP will drive AQ to increase by 0.0353%, 0.2636%, and 0.0334; Each 1% increase in IWA, PDPI, SO2 and NO2 will reduce AQ by 0.2397%, 0.2210%, 0.2250%, and 0.3058%. The results further show that the total emission of sulfur dioxide and the amount of industrial solid waste do not have a significant negative impact on air quality at the spatial-temporal level, and even show a positive correlation effect; However, PDPI does not show a positive spatial-temporal correlation with air quality, showing a negative correlation. It is found here that the core of the provincial environmental governance, namely, the decision-making of environmental governance investment has the significant characteristics of lag, and environmental governance needs a long cycle to achieve the improvement of environmental quality. Even if the amount of investment increases, the air quality will not be improved immediately in that year.

4 Further analysis

In the previous section, the geographical spatiotemporal weighted regression analysis between the government's environmental investment and air quality was conducted, and the conclusion was drawn that there was a spatiotemporal correlation. Further, through qualitative comparative analysis from the perspective of configuration, this paper intends to carry out effective path research on high performance of government environmental governance in dialogue with the actual situation, providing scientific basis for subsequent suggestions on governance policy optimization. In order to study the effective path of environmental governance by governments of different provinces and regions, it is necessary to introduce a multi-factor concurrent causal relationship that regards the environmental governance status of governments of different provinces as a combination of multiple conditions. On this basis, the research question that this part focuses on is what kind of antecedent configuration combination can achieve high environmental performance of government air control.

TABLE 5 Truth table of high performance in environmental governance configuration analysis.

CWTF	IWA	WSP	PDPI	SO2	NO2	number	AQ	cases	raw consist	PRI consist	SYM consist
1	0	0	1	0	0	1	1	1	0.961,702	0.852,460	0.852,459
1	0	1	0	1	0	1	1	1	0.941,624	0.806,723	0.806,722
0	0	0	0	0	0	3	1	3	0.904,696	0.800,000	0.802,326
0	1	0	0	1	0	1	1	1	0.940,141	0.788,819	0.798,742
0	1	0	0	0	0	1	1	1	0.948,133	0.761,905	0.784,314
1	1	0	0	1	0	1	1	1	0.931,166	0.727,273	0.727,273
0	1	1	1	1	0	2	0	2	0.886,894	0.689,655	0.689,655
1	0	0	1	0	1	1	0	1	0.904,166	0.682,758	0.682,759
0	0	1	0	0	1	1	0	1	0.858,667	0.554,622	0.554,622
1	1	0	1	1	1	1	0	1	0.876,033	0.523,810	0.523,810
0	0	0	0	0	1	3	0	3	0.806,763	0.502,075	0.502,075
1	0	1	1	1	1	1	0	2	0.840,449	0.418,033	0.432,203
1	1	1	1	1	0	2	0	1	0.775,542	0.349,776	0.349,776
1	0	1	1	0	1	1	0	2	0.817,500	0.298,077	0.298,077
0	1	1	1	0	1	1	0	1	0.797,753	0.250,000	0.250,000
1	1	1	1	1	1	4	0	4	0.669,291	0.176,470	0.176,470

TABLE 6 Consistency and coverage results of univariate necessity analysis.

Condition variable	Signification	Variable classification			
		AQ		~AQ	
		Consistency	Coverage	Consistency	Coverage
CWTF	High wastewater treatment	0.541,692	0.629,279	0.671,097	0.735,615
~CWTF	Low wastewater treatment	0.772,413	0.713,376	0.661,795	0.576,723
IWA	High soot emission	0.565,517	0.578,947	0.762,792	0.736,842
~IWA	Low soot emission	0.742,946	0.768,483	0.564,120	0.550,584
WSP	High industrial pollution	0.510,971	0.584,229	0.695,017	0.749,821
~WSP	Low industrial pollution	0.781,191	0.730,792	0.614,618	0.542,522
PDPI	High government investment	0.531,661	0.611,391	0.646,512	0.701,514
~PDPI	Low government investment	0.740,438	0.689,434	0.641,861	0.563,923
SO2	High sulfur pollution	0.589,968	0.611,436	0.737,542	0.721,248
~SO2	Low sulfur pollution	0.731,034	0.746,957	0.602,658	0.581,038
NO2	High nitrogen pollution	0.562,382	0.604,447	0.730,233	0.740,566
~NO2	Low nitrogen pollution	0.758,620	0.748,762	0.609,967	0.568,069

4.1 Variable design of the configuration analysis model

On outcome variables selection, based on the extensive reference of existing research results and data availability principle, this paper quantifies the outcome level of environmental governance of provincial administrative governments by using the number of days (days) when air quality reaches or is better than grade II. In the selection of conditional variables, following the principles of scientific and practical, combined with the results of geographical space-time weighted analysis in Section 3. Select "Annual operating cost of industrial wastewater treatment Facilities (ten thousand yuan)," "Total soot emission (ten thousand tons)," "Industrial solid waste production amount (ten thousand tons)" "Annual completed investment of Pollution Control Project (ten thousand yuan),"

TABLE 7 Effective approach to high performancein government environmental governance based on configuration analysis.

		Government investment leading type	Industrial structure optimization type	Pollution source restricted type	Governance of the whole process linkage type
Owning level	Driving force of conditional elements	1	2	3	4
Limitation at source	Nitrogen pollution	⊗	⊗	⊗	⊗
	Sulfur pollution	⊗		⊗	
	Industrial pollution	⊗	⊗	⊗	
	Soot emission			⊗	⊗
Process of intervention	Wastewater treatment	⊗			
Annual investment	Government investment				
	consistency	0.900,125	0.928,690	0.961,702	0.941,624
	raw coverage	0.452,037	0.351,097	0.283,385	0.232,602
	unique coverage	0.160,502	0.0507,838	0.062069	0.013166
	solution coverage	0.890,826			
	solution consistency	0.904,696			

"Unit of sulfur dioxide emissions (mg/m^3)", and "Unit of nitrogen dioxide emissions (mg/m^3)." The above six indexes were used as antecedent condition variables for configuration analysis. Among them, "total sulfur dioxide emissions (ten thousand tons)" and "sulfur dioxide emissions per unit (mg/m^3)" reflect homogeneity, so they are removed.

The time interval for collecting the performance index data of government environmental governance mentioned above is from 2003 to 2020, considering that regional government environmental governance is the result of long-term combined effects of multiple factors. Therefore, indicators such as"the number of days (days) with air quality reaching or better than grade II" of each provincial administrative region are selected to form a cross-sectional data set of 7 indicators for 31 provincial administrative regions in 2020.

4.2 Calibration of data

In fuzzy set qualitative comparative analysis (fsQCA), the relationship between regional environmental governance results and antecedent variables is described by Boolean algebra system. The membership degree of fuzzy set can be expressed continuously from 0 to 1 from "completely not in the set" to "neither in nor out of the set" to "completely in the set." Different from clear set qualitative comparative analysis (csQCA), which only accepts binary language expression (i.e., 0 or 1), the qualitative continuity of fuzzy set can better explain some properties that are not very precise in the requirements of this study (Campbell et al., 2016). To achieve the above fuzzy set data calibration, the continuous variables are first calibrated to a scale between 0.0 and 1.0. A value close to 0 corresponds to the "low" level of the variable; A value close to 1 corresponds to the "high" level of the variable. Direct calibration methods are used in this paper (e.g., Misangyi & Acharya, 2014; Campbell et al., 2016), specifying that the original variable values correspond to "full entry," "full exit," and "neither entry nor exit" of a set. Referring to the experience of Ragin and Tan Haibo in determining the qualitative breakpoint (" anchor point ") in calibration.

In this paper, 5% and 95% of the data points are selected as the anchor points to determine whether the result variables and condition variables enter the full membership state, and 50% of the fuzzy membership degree is selected as the crossover point. Therefore, calibration standards of each variable can be obtained, as shown in Table 4.

4.3 Configuration analysis of effective path of government environmental governance

4.3.1 Truth table construction

Based on the truth table algorithm in fs/QCA 2.0 (Ragin, 2006), the calibrated data set was initially analyzed. That is, a Boolean attribute space containing 2^k logical possible combinations is constructed, where k (6 in this study) is the number of conditional variables (Greckhamer et al., 2018). As shown in Table 5, the subsequent configuration analysis was based on the space consisting of 64 possible combinations of 6 predicted conditions.

4.3.2 Univariate necessity analysis

In order to test whether the above six indicators and the result variables of government environmental governance level constitute sufficient or necessary conditions. It is necessary to conduct univariate necessity analysis on the above factors first. This step can directly answer whether the result state of government environmental governance can be directly constituted by a certain antecedent condition. The critical value for determining that a single factor is necessary for the result state is the consistency level value of 0.9. In order to make the test both robust, this paper not only testes the consistency and coverage of the existence of single variable to the existence of positive high state results, but also takes the coefficient value generated by the missing state of single variable (represented by symbol ~) into account. The results of univariate analysis are shown in Table 6.

According to the results of univariate essential analysis on the existence of high performance of government environmental governance (AQ), no indicator with consistency level higher than 0.9 was found, that is, none of the six conditional variables could constitute the necessary conditions for high performance of government environmental governance alone. Among them, the index of low nitrogen pollution (~NO2) has the highest coverage rate of 74.9% while showing a high consistency level of 0.758,620. It means that the case of "sharing" the combination of low nitrogen pollution levels and other antecedent conditions has a high degree of consistency in leading to high performance results of government environmental governance, and has the highest degree of explanation. However, since the consistency level of no indicator exceeds 0.9, it is considered that the relative complexity of the single antecedent variable on the performance of political and environmental governance further confirms the spatiotemporal weighted analysis results mentioned above. At the same time, it means that coordination and matching among various elements at the level of government investment, treatment intervention and source restriction can effectively improve the high performance of environmental governance.

Similarly, this paper analyzes the necessity of the single variable when the high performance of government environmental governance is lacking, that is, the result state (~AQ) of low performance level of environmental governance. The results show that the consistency level generated by the existence or absence of each antecedent condition still does not exceed the critical value 0.9. It is further indicated that each single antecedent variable cannot constitute a necessary condition for high performance result state of government environmental governance.

4.4 The configuration analysis

Combined with the comparative analysis in the table above, it shows that whether regional environmental governance is high quality exists in the linkage matching of complex antecedents. Therefore, it is necessary to further explore the combined configuration of each antecedent condition variable through the following, so as to explore the compound effect of multiple concurrent antecedent conditions. The results of configuration analysis were obtained by Quinen-McCluskey algorithm, as shown in the report data in Table 7, and the total solution coverage of the results reached 0.904,696. The total solution consistency reaches 0.890,826, indicating that the solution set in this study has a high degree of explanation for the selected case set while achieving a good consistency level.

According to the method of Fiss reporting the results of configuration analysis, the core condition and auxiliary condition are determined by the condition that the intermediate solution and the simple solution appear together. A solid circle indicates that the condition exists, and a hollow circle with a fork indicates that the condition does not exist. A space indicates that the condition is not relevant in the configuration. Specifically, larger solid circles represent conditional variables that appear in both the simplified and intermediate solutions of the configuration analysis (i.e., core conditions in the efficient path), and smaller solid circles represent conditional variables that only exist in the intermediate solution but do not appear in the simplified solution (i.e., auxiliary conditions in the efficient path).

The four configurations reported in Table 7 form four driving paths, which can be respectively classified as Government investment leading type, Industrial structure optimization type, Pollution source restricted type and Governance of the whole process linkage type path according to different levels of core conditions.

The path of configuration 1 (~CWTF*~WSP*PDPI*~SO2P*~NO2) is represented as Low waste water treatment * Low industrial pollution * High government investment * Low sulfur pollution * Low nitrogen pollution, and the representative regions are Hainan, Xizang, Beijing and Jilin. In this configuration, the level of core conditions is annual investment and limitation at source, that is, government investment leads to the improvement of environmental governance in the form of low nitrogen pollution, so it is named as government-led path.

The path of configuration 2 (IWA*~WSP*PDPI*SO2P*~NO2) is: high soot emission * Low industrial pollution * high government investment * high sulfur pollution * low nitrogen pollution, representing Heilongjiang and Hunan. In this configuration, the level of core conditions is focused on the source constraint. Specifically, on this path, the high performance of environmental governance cannot be achieved without reducing nitrogen pollution and industrial solid pollution, which are the two basic sources of control. In other words, the inhibition of sulfide pollution may not improve the consequence of environmental governance, but the effective mitigation of nitrogen pollution and industrial pollution will certainly improve the consequence of environmental governance. Therefore, it can be summarized that the government through the optimization of industrial structure upgrade path to realize the comprehensive environmental governance.

The path of configuration 3 (CWTF*~IWA*~WSP*PDPI*~SO2P*~NO2) is represented as High wastewater treatment * Low soot emission * Low industrial pollution * High government investment * Low sulfur pollution * Low nitrogen pollution, and representative areas are: Fujian. In this configuration, the level of core conditions also focuses on the limitation at source, indicating that the government adds double weights to improve environmental governance results from the source level of air pollutants and particle pollutants by limiting nitrogen emission and soot emission.

The path of configuration 4 (CWTF*~IWA*WSP*PDPI* SO2P*~NO2) is represented as High wastewater treatment * Low soot emission * High industrial pollution * High Government investment * Low sulfur pollution * Low nitrogen pollution, and the representative areas are: Jiangxi. Different from the above three configurations, the frequency of solid condition in this configuration is the largest, reaching 2/3. By observing the level where solid conditions appear, it is found that they belong to limitation at source, process of intervention and annual investment respectively. This type of approach means that improving the treatment and intervention level of environmental governance alone, or restricting pollution sources in a one-size-fits-all manner, or even relying solely on strengthening government investment, are powerless to produce high performance results of environmental governance. The improvement of the overall environmental governance results in some regions depends on the coordination and linkage of the support power from the prior source restrictions, whole process intervention and government governance investment, which is indispensable.

5 Discussion

Many studies acclaimed the importance of government policies in environmental governance (Zheng and Na, 2020; Peng et al., 2021). However, some studies have found that there is a significant negative correlation between government scale and environmental quality. The higher the percentage of government expenditure in GDP, the more ambient air pollution (Bernauer and Koubi, 2013). And there is an obvious spatial spillover effect on air pollution among key cities (Gong and Zhang, 2017), it means that the environmental deterioration of one area may be affect its surrounding areas. Contrary to common knowledge, some scholars pointed out that the administrative intervention of local governments is not conducive to environmental improvement. Due to the competition of GDP growth between local governments, this adverse impact has a spatial spillover effect (Liu et al., 2021; Han et al., 2022). The analysis results of this study also confirm that there is a negative relationship between environmental governance investment and air quality based on time and space. It shows that the air quality control or other environment actions are complex cross-provincial projects, the air quality of one province and its neighboring provinces cannot be improved only by increasing the environmental investment.

Since China's Reform and Opening up in 1978, the rapid industrialization process has been accompanied by the deterioration of air quality, and air pollution has exacerbated the health burden (Chen et al., 2013). Although local governments have issued environmental protection policies and strengthened the implementation, the effect on air pollution is not sustainable (Cao and Ramirez, 2020). Therefore, based on the previous findings, this study puts forward the following suggestions for air protection.

Firstly, government should formulate long-term air governance policies, focusing not only on the present, but also on the future. The central government of China has issued a series of documents on environmental governance and air pollution, which play a guiding role in the actions of local governments. However, the proportion of environmental governance indicators in the assessment of local government leaders is not prominent, environmental governance has not been paid attention to for a long time. Eastern and central provinces (such as Shandong, Shanxi, and Hebei) have a good industrial base, and their industrial structure is more industrial. From the Figure 1, the data shows that despite increased investment in environmental governance, these provincial governments have placed more importance on economic development, so environmental improvement represented by air quality has been difficult to achieve. In connection with the United Nations SDGs 2030 Goals and China's Carbon Goal of Emission Peak and Carbon Neutrality, China Central government needs to increase the importance of environmental governance in the assessment system for government officials, urging local officials to pay attention to environmental governance.

Secondly, government environmental governance of air pollution should pay attention to the cooperativity of environmental governance between regions. The actions of local governments are crucial to China's environmental governance because they need to implement the central environmental policy and take responsibility for local social welfare and public health (Wu and Hu, 2019). Although this study only used the data of 31 provinces, and did not analyzed the more detailed data of Municipality-level cities, the Moran Index analysis of still showed the trend of spatial aggregation about the AQ, from insignificant at 2003 to significant at 2018. This article shows that there is a negative correlation between environmental governance and air quality under the spatiotemporal weighted analysis (GTWR). Besides, ambient air pollution has spill effect. According to Figure 1, eastern and central provinces in northern China replaced western provinces as areas with poor air quality. That is so say, air quality in one area can be affected by pollution in other areas. Therefore, the central government should formulate a unified plan, build a cross provincial environmental governance plan, and coordinate different provinces in nearby regions to participate in environmental governance.

Thirdly, the third sectors, companies and the public should be encouraged in air protection. Some empirical analyses have been shown that Environmental Non-Governmental Organizations (ENGOs) and companies have a positive impact on the improvement of environmental quality (Bao et al., 2020; Li et al., 2021). Local people can be mobilized and organized by ENGOs and companies to participate in environmental improvement activities (Wang et al., 2020), which will alleviate the pressure of governments on environmental protection. The underdeveloped provinces can hardly balance the limited financial resources of environmental governance with economic and social development, while the governments of developed provinces can invest more funds in environmental governance. With the increasing importance of environmental governance, governments can change the previous environmental strategy and provide some financial support to ENGOs and companies, so that they can play a greater role in environmental governance. This paper suggests that governments with poor financial capacity, they can still mobilize social forces to participate in environmental governance. For example, governments can propagate and promote the application of ESG (Environmental, Social and Governance) which is an investment concept and evaluation standard that focuses on enterprise environment, society and governance performance rather than financial performance (Daugaard and Ding, 2022). ESG will encourage companies to increase investment on air protection and alleviate the increasing pressure of government environmental investment.

Fourthly, government should build a whole-process air governance strategy. Based on the configuration analysis in Chapter four, this paper suggests that the whole process of government environmental governance strategy should be constructed. At the early stage of air governance, governments should adopt legislation and standard formulation to improve air pollutant emission standards, which can reduce emissions and strengthen source control of pollutants. Then, in the process of air governance, governments can encourage the participation of enterprises, the public and the third-party by fiscal and tax policy enactment (Tu et al., 2020), propagating and education. In the later stage of air governance, governments should to strengthen the responsibility review of government managers and air governance evaluation, and urge governments with poor air governance effects to improve their air governance results immediately.

The analysis of this paper is based on the environmental data of the macro panel, which has enlightening significance for the air quality governance between different local governments. However, panel data may not respond to individual and company behavior. Company environmental governance and strategy are also very important, such as ESG which can help people to know the emission decision-making, social responsibility and environmental protection behavior of companies. This paper suggests researchers to conduct more researches on ESG.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: http://www.stats.gov.cn/search/s?qt=%E4%B8%AD%E5%9B%BD%E7%8E%AF%E5%A2%83%E7%BB%9F%E8%AE%A1.

Author contributions

ZD and CM led the conceptual design of the manuscript. ZD, CM, YL, and CX wrote the initial drafts, YW and GC advised the data model and all authors reviewed the manuscript and provided comments and feedback.

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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 impact of environmental regulation or bargaining power on green total factor productivity: Evidence from Taiwan-funded enterprises in Chinese mainland

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Energy conservation and emission reduction of the manufacturing industry are of great significance for promoting China's high-quality economic development. In this paper, the Luenberger productivity index based on the data envelopment analysis (DEA) method is used to measure the green total factor productivity (GTFP). The regression results show that, on one hand, environmental regulation on Taiwan-funded enterprises has a negative impact on the GTFP, which implies that these enterprises need to pay "compliance costs" due to the implementation of environmental regulation policies of Chinese local governments. On the other hand, Taiwan-funded enterprises who can create a large number of jobs have strong bargaining power with the local governments, hence have more opportunities to be exempted from environmental regulations to a certain extent. Therefore, in order to prevent local governments from failing to strictly implementing environmental regulations on Taiwan-funded enterprises, it is suggested that environmental protection achievements be included in the performance appraisal system for the local governments. Chinese local governments should start with a weaker enforcement of environmental regulation, by giving Taiwan-funded enterprises a certain buffer period to gradually adjust the policies intensity. Production characteristics and pollution density of Taiwan-funded enterprises should be considered when enforcing environmental regulation. It is also suggested that environmental, social and governance (ESG) scores of Taiwan-funded enterprises should be taken as a part of their credit qualifications, so as to enhance the internal motivation of energy conservation and emission reduction of these enterprises. In this way, environmental regulation will play a full role in promoting the GTFP of Taiwan-funded enterprises, and help the high-quality development of Chinese economy.

KEYWORDS

Taiwan-funded enterprises, green total factor productivity (GTFP), environmental regulation, bargaining power, high-quality development of Chinese economy

1 Introduction

In the past century, the development of science and technology has led to continuous economic growth. However, the huge consumption of the energy and the damage of the environment have made the conflict between human and nature increasingly acute. It is imminent to establish a resource-saving and environment-friendly society, to develop a low-carbon and circular economy. As the world's second largest economy, China has to undertake the responsibility of energy conservation, emission reduction and environmental protection. At the 75th Session of the United Nations General Assembly in 2020, Chinese President announced that China would achieve the goal of peaking carbon dioxide and other greenhouse gas emissions by 2030 and achieving carbon neutrality by 2060. Energy conservation and emission reduction as well as green transformation and upgrading of the manufacturing industry are of great significance for promoting China's high-quality economic development and achieving the goal of carbon neutrality, and promoting the GTFP of manufacturing enterprises.

Since the Chinese government put forward the "double carbon" target in 2020, emissions reduction has become the focus of the Chinese government's work (Jiang et al., 2022), a series of environmental regulations has been enacted. Scholars also pay more and more attention to the issue about energy conservation, emission reduction and environmental protection, there are many related studies in the existing literature. However, there is almost no research on the environmental performance of Taiwan-funded enterprises. When scholars study the impact of environmental regulation on the GTFP of enterprises, most of them focus on domestic-funded or foreign-funded enterprises. Compared with other types of enterprises, Taiwan-funded enterprises have specific characteristics. Since the recovery of cross-strait economic and trade relations in the late 1980s, Taiwan-funded enterprises have played an important role in providing employment, promoting industrial upgrading, and helping Chinese mainland deeply enter the international market. According to the statistics of "Taiwan's Investment Board of Ministry of Economic Affairs", Taiwan's cumulative investment in Chinese mainland reached 192.42 billion US dollars during the period from 1991 to 2020; According to the Ranking of China's Top 500 Foreign Trade Enterprises in 2020 released by the Statistical Society for Foreign Economic Relations and Trade of China, Taiwan-funded enterprises occupied 3 seats among the top 10. However, as the environmental regulation implemented strictly, Taiwan-funded enterprises with high energy consumption, high pollution are facing the pressure of energy conservation, emission reduction and green transformation (Wu and Deng, 2019). In addition, Taiwan-funded enterprises in the mainland had advantages in technology, management and capital in the early stage of reform and opening up, and the mainland have implemented preferential policies for them to attract them to invest in the mainland, which gave them certain advantages in bargaining. Therefore, this paper focuses on Taiwan-funded enterprises in Chinese mainland and aims to answer two questions: first, how do environmental regulation policies in Chinese mainland affect Taiwan-funded enterprises' GTFP? Second, whether Taiwan-funded enterprises have bargaining power on the environmental regulation policies with local governments of the Chinese mainland? If Taiwan-funded enterprises have, how does bargaining power affect the relationship between local government environmental regulation policies and enterprises' green total factor productivity? To answer these questions, we conduct an empirical analysis, and the main findings are: the Chinese mainland environmental regulation will reduce the GTFP of Taiwan-funded enterprises; the more jobs opportunities the Taiwan-funded enterprises creates, the higher the bargaining power with the local governments, and the greater the possibility being exempted from environmental regulation to a certain extent.

This paper is different from the previous literature in several aspects. First, in China, it is of special significance to study the bargaining power, especially the bargaining power of Taiwan-funded enterprises in Chinese mainland, because of the particularity of Taiwan-funded enterprises and the great flexibility of Chinese local governments in implementing environmental regulations. At present, research on the bargaining power of Taiwan's enterprises in Chinese mainland is almost blank. Most researches focus on the role of policies on enterprises, and this paper also examines on the reaction of enterprises to policy implementation; Second, different from the previous literature that mainly uses output value or tax to measure enterprises' bargaining power, this paper finds it is more reasonable to use employment to measure bargaining power for Taiwan-funded enterprises; Third, unlike the existing literature, this paper uses the green TFP to measure the productivity of enterprises, rather than the traditional TFP. It is generally believed that the traditional TFP overestimate true productivity; Fourth, many of current literatures focus on carbon emissions, while this paper applies to various forms of pollutants, mainly waste gas pollution, waste water pollution and industrial soot pollution; Last but not least, the existing literature often analyze a group of countries within one framework, ignoring the lack of uniform environmental regulations across countries. This paper focuses on different enterprises inside one country, so there is no such a problem of legal heterogeneity. Based on these, we believe that, studying the impact of environmental regulation policies on the GTFP of Taiwan-funded enterprises in Chinese mainland will add micro-evidence to relevant theories, and discussing the distortion of environmental regulation policies by bargaining power of Taiwan-funded enterprises will provide a useful reference for policy makers or enforcers.

The rest of this paper is arranged as follows: Section 2 proposes two theoretical hypotheses, that is, the environmental regulation will reduce the GTFP of Taiwan-funded enterprises, and the bargaining power of Taiwan-funded enterprises has a negative effect on the implementation of the environmental regulation policies in Chinese mainland; Section 3 explains the processing of variables, focusing on calculating the GTFP index of Taiwan-funded enterprises and the urban environmental regulation index; Section 4 conducts empirical analysis using panel data of Taiwan-funded enterprises, to verify the two theoretical hypotheses proposed, to reveal the impact of environmental regulation on the GTFP of Taiwan-funded enterprises and the negative effect of the bargaining power of Taiwan-funded enterprises with the local governments; Section 5 are the conclusions and policy recommendations.

2 Theoretical hypotheses

2.1 The impact of environmental regulation on the green total factor productivity

With the increasing amount of attention given to ecological protection, the balance between environmental regulation and economic development is at the center of academic and policy debates. Environmental regulation, such as collecting the pollution discharge fees, is the main mean for the government to realize the green transformation of enterprises. In China, the relationship between environmental regulation and green total factor productivity of enterprises is so important that it cannot be overemphasized, but the conclusions remain controversial. The impact of environmental regulation on the GTFP of enterprises is mainly summarized as "Porter Hypothesis" and "Compliance Cost Hypothesis". The "Porter Hypothesis" believes that reasonable environmental regulation can stimulate the "innovation compensation effect," which can not only compensate the "compliance cost," but also improve the productivity and competitiveness of enterprises (Porter and Linde, 1995). Jaffe and Palmer (1997) also believe that the mechanism of environmental regulation is to internalize the externalities generated in the production activities into the production costs of enterprises, and then force enterprises to carry out technological innovation. Fan et al. (2022) show that environmental regulation indirectly promotes GTFP by enhancing green technological innovation level. Jin et al. (2022) constructs a GTFP evaluation index system and analyzes the impact of environmental regulation on GTFP in the context of increasing innovative labor force. Guan and Wu (2020), Liu et al. (2020), Xiao et al. (2020) all support the "Porter Hypothesis". The "Compliance Cost Hypothesis" believes that environmental regulation will lead to a "distortion effect of resource allocation" and hinder the improvement of GTFP. Xie et al. (2017), Yuan and Xiang (2018) show that environmental regulation will increase the cost of enterprises and squeeze out R&D investment, which is not conducive to the improvement of GTFP of enterprises.

However, more and more studies have found that the impact of environmental regulation on the GTFP of enterprises cannot be simply attributed to "Porter Hypothesis" or "Compliance Cost Hypothesis." Shen and Liu (2012) show that there is a U-shaped relationship between the intensity of environmental regulation and technological innovation, and the "Porter hypothesis" can only be realized when the intensity of environmental regulation exceeds a certain threshold; Li and Tao (2012) show that the intensity of environmental regulation in heavily polluted industries is relatively reasonable, which may promote the GTFP, improve technological innovation and efficiency. The relationship between environmental regulation and GTFP, technological innovation or technological efficiency is U-shaped in moderately and mildly polluted industries. Yu and Hu (2016) show that environmental regulation always has a negative impact on the technological innovation in the heavily polluted industries, an impact with the U-shaped relationship in the mildly polluted industries. Yin and Wu (2021) show that the impact of government-controll environmental regulation follows the "Compliance Cost Hypothesis" with a lag of two periods, and the impact of public participation environmental regulation follows the "Porter hypothesis" with a lag of two periods, and the impact has regional differences. Cheng and Kong (2022) show that command-and-control (management) environmental regulations will boost the expansion of GTFP. This is mainly achieved by improving technological efficiency and narrowing the technological gap. Market-based environmental regulations can also accelerate the growth of GTFP, principally through improvements in the advancement of technology and a narrowing of the technological gap. Zou and Zhang (2022) show that the effect of command-and-control environmental regulation on GTFP is a significant inverted U-shape curve, which is currently the primary driving role in green development, but it is too strict and increasingly less effective. Both market incentive and voluntary environmental regulations appear as positive U-shape curves, and their proper enhancement is breakthrough for future green development. Besides, market incentive environmental regulation is more effective in pollution-intensive industries with relatively low pollution, while voluntary environmental regulation is sensitive to pollution-intensive industries with relatively serious pollution. Li and Chen (2019) show that environmental regulation reduces the GTFP of enterprises in the short-term, and promotes the GTFP in the long-term.

Therefore, the net impact of environmental regulation on the GTFP of enterprises depends on the balance between the innovation compensation effect and the resource distortion effect produced by the policies. In fact, in the past 30 years, many industries invested by Taiwanese in Chinese mainland were the sunset industries in Taiwan, with heavy pollution and

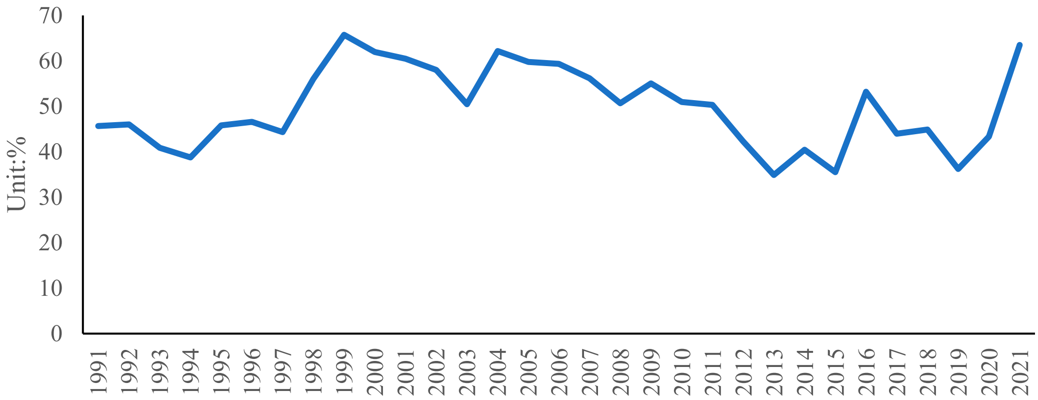

FIGURE 1
The proportion of Taiwanese funded enterprises investing in heavily polluting industries in Chinese mainland during 1991 and 2021. Note: Figure is based on the data from "Taiwan's Investment Board of Ministry of Economic Affairs". According to the Guidelines for Environmental Information Disclosure of Listed Companies issued by the Ministry of Ecology and Environmental of the People's Republic of China in 2010, mining industry, chemical manufacturing, chemical materials, plastic products, metal products, electronic components, computers, electronic products, and optical products, textile industry, leather, fur and their products, and pulp, paper, and paper products are regarded as heavy pollution industries.

high energy consumption. The data in Figure 1 supports this: during 1991 and 2021, about 50% of Taiwanese investment in Chinese mainland was concentrated in heavily polluting industries. In 2021, the proportion of Taiwanese investment in heavily polluting industries in Chinese mainland reached 64%. In terms of environmental management, the Ministry of Environmental Protection said that Taiwan-funded enterprises would be treated equally with mainland enterprises.[1] This means that Taiwan-funded enterprises have to pay more than before for the environmental treatment costs, such as pollution discharge fees, which may reduce their GTFP. Based on this, this paper presents the first hypothesis: Chinese mainland environmental regulation policies will reduce the GTFP of Taiwan-funded enterprises.

2.2 The negative effect of the bargaining power of enterprises on environmental regulation

In China, environmental regulatory policies are generally formulated by the central government and implemented by the local governments. Due to the performance appraisal system of local governments and the promotion system of officials, local governments tend to pay more attention to economic development rather than environmental performance. Therefore, it is not unusual that local governments pursue a single economic goal and fail to accommodate long-term and overall interests by choosing to relax environmental controls, so enterprises may use their greater contribution to the performance appraisal of the local governments as a "bargaining chip" to obtain exemption or loose enforcement of environmental regulation. Xi (2017) point out that large taxpayers who make greater contribution to the performance appraisal of the local governments have strong bargaining power with the local governments which can weaken the effect of environmental regulation. In the view of Li and Chen (2019), to reflect the bargaining power of enterprises, regional GDP and stable employment are also important tasks for the local governments. The higher the industrial output value or more employees of the enterprises, the greater the contribution to the local governments, and then the enterprise will obtain greater bargaining power. When constructing the indexes of the bargaining power of Taiwan-funded enterprises, this paper uses Li and Chen (2019) as the main reference.

Employment, value-added tax and industrial output value are the three major contributions of Taiwan-funded enterprises to the local governments. Among the three, the highest contribution is employment, rather than value-added tax or industrial output value. First, the value-added tax payment of Taiwan-funded enterprises is relatively limited, which is not enough to form a strong bargaining power. For example, in 2007, the actual value-added tax rate of Taiwan-funded enterprises was 10.2%, far lower than the statutory rate of 17% (Yang et al., 2017); Second, the industrial output value of Taiwan-funded enterprises is also relatively limited. Most of the Taiwan-funded enterprises "put both ends abroad" (put the raw material market and sale market in the international market). According to the 2020 Factual Survey on Overseas Production of Export Orders, Taiwan's manufacturing export orders accounted for 45.5% of its production in the mainland, of which 72.1% were exported to the United States or other countries. Therefore, the actual contribution of the industrial output value of Taiwan-funded enterprises to the local governments has been discounted. Third, most importantly, Taiwan-funded enterprises have created a large number of employment opportunities in the past decades. The minister of the Ministry of Commerce of the People's Republic of China, pointed out in 2020: "Foreign trade and foreign investment directly and indirectly created more than 200 million jobs." Taiwan-funded enterprises have created more than 12 million jobs in the mainland (Bai and Liu, 2020). Therefore, the bargaining power of Taiwan-funded enterprises with the local governments is mainly reflected in employment. Based on this, this paper presents the second hypothesis: the more the jobs created, the stronger the bargaining power of Taiwan-funded enterprises with the local governments and the greater they can weaken the implementation of environmental regulation.

3 Variables and data

3.1 Variable description and data processing

According to the two hypotheses put forward above, this paper will use the panel data of Taiwan-funded enterprises to examine the impact of environmental regulation or bargaining power on the GTFP. Therefore, the theoretic regression model is set up as follows:

$$GTFP_{it} = a_0 + a_1 ERI_{mt} + a_2 BP_{it} + a_3 X_{it} + a_4 Y_{mt} + \varepsilon_{it} \qquad (1)$$

In Eq. 1, GTFP is the green total factor productivity of Taiwan-funded enterprises, ERI is the environmental regulation intensity of the city where the enterprises are located, BP is the bargaining power of Taiwan-funded enterprises with the local government, vector X contains the control variables at the enterprise level, and vector Y contains the control variables at the city level, and ε is the error term. In general, $\varepsilon_{it} = v_t + w_i + u_{it}$, v_t is time effect, and w_i is individual effect. In the next section, the individual fixed regression will be run based on Hausman test; the subscript i represents the enterprise, t represents the year, and m represents the city.

There are two types of core explanatory variables in Eq. 1. First, the urban environmental regulation index (ERI) is calculated referring to the research of Fu and Li (2010). Three indexes (industrial wastewater discharge standard rate, industrial sulfur dioxide removal rate and industrial soot removal rate) are selected to measure the level of environmental regulation of a city. The data source used to calculate these indexes is the China City Statistical Yearbook over the years. Second, the bargaining power (BP) of Taiwan-funded enterprises is calculated referring to the research of Li and Chen (2019). This paper calculates three variables to indicate bargaining power, represented by BP_1, BP_2, and BP_3, respectively. Mathematically, the three variables are defined as follows:

$$BP_1 = \frac{\text{industrial output value of an enterprise}}{\text{total industrial output value of a city}} \times \text{ERI}$$

$$BP_2 = \frac{\text{value} - \text{added tax of an enterprise}}{\text{total value} - \text{added tax of a city}} \times \text{ERI}$$

$$BP_3 = \frac{\text{employment of an enterprise}}{\text{total employmen of a city}} \times \text{ERI}$$

The data sources used to calculate the above three variables are the Chinese Industrial Enterprise Database and the China Urban Statistical Yearbook.

Two control variables are selected at the enterprise level: The first is regarded to the current asset ratio (CAR), measured by the proportion of current asset as the sum of current asset and fixed asset; The second is the financing constraint (FC), which is expressed as the ratio of interest expense to fixed asset. The data source used to calculate these two firm-level control variables is the Chinese Industrial Enterprise Database.

Two control variables are also selected at the city level: The first is the development level (DL), expressed by per capita GDP; The second is the scientific importance (SI), measured by the proportion of scientific expenditure in GDP in a city. The data source used to calculate these two city-level control variables is the China Urban Statistical Yearbook.

The explained variable, GTFP in Eq. 1, is calculated using the Luenberger Productivity Index of the SBM (Slack-Based Measure) directional distance function, see below for details.

From the description of the above variables, it can be seen that the data at the enterprise level are all derived from the Chinese Industrial Enterprise Database. To accurately select the Taiwan-funded enterprises from the Chinese Industrial Enterprise Database is an extreme difficult task because the database is huge with over 4 million enterprises, and there are many errors, omissions and changes of the enterprise names. Before matching the enterprise names of Taiwan-funded enterprises with the database, this paper first excludes the invalid observations of key variables that do not meet the requirements according to the accounting standards, retains the manufacturing enterprises with industry code between 13 and 42 in the Chinese Industrial Enterprise Database. The names of provinces and cities and the area-codes of enterprises are also repaired in accordance with documents of the Ministry of Civil Affairs and the Ministry of Industry and Information Technology. Then, this research begins to match the names of the Taiwan-funded enterprise in the Directory of Taiwan Enterprises in the Mainland (six volumes), the Directory of Investment Undertakings of Listed Companies in Chinese mainland and the Top 1,000 Taiwan Business Companies with the Chinese Industrial Enterprise Database. Due to enterprise restructure, reorganization or expansion, the enterprise names may change over years, so the common words such as "limited company," "group," and "factory" are crossed out for matching purpose. Based on the sequential

TABLE 1 Summary statistics.

Variables	Observations	Mean	Standard deviation	Min	Max
Green total factor productivity (GTFP)	17,139	1.119	3.042	−23.515	48.069
Environmental regulation index (ERI)	17,139	32.397	16.482	5.182	99.436
Bargaining power 1 (BP_1)	17,139	0.003	0.009	0.000	0.382
Bargaining power 2 (BP_2)	17,139	0.000	0.003	0.000	0.145
Bargaining power 3 (BP_3)	17,139	0.002	0.007	−0.118	0.127
Current asset ratio (CAR)	17,139	0.670	0.205	−0.077	1.000
Financing constraint (FC)	17,139	0.024	0.129	−2.681	8.628
Development Level (DL)	17,139	4.239	1.695	0.349	7.880
Science importance (SI)	17,139	0.001	0.001	0.000	0.005

matching logic of Brandt et al. (2012), this paper uses the following variables and variable combinations to match the data of two or three years: "legal person code," "enterprise name," "area code + phone number," "legal person + zip code + product[2]," "opening time + phone number + city." The use of variable combination helps to improve the matching accuracy. Limited by the availability of data from Taiwan-funded enterprises and the "typos" in the Chinese Industrial Enterprise Database, this paper finally selects 2005–2007 as the sample with a total of 17,139 observations.

The summary statistics of the main variables is shown in Table 1.

3.2 Measuring the green total factor productivity of Taiwan-funded enterprises

Total factor productivity (TFP) is an important guarantee for economic growth in long-term, but traditional TFP does not take into account the damage to environmental resources caused by economic growth, thus distorting the evaluation of social welfare and economic performance (Hailu and Veeman, 2000). With the current rapid economic development and unearthed environmental problems, we cannot ignore environmental factors when considering total factor productivity (Li et al., 2019). Compared with traditional TFP, GTFP can take the undesired outputs such as industrial wastewater, industrial sulfur dioxide, and industrial soot produced by the industrial enterprises, into account, which is an important guarantee for sustainable economic growth (Li and Liao, 2020).

In the empirical analysis, the green total factor productivity index will be represented by the Luenberger productivity index calculated by Data Envelopment Analysis (DEA) method. The DEA proposed by Charnes et al. (1978) does not require parameter assumptions, can solve the problem of multiple inputs and multiple outputs, and can simultaneously incorporate capital input and pollutant emissions into the analysis framework. It takes into account undesired output and is currently a widely applicable method for calculating GTFP (Wang et al., 2010). Therefore, this paper chooses this method to calculate GTFP. The calculation process is specified as follows:

First, according to the research of Fukuyama and Weber (2010), the SBM directional distance function is defined:

$$S_C^t\left(x^{t,i}, y^{t,i}, b^{t,i}, g^x, g^y, g^b\right) = \max_{s^t,s^t,s^t}\left[\frac{1}{N}\sum_{n=1}^{N}\frac{s_n^x}{g_n^x} + \frac{1}{M+I}\left(\sum_{m=1}^{M}\frac{s_m^y}{g_m^y} + \sum_{j=1}^{I}\frac{s_j^b}{g_j^b}\right)\right]\Big/2 \tag{2}$$

$$\text{s.t.}\sum_{i=1}^{K}\lambda_i^t x_{in}^t + s_n^x = x_{in}^t, \forall n; \sum_{i=1}^{I}\lambda_i^t y_{im}^t - s_m^y = y_{im}^t, \forall m; \sum_{i=1}^{I}\lambda_i^t b_{ij}^t + s_j^b = b_{ij}^t, \forall j \tag{3}$$

$$\sum_{i=1}^{K}\lambda_i^t = 1, \lambda_i^t \geqslant 0, \forall i; s_n^x \geqslant 0, \forall n; s_m^y \geqslant 0, \forall m; s_j^b \geqslant 0, \forall j \tag{4}$$

where x represents input, $x = (x_1, \ldots, x_n) \in R_N^+$; y indicates the desired output, $y = (y_1, \ldots, y_m) \in R_M^+$, b indicates undesirable outputs, $b = (b_1, \ldots, b_j) \in R_J^+$. S_C^t represents the directional distance function, at each period t (t = 1, 2,. . ., T). ($x^{t,i}$, $y^{t,i}$, $b^{t,i}$), (g^x, g^y, g^b) and ($s_n{}^x$, $s_m{}^y$, $s_j{}^b$), are the input and output vectors, direction vectors and relaxation vectors of the enterprises i (i = 1, 2,. . ., I), respectively.

If the technological progress of the enterprise is denoted by TP and the technological efficiency of the enterprise is denoted by TE, then the GTFP index between the period t and period t + 1 is:

$$GTFP_{it} = \frac{1}{2}\{[S_C^t(x^t, y^t, b^t; g) - S_C^t(x^{t+1}, y^{t+1}, b^{t+1}; g)] + [S_C^{t+1}(x^t, y^t, b^t; g) - S_C^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; g)]\} \tag{5}$$

$$TP_{it} = S_C^t(x^t, y^t, b^t; g) - S_C^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; g) \tag{6}$$

$$TE_{it} = \frac{1}{2}\{[S_C^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; g) - S_C^t(x^{t+1}, y^{t+1}, b^{t+1}; g)] + [S_C^{t+1}(x^t, y^t, b^t; g) - S_C^t(x^t, y^t, b^t; g)]\} \tag{7}$$

In the empirical analysis, the input factor is the fixed asset of the enterprises, and the desired output is the industrial output value of the enterprises; The undesired outputs are the industrial

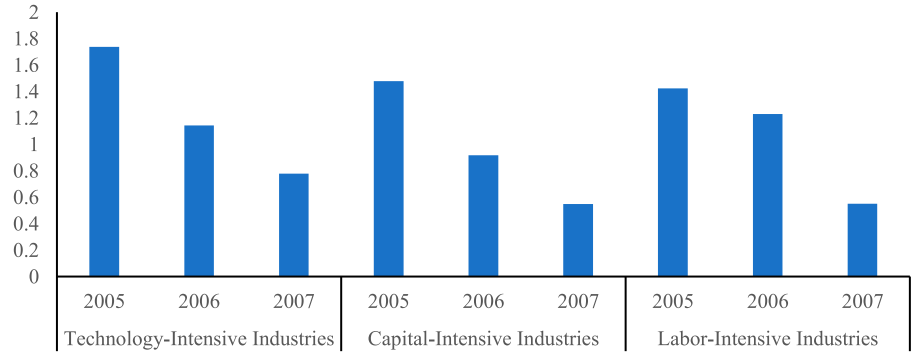

FIGURE 2
Changes in GTFP of Taiwan-funded enterprises of different industrial types from 2005 to 2007. Note: The criteria for the classification of the types of Taiwan-funded enterprises refer to Yang et al. (2018).

emissions of wastewater, sulfur dioxide and industrial soot. This paper uses the methods of Cui and Lin (2019) to calculate the three undesired outputs: first, calculate the weight of each pollution index in the city, using the equation $W_{mz} = (P_{mz}/\sum P_{mz})/(O_m/\sum O_m)$, where P_{mz} is the emission of pollutant z (z = 1, 2, 3) in the city m, $\sum P_{mz}$ is the total national emission of pollutant z, O_m is the gross industrial output of the city m, and $\sum O_m$ is national total industrial output; second, calculate the weighted adjusted emission of the city's pollutant, using the equation $em_{mz} = W_{mz} \times Y_{mz}$, where Y_{mz} is the original emission of pollutant z in the city m; finally, calculate the emission of pollutant z of Taiwan-funded enterprise i in city m, using the equation $es_{iz} = em_{mz} \times (Q_i/\sum Q_i)$, where Q_i is industrial output of the enterprise i, $\sum Q_i$ is the total industrial output of the city where the enterprise is located.

According to the above input-output data, this paper uses MAXDEA software to calculate GTFP of Taiwan-funded enterprises. The results show that the average GTFP of technology-intensive enterprises is the highest, which is 1.192; the average GTFP of labor-intensive enterprises is the second highest, which is 1.036; the average GTFP of capital-intensive enterprises is the lowest, which is 0.966. Observing Figure 2, it can be seen that the GTFP of Taiwan-funded enterprises in different industries showed a downward trend from 2005 to 2007. It may be that the increasingly stringent environmental regulation had a negative impact on the GTFP.

4 Emprical analysis

4.1 Multicollinearity test

In Tables 2, 3, except for the positive correlation between BP_2 and GTFP, all other variables are negatively correlated. The maximum value of VIF is 1.34, which is much less than 10. It can be preliminarily determined that there is no multicollinearity among variables.

The Hausman test results in Table 4 show that the *p*-value is less than 0.01, which means that the null hypothesis is rejected, so this paper chooses individual fixed effect model to run the regressions.

4.2 Regression results

First, Table 5 shows the regression results of five models with regard to the Taiwan-funded enterprises. Model 1 is the basic regression without considering the bargaining power (BP) of enterprises. The results of model 1 show that the environmental regulation index (ERI) of the city has a significant negative impact on GTFP, which rejects the "Porter Hypothesis" and supports the "Compliance Cost Hypothesis." This paper argues that the time period selected by the sample from 2005 to 2007 coincided with the third wave of boom of Taiwanese investment in the Chinese mainland. A large number of enterprises with large energy consumption and serious environmental pollution moved from Taiwan to the Chinese mainland. The Department of Environmental Protection begun to treat all enterprises equally on pollution control with no more preferential policies for foreign and overseas enterprises during that period. Theoretically, the investment of enterprises in pollution prevention and control tends to crowd out the investment in R&D and technology innovation, which will have a negative impact on green total factor productivity (Qi et al., 2016). With the strict implementation of environmental regulation, Taiwan-funded enterprises have increased investment in pollution control, decreased investment in technology research, distorted resource allocation, and decreased GTFP. This conclusion confirms the first hypothesis proposed in this paper.

TABLE 2 Correlation coefficients.

Correlation	GTFP	ERI	BP_1	BP_2	BP_3	CAR	FC	DL	SI
GTFP	1.00								
ERI	−0.10	1.00							
BP_1	−0.04	0.05	1.00						
BP_2	0.04	0.06	0.20	1.00					
BP_3	−0.01	−0.04	0.21	0.05	1.00				
CAR	−0.19	−0.02	0.00	−0.05	0.00	1.00			
FC	−0.04	0.04	0.04	0.00	0.01	0.10	1.00		
DL	−0.22	0.31	−0.08	−0.06	−0.11	0.07	−0.04	1.00	
SI	−0.14	0.01	−0.15	−0.04	−0.21	0.07	−0.02	0.39	1.00

TABLE 3 Variance inflation factors.

Variance inflation factor	GTFP	ERI	BP_1	BP_2	BP_3	CAR	FC	DL	SI
VIF	1.15	1.11	1.05	1.09	1.02	1.02	1.34	1.25	1.13
1/VIF	0.87	0.90	0.95	0.92	0.98	0.98	0.75	0.80	0.89

TABLE 4 Hausman test results.

Variables	FE model	RE model	Hausman test	
			FE-RE	S. E
ERI	−0.11***	−0.04***	−0.07	0.00
BP_1	−13.46***	−14.85***	−1.39	5.30
BP_2	58.10***	50.42***	7.68	6.73
BP_3	−19.92***	−2.55***	−17.37	2.28
observations	17,139	17,139	Chi-squared = 1,047.46	
Adjusted R^2	0.15	0.14	p-value = 0.0000	

Note: (1) ***, **, * in the table indicate statistical significance at 1%, 5%, and 10% levels, respectively; (2) The explained variable is GTFP, the same below.

Second, Table 5 also shows the regression results of model 2, model 3, model 4, model 5. In order to investigate the reaction of the bargaining power of enterprises on the environmental regulation policies, the variables BP_1, BP_2, and BP_3 enter the regression sequentially. It can be seen that the signs of all explanatory variables have not changed, and they are all statistically significant at the 1% level, indicating reliability of the results to a certain degree. The signs of the coefficients of BP_1 and BP_3 are significantly negative, −1.6 and −1.75, respectively, indicating that the industrial output value and VAT tax payment of Taiwan-funded enterprises cannot become the effective bargaining power, and Taiwan-funded enterprises still have to pay “compliance costs” for the pollution caused by them. The reason is that, on one hand, the business model of Taiwan-funded enterprises in the Chinese mainland is “put both ends abroad” (put the raw material market and sale market in the international market). Although the import and export amounts are high, the actual net amount is relatively small, so the contribution to the local gross output value is discounted; On the other hand, Chinese mainland has provided favorable tax policies for Taiwan-funded enterprises. During the sample period, zero value-added tax rate was applied to the export products of Taiwan-funded enterprises, that is, all taxes will be refunded after the products are declared for export. On the contrary, the coefficient of BP_2 is always significantly positive, indicating that the more jobs created, the greater the contribution to the local governments, the higher the bargaining power, and the greater the possibility of obtaining exemptions or loose implementation of environmental regulation. Thereby, the greater the contribution to the local employment, the stronger force to counteract environmental regulation. This conclusion confirms the second hypothesis proposed in this paper.

The coefficients of CAR and FC are both significantly negative, indicating that the higher the proportion of current asset or the stronger the financing constraint, the lower the GTFP. Enterprises with a high proportion of current asset or strong short-term liquidity may crowd out R&D or other long-term expenditures. Enterprises have strong financing constraint

TABLE 5 Regression results of Taiwan-funded enterprises.

Variables model	Model 1	Model 2	Model 3	Model 4	Model 5
ERI	−0.09*** (0.0000)	−0.09*** (0.0000)	−0.09*** (0.0000)	−0.09*** (0.0000)	−0.09*** (0.0000)
BP_1		−1.60*** (0.0000)			−1.60*** (0.0000)
BP_2			6.87*** (0.0000)		6.94*** (0.0000)
BP_3				−1.75*** (0.0000)	−1.73*** (0.0000)
CAR	−4.96*** (0.0000)	−4.93*** (0.0000)	−4.97*** (0.0000)	−4.89*** (0.0000)	−4.88*** (0.0000)
FC	−0.93*** (0.0020)	−0.93*** (0.0020)	−0.93*** (0.0020)	−0.90*** (0.0000)	−0.91*** (0.0000)
DL	−0.25*** (0.0000)	−0.29*** (0.0000)	−0.23*** (0.0000)	−0.28*** (0.0000)	−0.30*** (0.0000)
SI	−45.58*** (0.0000)	−50.74*** (0.0000)	−42.35*** (0.0000)	−101.56*** (0.0000)	−103.04*** (0.0000)
constant	8.43*** (0.0000)	8.70*** (0.0000)	8.38*** (0.0000)	8.65*** (0.0000)	8.84*** (0.0000)
Individual fixation	Yes	Yes	Yes	Yes	Yes
Observations	17,139	17,139	17,139	17,139	17,139
R − squared	0.18	0.18	0.18	0.18	0.19

Notes: Numbers in parentheses are t statistics, the same below.

may hinder energy conservation and emission reduction, and then may increase the undesired output. The coefficients of DL and SI are also significantly negative, indicating that the increasing in per capita income or the increasing government's emphasis on scientific research in cities have a negative impact on the GTFP in short run. The higher the level of economic development of a city, the higher the cost of sacrificing the natural environment, and the lower the green total factor productivity of enterprises in the city (Li et al., 2021). With the improvement of people's living standards, or with the greater the city's expenditure on scientific research, the city has higher requirements on achieving green transformation and upgrading, which force enterprises to pay high environmental costs.

4.3 Reliability checking with different samples

In order to further test the reliability of the regression results, this paper selects technology-intensive enterprises to run regression again. The number of observations of Taiwan-funded technology-intensive enterprises is 9,791, accounting for 57.13% of the total sample. According to Table 6, after changing the sample, the signs of the regression coefficients of the explanatory variables have not changed, and they are still significant, which shows that the model setting and regression results in this paper are reliable to some extent. The two hypotheses proposed in this paper are still valid. With strict implementation of environmental regulation, the technology-intensive enterprises will make some adjustments. First, these enterprises may reduce production to cope with the impact of short-term environmental regulation. Second, these enterprises may increase environmental governance expenditures by reducing investment in technological innovation. Therefore, the environmental regulation also has a negative impact on the GTFP of Taiwan-funded technology-intensive enterprises. In comparison, Taiwan-funded technology-intensive enterprises enjoy greater tax incentives. Since 1 October 1999, after the mainland levied the statutory tax rate of 17% on computer software products, the value-added tax rate has been reduced to 6%, and the value-added tax rate of exported products is zero. Most of the Taiwan-funded technology-intensive enterprises also "put both ends abroad." The abundant and cheap labor resources in Chinese mainland are still the key to attracting Taiwanese to invest. Therefore, job creation is still the bargaining power of Taiwan-funded technology-intensive enterprises to obtain exemptions or loose implementation of environmental regulation.

In addition, the research also collapses the panel data into a cross-sectional data to run an OLS regression, and the main results do not change significantly. The regression results are not reported to save space. Therefore, the regression results of Table 5 is very likely to be reliable.

5 Conclusions and policy recommendations

Using the matching results of the Chinese Industrial Enterprise Database, the Taiwanese Enterprise Directory and the China Urban Statistical Yearbook, this paper constructs the panel data of Taiwan-funded enterprises in Chinese mainland, uses the data envelopment analysis method to calculate the green total factor productivity index of Taiwan-funded enterprises, examines the impact of the environmental regulation on GTFP of Taiwan-funded enterprises, and discusses

TABLE 6 Regression results of Taiwan-funded technology-intensive enterprises.

Variables model	Model 1	Model 2	Model 3	Model 4	Model 5
ERI	−0.09*** (0.0000)	−0.09*** (0.0000)	−0.09*** (0.0000)	−0.09*** (0.0000)	−0.09*** (0.0000)
BP_1		−2.25*** (0.0010)			−1.75*** (0.0070)
BP_2			6.29*** (0.0000)		6.37*** (0.0000)
BP_3				−2.20*** (0.0000)	−2.11*** (0.0000)
CAR	−4.48*** (0.0000)	−4.46*** (0.0000)	−4.46*** (0.0000)	−4.44** (0.01200)	−4.40*** (0.0000)
FC	−0.95*** (0.0080)	−0.96*** (0.0020)	−0.96*** (0.0080)	−0.90*** (0.0000)	−0.92** (0.0100)
DL	−0.32*** (0.0000)	−0.37*** (0.0000)	−0.30*** (0.0000)	−0.36*** (0.0000)	−0.38*** (0.0000)
SI	−20.46 (0.5360)	−24.29*** (0.0000)	−15.64*** (0.0000)	−90.39*** (0.0080)	−85.61** (0.01200)
constant	8.29*** (0.0000)	8.62*** (0.0000)	8.19*** (0.0000)	8.58*** (0.0000)	8.73*** (0.0000)
Individual fixation	Yes	Yes	Yes	Yes	Yes
Observations	9,791	9,791	9,791	9,791	9,791
R − squared	0.19	0.19	0.19	0.18	0.19

the reaction of the bargaining power of these enterprises with the local governments. The findings of this study are: first, the Chinese mainland environmental regulation will reduce the GTFP of Taiwan-funded enterprises; second, the more jobs opportunities the Taiwan-funded enterprises creates, the greater the contribution to the local economy, the higher the bargaining power with the local governments, and the greater the possibility being exempted from environmental regulation to a certain extent. However, in term of industrial output value or value-added tax, Taiwan-funded enterprises have low bargaining power with the local governments. Compared with previous studies, Taiwan-funded enterprises have prominent ability to increase the employment, which is greater contribution to local government achievements, and hence they can obtain strong bargaining power.

In view of this, in order to truly achieve the goals of energy conservation and emission reduction and sustainable high-quality economic development in Chinese mainland, this paper makes the following suggestions.

First, to reduce the reaction force of Taiwan-funded enterprises to the environmental regulation, the central government should consider environmental protection as important as economic development, supervise the implementation of environmental protection policies in a timely manner, reduce the adverse effect of bargaining power of Taiwan-funded enterprises in Chinese mainland, by incorporating environmental achievements into the local government performance appraisal framework, formulating long-term environmental regulation policies, and forming an institutionalized, systematic and normalized environmental supervision mechanism.

Second, China should adjust the pace of enforcement of environmental regulation. One of the reasons why environmental regulation policies have a negative impact on Taiwan-funded enterprises is that the policies are relatively tough, and some are even "one size fits all." Polluting enterprises do not have enough time to adjust their production or improve technology or increase investment in pollution prevention and control equipment, and have to adopt stress strategies to deal with it. Local governments should start with weaker enforcement of environmental regulation, by giving Taiwan-funded enterprises a certain buffer period to gradually adjust the policy intensity, to improve environmental protection standards, and then to achieve the green transformation and upgrading of the manufacturing industry.

Third, the pollution degree of Taiwan-funded enterprises is different, and the impact on the environment is different. [1]. Therefore, when implementing environmental regulation policies, local governments should first distinguish the types and characteristics of Taiwan-funded enterprises, and pollution density of targeted industries (Zou and Zhang, 2022), then carry out differentiated environmental regulation means on polluting enterprises.

Fourth, China should build and improve the Environmental, Social and Governance (ESG) scoring standards of Taiwan-funded enterprises, take ESG scoring as part of credit, and encourage financial institutions to provide Taiwan-funded enterprises with high ESG scores the lower-cost and higher-amount loans[2]. This way will enhance the internal motivation of Taiwan-funded enterprises in energy conservation, emission reduction and green transformation.

Due to the extremely difficult availability the of data of Taiwan-funded enterprises in Chinese mainland, the sample

1 Taiwan, China.com: Ministry of Environmental Protection: Chinese Mainland Treats Environmental Management of Taiwan-Funded Enterprises Equally, last visited on 8 June 2022, website: http://www.taiwan.cn/xwzx/bwkx/201303/t20130315_3909820.htm.

2 The "product" here is referred to a product category in the Chinese Industrial Enterprise Database.

interval of this paper is selected from 2005 to 2007. Since 2007, Chinese mainland has introduced a series of macro-control measures, including new land and environmental protection policies, tax reform, and the new labor contract law. These macro-control measures have further increased the cost of Taiwan-funded enterprises. In recent years, energy, environment and climate change have posed important challenges to Chinese mainland, and Taiwan-funded enterprises are also facing more severe pressure from green transformation. Therefore, the follow-up research will expand the sample with more years, analyze Taiwan-funded enterprises based on different industry types, and further examine the impact of different types of environmental regulation policies on the green total factor productivity.

Data availability statement

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

Author contributions

YH is mainly responsible for model construction, regression analysis and full-text writing. XL is responsible for the collection and collation of literature and data; YL is responsible for data processing.

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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 impact of environmental subsidy on the performance of corporate environmental responsibility: Evidence from China

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Corporate environmental responsibility (CER) has become a critical factor for measuring the competitiveness of firms in China, and environmental subsidies may be a catalyst for promoting firms' CER. This study uses data from Chinese A-share listed firms during 2010–2020. Using the instrumental variable two-stage least squares (IV-2SLS) method, we found that environmental subsidies significantly improve corporate environmental performance but have no significant impact on the disclosure and governance of pollution emissions. We find that environmental subsidies are better for chemical and energy firms with high pollution levels, provide incentives for non-state-owned firms to improve CER and that their effect in western and eastern China is better than that in the central region. We also found that corporate social responsibility plays a moderating role in environmental subsidies that affect CER. Finally, this study finds that environmental subsidies may crowd out corporate investments to improve environmental performance. Based on the above results, we provide the corresponding policy suggestions.

KEYWORDS

corporate environmental responsibility, environmental subsidies, panel data, IV-2SLS, China

1 Introduction

China's economic development model has shifted from rapid growth to high-quality growth. According to the World Development Indicators (2022), China's GDP growth rate has gradually slowed since 2010. The growth rates of total and per capita carbon emissions have also decreased (World Development Indicator, 2022). However, serious environmental pollution caused by China's rapid economic growth in the past, especially a series of "high pollution-high energy consumption-high emissions" during industrial development, has not been solved (Hanlon, 2020). Environmental issues have attracted considerable attention in recent years. In 2015, the Fifth Plenary Session of the 18th Central Committee of the Communist Party of China incorporated the construction of ecological civilization into the 13th Five-Year Plan. The concept of green development was considered essential to China's economic development. The Ministry of Finance of China promulgated interim measures to manage energy conservation and emission reduction subsidy funds in 2015. In 2020, the Ministry of Finance revised the Interim Measures for the Management of Energy Conservation and Emission Reduction Subsidy Funds, added a performance management mechanism for energy conservation and emission reduction subsidy funds, and monitored the performance of firms applying for subsidies. Firms should also provide performance information and openly and actively accept social supervision. The continuous implementation of these regulations shows that government environmental subsidies have established a standardized mechanism in China.

From a micro perspective, corporate environmental responsibility (CER) and positive environmental, social responsibility, and corporate governance (ESG) information disclosure can show firms' self-regulatory ability and business operations. This can help attract investment and achieve long-term development goals (Dyck et al., 2019). Firms that lack humanistic care and environmental governance are less attractive to consumers, whereas firms with better environmental performance are more competitive (Wenqi et al., 2022). However, the negative externalities of environmental pollution cause firms to lack the motivation to improve their green social responsibility. As an economic instrument, government environmental subsidies can internalize the positive externalities of firms to improve their environmental performance. These subsidies are compatible with firm incentives compared with administrative instruments and can improve firms' environmental responsibility (Shi et al., 2015). In China, CER is different from other forms of social responsibility because environmental protection is a public management function of the government and is related to government officials' performance and political promotion. Therefore, the Chinese government's CER participation is higher than in other countries (Wang et al., 2020). Compared to Western countries, Chinese firms improve environmental responsibility to obtain government support, and the government can also benefit from improving environmental responsibility (Lee et al., 2017). Environmental subsidies, taxes, and regulations are government policy tools for improving the environment. Some studies have discussed the relationship between environmental subsidies and China's CER (Lee et al., 2017; Qi et al., 2021; Wenqi et al., 2022).

This study obtains data for 2010–2020 for listed firms in China from the China Stock Market and Accounting Research (CSMAR) database and concludes similar to those in the existing literature. Based on this, we expand our empirical research. First, we introduce the two-stage least squares regression method of instrumental variables (IV-2SLS) to overcome endogeneity. Specifically, we consider a firm's industry average environmental subsidy ratio (IV). Second, we distinguish between industries and state-owned or non-state-owned firms and find that environmental subsidies significantly improve CER in manufacturing and non-state-owned firms. Third, corporate social responsibility (CSR) plays a regulatory role. The higher the level of social responsibility, the more likely it is to use environmental subsidies to improve CER performance. Finally, we discuss the mediating mechanism of research and development (R&D) input. A mediating mechanism cannot exist, but we find that environmental subsidies may crowd out private R&D inputs. After summarizing the above findings, this study provides policy suggestions.

2 Literature review

2.1 Influencing factor of corporate environmental responsibility

CER refers to corporate responsibility for sustainable development (Wang et al., 2020). CER is a corporate social responsibility (CSR) branch, but CERs gradually separate from CSR to become independent concepts (Timpere, 2008). Fulfilling environmental responsibilities requires firms to pay additional costs and reduce their profits (Ganescu and Dindire, 2014). However, firms still have incentives to increase their investment in environmental research and improve their environmental performance. In recent years, consumers' willingness to pay for green products has gradually increased, and firms have to respond promptly (DesJardins, 1998). Many factors affect firms' environmental responsibility levels. First, firms of different sizes face varying environmental responsibility constraints. Larger firms usually have higher public awareness, leading to greater public and regulatory pressure; thus, they are more inclined to disclose CER information. They also have better management organizations and a stronger ability to deal with environmental responsibility issues (Brammer and Millington, 2006).

There is scant literature on the relationship between firm age and CER. Yang, (2009) found that the longer a firm's business life, the more conducive it is to establishing a broad social network and a stable image of social responsibility, reducing information asymmetry between firms and investors. CER is also related to the corporate financial situation. Well-funded firms are willing to disclose CER-related information to attract more external investments and ensure that the firm is not undervalued (Chen and Hamilton, 2020). Specifically, some studies show a positive correlation between firms' financial leverage and CER (Dimitropoulos and Koronios, 2021). However, some studies propose the opposite view that high financial leverage will become a burden on environmental investment (Meng et al., 2016). Another critical financial indicator affecting CER is a firm's growth capacity. CER

TABLE 1 Variable description.

Variables	Variable description
Dependent Variables	
Performance	Firms' environmental performance scores calculated by PCA. See Supplementary Appendix S1 for the first principal component
Disclosure	Firms' pollution disclosure scores calculated by PCA. See Supplementary Appendix S1 for the first principal component
Emissred	Firms' pollution governance performance scores calculated by PCA. See Supplementary Appendix S1 for the first principal component
Independent Variable	
Subsidy	Environmental subsidy ratio expressed as environmental subsidy divided by operating revenue. This variable is collected, summarized, and calculated through keyword screening. To facilitate the display of regression results, we multiply the value of this variable by 100
Instrumental Variable	
IV_Subsidy	Taking the classification and code of listed companies published by the CSRC as the basis for industry division, calculate the average environmental subsidy ratio of the industry in which the firm is located
Control Variables	
ROA	Return on total assets, calculated by dividing net profit by total assets
Size	Logarithm of firms' total assets
Lev	Firms' finance leverage
Age	Firm's years of listing calculated by t minus the year the firm was listed
Gr_sales	Growth rate of operating revenue
Int	Net intangible assets divided by total assets
PE	P/E ratio, calculated by share price divided by earnings per share (EPS)

TABLE 2 Descriptive statistics

Variable	Obs	Mean	Std. Dev	Min	Max
Performance	16370	0.3233	1.9823	−1.3216	10.3310
Disclosure	16388	0.2395	1.8757	−0.8644	9.8179
EmissRed	16388	0.3010	2.0228	−1.1910	8.2708
Subsidy	17395	0.0163	0.0609	0.0000	0.6341
IV_subsidy	17395	0.0063	0.0083	0.0000	0.2632
ROA	17395	0.0289	0.0286	−0.1142	0.2690
Size	17395	22.5745	1.0739	19.9251	27.1866
Lev	17395	1.9648	1.9769	0.2925	19.6211
Age	17395	10.2155	7.2375	0.0000	30.0000
Gr_sales	17395	0.2660	0.9482	−0.3219	15.6107
Int	17395	0.0332	0.0303	0.0000	0.2165
PE	17395	76.8824	118.6603	5.9949	1225.4510

information disclosure can show external investors the sustainable development ability and prove their profitability and development prospects to improve access to financing (Crisóstomo et al., 2019). However, some studies find a negative correlation between financial performance and CER. Corporate executives and managers are more willing to invest in projects with higher short-term returns than in CER (Farag et al., 2015). Other studies show that companies with poor financial performance may disclose more CSR information and hide their poor financial performance, resulting in a negative correlation between financial performance and CER disclosure (Li et al., 2004). Although there are some differences in the current research on the influencing factors of CERs, it can be considered that corporate characteristics have a decisive impact on CER; therefore, we select the control variables for regression analysis based on the above research.

2.2 Environment subsidy and corporate environmental responsibility

Subsidies are an effective way to solve externalities (Fogarty and Sagerer, 2016). Existing literature focuses on government subsidies, whereas there are few documents on the economic benefits of environmental subsidies. Environmental subsidies encourage firms to adopt clean technologies, implement energy conservation and emission reduction strategies, and innovate green technologies (Bai et al., 2018). As a policy tool opposed to environmental taxes, although environmental subsidies are less effective than environmental taxes in the short term, they can internalize the external economy in the long run (Li et al., 2004). The government can provide financial resources to ease financing constraints through environmental subsidies, and sufficient funds are invested in CER (Wu, 2019). Whether environmental subsidies or taxes are compatible with incentives, firms may still have room to allocate resources reasonably under the existing subsidies and tax frameworks. In administrative terms, the interests of governments and firms may be inconsistent, and firms' actions may not

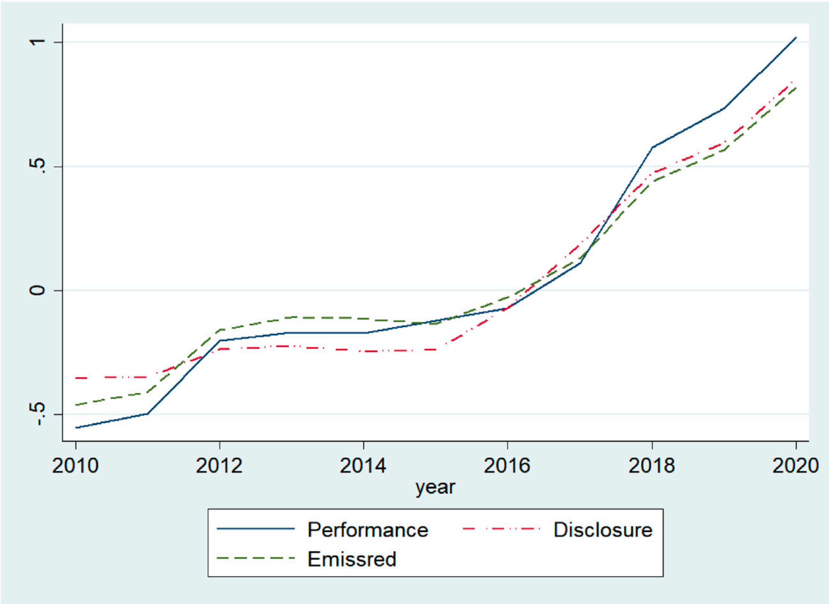

FIGURE 1
Time trend of the dependent variables.

maximize social welfare (Shi et al., 2015). In addition, government environmental subsidies can signal to the market that subsidized firms have been recognized by the government, conducive for firms to compete for resources to improve their CERs (Wei and Zuo, 2018).

Zhang et al. (2014) studied the role of subsidies in China's renewable energy industry and found that government subsidies have increased the overall performance of renewable energy companies. However, the relationship between business executives and the government may weaken the role of subsidies. Therefore, we believe that environmental subsidies positively affect CER. However, some studies have proposed the opposite view, that subsidies are not conducive to improving CER performance. After receiving subsidies, firms may increase their dependence on subsidies and lack the motivation to actively use idle resources to improve CERs (Jia et al., 2021). Rent-seeking may also lead firms to reallocate resources to seek government support, negatively impacting environmental performance (Nilsson, 2017). To ensure future subsidies, firms prioritize R&D research projects that can produce results, leading to improper resource allocation and neglecting clean technologies conducive to improving CER performance (Hall and Harhoff, 2012). The above literature indicates that the relationship between environmental subsidies and CER performance may be more complex. Given China's industrial transformation and upgradation, it is necessary to examine the heterogeneity of environmental subsidies in different industries and property rights. In addition, it is crucial to investigate the theoretical path through which environmental subsidies affect the CER. Therefore, we also check for a mediating effect between environmental subsidies and private R&D investments.

3 Data models and variables

Sample data were obtained from the CSMAR database. Finally, this study determines the sample range of Chinese A-share listed firms during 2010–2020. All nominal variables in this study were reduced to 2010 as the base period. In addition, we winsorized all the variables at the 1% level to reduce the impact of extreme values. Referring to the model settings discussed (Ren et al., 2021; Wang et al., 2021), we used the following measurement model in the regression analysis:

$$Performance_{i,t} = \beta_0 + \beta_1 Subsidy_{i,t} + \delta^T \sum X_{it} + \mu_j + \epsilon_k + \theta_t + \varepsilon_{i,t} \tag{1}$$

$$Disclosure_{i,t} = \beta_0 + \beta_1 Subsidy_{i,t} + \delta^T \sum X_{it} + \mu_j + \epsilon_k + \theta_t + \varepsilon_{i,t} \tag{2}$$

$$EmissRed_{i,t} = \beta_0 + \beta_1 Subsidy_{i,t} + \delta^T \sum X_{it} + \mu_j + \epsilon_k + \theta_t + \varepsilon_{i,t} \tag{3}$$

$Performance_{i,t}$, $Disclosure_{i,t}$, and $EmissRed_{i,t}$ represent the annual environmental performance, emission disclosure, and emission governance scores of firms, respectively, and are

TABLE 3 Results of IV-2SLS regression

	(1)	(2)	(3)	(4)	(5)	(6)
IV-2SLS: Stage I						
Dependent Variable: Subsidy						
IV_subsidy	2.0931*** (12.63)	2.0976*** (12.65)	2.0976*** (12.65)	2.1830*** (12.63)	2.1866*** (12.66)	2.1866*** (12.66)
F Value	159.59	160.12	160.12	159.53	160.20	160.20
IV-2SLS: Stage II	Performance	Disclosure	EmissRed	ΔPerformance	ΔDisclosure	ΔEmissRed
Subsidy	3.7018***	0.2055	1.1354	1.1807	0.9647*	1.0999*
	(3.21)	(0.31)	(1.37)	(1.43)	(1.75)	(1.65)
ROA	1.9739***	3.0281***	3.7787***	1.1521***	1.4140***	0.8609*
	(3.64)	(5.63)	(6.34)	(2.60)	(3.40)	(1.75)
Size	0.6384***	0.4882***	0.5794***	0.0521***	0.0361**	0.0344**
	(38.46)	(27.86)	(33.42)	(3.60)	(2.46)	(2.21)
Lev	0.0448***	0.0591***	0.0638***	0.0089	0.0127*	0.0126*
	(5.42)	(6.69)	(7.01)	(1.37)	(1.87)	(1.71)
Age	0.0090***	0.0011	0.0011	−0.0047**	−0.0042**	−0.0048**
	(3.61)	(0.46)	(0.42)	(-2.40)	(−2.12)	(-2.30)
Gr_sales	−0.0767***	−0.0593***	−0.0784***	0.0081	0.0033	0.0081
	(−5.58)	(−4.75)	(−5.35)	(0.66)	(0.35)	(0.62)
Int	4.1888***	4.0338***	2.9950***	0.5778	0.4252	−0.0680
	(8.60)	(8.64)	(6.28)	(1.42)	(1.12)	(−0.17)
PE	−0.0008***	−0.0003**	−0.0006***	-0.0000	0.0000	−0.0001
	(−7.08)	(-2.51)	(-5.57)	(-0.06)	(0.28)	(−0.78)
Province FE	Y	Y	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
F Value	89.89	58.25	74.57	6.06	4.10	3.56
N	16370	16388	16388	15401	15428	15428

t-statistics are in parentheses. Significance levels are presented as follows: ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$.

calculated using principal component analysis (PCA). The three CER dimensions provided by CSMAR were used to construct the three dependent variables. Most literature only discusses environmental performance, while few studies discuss the other two dimensions. Therefore, we focus on environmental performance and the other two dimensions as contrasts. Referring to Qiu and Yin (2019) and Chen et al. (2022), we use the corporate environmental performance rules provided by the CSMAR database to construct the first principal component of these three variables. $Subsidy_{i,t}$ represents government environmental subsidies divided by operating revenue. X_{it} represents control variables. The environmental subsidy policy and the performance of CER varies greatly in industry and region; therefore, we control for the fixed effect of the industry and region in the model, represented by $\mu_j$and ϵ_k. The industry is subject to the Classification and Code of Listed Companies published by the China Securities Regulatory Commission (CSRC), and the region is subject to the province to which the firm belongs. We also controlled for the time-fixed effect θ_t, which enables the model to consider the impact of policies such as the Environmental Protection Tax Law on the entire industry. $\varepsilon_{i,t}$ represents random error items. Table 1 lists the variables introduced in the regression analysis and their detailed descriptions.

The environmental protection decisions of listed firms may reflect and affect the trend of environmental protection and impact government policies. Both backward causality and sample selection biases exist. An effective treatment method is the use of IV to overcome the endogeneity problem. Therefore, the IV-2SLS method was used in these regression analyses. IV is the average of $Subsidy_{i,t}$ by industry, represented as $IV\_Subsidy_{i,t}$. As environmental subsidies vary greatly according to the degree of pollution emissions in the industry, the environmental subsidies received by firms are largely related to the industry to which they belong, thus meeting the relevance of IV. To meet the exogenous nature

TABLE 4 Sub-sample regression

Panel A: Distinguishing between state-owned and non-state-owned firms.

	Non-State-owned			State-owned		
	Performance	**Disclosure**	**EmissRed**	**Performance**	**Disclosure**	**EmissRed**
Subsidy	3.5957***	2.6008***	3.1657***	3.5542*	-2.3224**	-0.7722
	(2.89)	(2.68)	(2.65)	(1.77)	(-1.96)	(-0.59)
Province FE	Y	Y	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
F Value	37.79	24.20	34.34	58.40	38.80	48.25
N	8213	8226	8226	8157	8162	8162

Panel B: Distinguishing industries (dependent variable: Performance).

	Agriculture and Service Industry	Chemical and Energy Industries	Metals and Mining Industries	Electronics and machinery manufacturing	Food and commodity industry	Others
Subsidy	2.9653*	7.9374*	3.9931	−2.56134**	6.7642	4.7737
	(1.88)	(1.95)	(1.38)	(−2.23)	(1.37)	(1.00)
Province FE	Y	Y	Y	Y	Y	Y
Industry FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
F Value	39.65	29.84	31.22	31.45	17.78	7.42
N	3059	4214	1639	4937	1927	594

Panel C: Distinguishing regions (dependent variable: Performance).

	Eastern Region	Central Region	Western Region
Subsidy	3.4997***	1.1715	6.8308**
	(2.69)	(0.43)	(2.38)
Province FE	Y	Y	Y
Industry FE	Y	Y	Y
Year FE	Y	Y	Y
F Value	83.68	32.88	30.50
N	11224	3102	2044

t-statistics are in parentheses; significance levels are presented as follows: ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$.

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TABLE 5 Moderating effect (dependent variable: Performance)

	(1)	(2)	(3)
Subsidy	4.1473***	5.2250***	5.7080***
	(2.83)	(4.12)	(3.66)
Subsidy×S	2.1315***		2.2739***
	(3.86)		(3.45)
S	0.2724***		0.2647***
	(23.35)		(20.40)
Subsidy×G		−0.3322	−0.7827
		(−0.48)	(−1.17)
G		0.0560***	0.0039
		(3.71)	(0.28)
Control	Y	Y	Y
Province FE	Y	Y	Y
Industry FE	Y	Y	Y
Year FE	Y	Y	Y
F Value	75.33	134.20	109.83
N	14413	16203	14259

t-statistics are in parentheses; significance levels are presented as follows: ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$.

TABLE 6 Mechanism analysis.

	(1)	(2)	(3)
	RDInput	Performance	Performance
Subsidy	−2.6856***	5.4741***	5.6559***
	(−3.02)	(3.62)	(3.76)
RDInput			0.0677***
			(4.51)
Control Variable	Y	Y	Y
Province FE	Y	Y	Y
Industry FE	Y	Y	Y
Year FE	Y	Y	Y
F Value	131.05	77.51	76.59
N	13309	13309	13309

t statistics in parentheses; significance levels are presented as follows: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

of the IV, the environmental subsidies received by firms are not directly related to other firms in the industry. Table 2 presents descriptive statistics of the study variables. The sample firms' CER performance and environmental subsidies are relatively heterogeneous. In Figure 1, we plot the time trend of these three dependent variables, which shows that the CER level of our sample is on the rise and the growth rate has increased significantly since 2015, which may be related to the inclusion of ecological construction in China's 13th Five-Year Plan.

4 Empirical result

4.1 Basic empirical results

Table 3 shows the regression results for the IV-2SLS. Columns 1–3 show the regression results for the dependent variables of environmental performance, emission disclosure, and governance. The dependent variables in Columns 4–6 represent the first-order differences between the above three variables. According to the regression results of the first-stage IV regression in Table 3, the coefficients of $IV\_Subsidy$ are significantly positive, consistent with expectations, indicating that the environmental subsidy is positively correlated with the average level of the industry. The F value in the first stage was at least 159.53, and the corresponding p-value was not more than 1%, indicating that the IV was statistically effective. The results of Stage II show that $Subsidy$ only significantly and positively affects corporate environmental performance. However, the regression coefficient of the first-order difference in emission disclosure and governance (i.e., Columns 5 and 6) is significantly positive. In the control variables, the coefficient symbol and significance of the *ROA*, *Size* and *Int* meet the expectations. The coefficient of *Lev* is significantly positive except in Column 4. Under the IV-2SLS method, it can be considered that increasing the environmental subsidy ratio positively affects CER. Our conclusions are close to those in the existing literature (Wenqi et al., 2022), but this study distinguishes between the different aspects of CER. Environmental subsidies are more inclined to improve the disclosure of environment-related concepts and systems and have less impact on pollution emissions and governance. We conduct an in-depth analysis in the following sections.

4.2 Heterogeneity analysis

This study conducted a subsample regression considering the large heterogeneity of firms in the sample. We adopt two classification bases to distinguish between industries and property rights: state-owned and non-state-owned. In Panel A, we regress according to the sample of state-owned and non-state-owned firms, and the classification is based on the list of state-owned listed firms provided by CSMAR. Although the CER level of Chinese firms is significantly higher than that of non-state-owned firms, the regression results show that environmental subsidies have a stronger incentive to improve the CER of non-state-owned firms, consistent with Lee et al. (2017). For state-owned firms, the coefficient of Subsidy is less significant. When disclosure is the dependent variable, the coefficient is significantly negative. Owing to the natural political ties from state-owned equity, state-owned firms can obtain more long-term debt financing and policy preferences. Non-state-owned firms are more likely to cater to policies and adopt corresponding political strategies (Zhang and Zhang, 2005). Therefore, non-state-owned firms are more likely to use government subsidies to improve CER performance. Panel B in Table 4 presents the regression results for distinguishing industries according to the classifications and codes of listed companies. Notably, the regression coefficients of the different subsamples are not comparable due to different samples. However, environmental subsidies had a higher regression coefficient for chemical and energy industries, agriculture, and services. In contrast, the regression coefficients of firms in the food and commodity industries, metals, and mining industries were not significant. The coefficient of the electronics and machinery manufacturing industry is significantly negative. Therefore, we believe that because firms in the chemical and energy industries have relatively higher pollution levels and greater environmental governance pressure, environmental subsidies incentivize such firms to improve their CER. Finally, in Panel C, we conduct a subsample regression according to the regional division criteria of Eastern, Central, and Western China provided by the National Development and Reform Commission. The results indicate that environmental subsidies play a more significant role in the eastern region. They effectively improve the environmental performance of enterprises in Western China, but the effect of environmental subsidies in Central China is not significant.

4.3 The moderating role of social responsibility and corporate governance

CSR may be related to entrepreneurship, and responsible entrepreneurs are more willing to actively implement technological innovation, achieve green development, and fulfill social and environmental responsibilities (Chen et al., 2021). Some studies illustrate the relationship between corporate governance structures and CSR or the sustainability of firm development (Aras and Crowther, 2009; Wang, 2016). Referring to Qiu and Yin (2019), this study calculates firms' social responsibility and corporate governance scores using the CSMAR database and PCA, which are represented as S and G respectively. In the regression, we regard $Subsidy$ and the interaction of $Subsidy$ and S or G as endogenous variables according to the IV variable selection method of interaction provided by Rajan and Zingales (1998), whereas $IV\_Subsidy$ and the interaction of $IV\_Subsidy$ and S or G are regarded as IV. Column 1 of Table 3 shows that the regression coefficient of CSR on CER is significantly positive and that of social responsibility and environmental subsidies is also significantly positive. Therefore, CSR can be considered to have a moderating effect in Model one; the higher the level of social responsibility, the more it can use environmental subsidies. Column 2 of Table 5 shows that the interaction between G and $Subsidy$ is not significant. Therefore, even if the corporate governance factor can improve the CER (because the coefficient of G in Column 2 is significantly positive), we cannot infer that corporate governance factors have a moderating effect. In Column 3, all variables are entered into the regression equation, and the conclusion remains the same.

4.4 Mechanism analysis

As environmental R&D investment can improve CER performance, we speculate a mediating mechanism between environmental subsidies and environmental R&D investment. After collecting the R&D input data of each firm and taking logarithmic processing after flattening in 2010, this study determines the mediating mechanism of R&D investment through a step-by-step regression method. Based on the regression results in Table 6, we find that the regression coefficient of environmental subsidies for R&D inputs in Column 1 is significantly negative, the coefficients of R&D inputs and environmental subsidies in Column 3 are significantly positive, and the coefficients of Subsidy in Column 3 are larger than those in Column 2. As the direct effect (i.e., the coefficient of $Subsidy$ in Column 3) is the opposite of the indirect effect (the coefficient of $Subsidy$ in Column 1 multiplied by the coefficient of $RDInput$ in Column 3), no mediating effect of R&D investment is found at this time, but a suppressing effect (MacKinnon et al., 2002). Environmental subsidies crowd out firms' R&D spending, which may be related to shortsighted management decisions caused by shareholder debt constraints (Wu et al., 2022).

5 Conclusion and discussion

China is in a transition period of industrial structure optimization and upgradation, and improving the performance of CER is a challenge for Chinese firms in the transformation process. To reasonably guide firms to optimize resource allocation and use idle resources, a series of economic means, represented by environmental subsidies and taxes, have entered the public view and play an important role. Based on the background of the gradual improvement of China's environmental subsidy system and the rising social influence of the CER concept, this study collected samples of listed firms in China from 2010 to 2020 using the CSMAR database. Through IV-2SLS regression, this study examines whether environmental subsidies have a significant positive effect on CER. We found that significantly increasing environmental subsidies has indeed improved the performance of firms in CERs, but it has no significant impact on pollution emissions and controls. In the analysis, we distinguish between industries and property rights. Environmental subsidies can play a critical role in the more seriously polluting chemical and energy industries and non-state-owned firms with greater survival pressure. The effect of environmental subsidies in western and eastern China is significant but not in the central region. We also find that a firm's sense of social responsibility can play a moderating role in the path of environmental subsidies to improve CER performance. Finally, through mechanism analysis, we find a crowding-out effect between environmental subsidies and private R&D investment.

The empirical results can provide policy guidance. When formulating an environmental subsidy mechanism, the government must follow the principle of adapting to local conditions. Simultaneously, policymakers can further strengthen the supervision of corporate behavior by the public and media to play a coupling effect with environmental policies and promote firms to improve environmental performance. Finally, the government should actively promote the diversification of environmental subsidy mechanisms to ensure that subsidies and environmental R&D investments have complementary effects. The limitations of this study are as follows. Due to the lack of data related to environmental subsidies and environmental performance, more sample sizes have been lost, so there will be certain errors in estimating the effect of environmental subsidies on Chinese listed firms. However, there is still room for improvement in this study's calculation method for the CER performance. However, there are few indicators related to the environmental behavior of Chinese firms in the existing database, and there is no agreement on the estimation of CER performance in empirical studies. With the deepening of the concept of CER and the improvement of the relevant database, the measurement dimensions of CER will be further expanded.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

GC conceived and designed the research method; RZ conceived and designed the research method with GC and provided financial support; BW analyzed the data, wrote, and finalized the manuscript. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that this research was conducted without any commercial or financial relationships construed as potential conflicts of interest.

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Supplementary material

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Evaluating green supply chain performance based on ESG and financial indicators

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To reduce carbon emission and enhance social development simultaneously, "Environmental, Social and Governance" (ESG) plays a significant role in supply chain management. The study collected 2,400 financial data and ESG performance of 200 companies from the Clean 200 list of global public companies from 2019 to 2021. It aimed to: 1) evaluate green supply chain performance based on financial indicators and corporate's ESG performance; 2) use the entropy weight method (EWM) to determine the weight of ESG elements in green supply chain; 3) validate this ESG-based green supply chain performance using real world examples. The results showed that operational performance had the highest weight, followed by environmental performance, and profitability ranked the last. The results suggested that managers should focus more on the governance and environment rather than emphasizing short-term financial benefits. It contributes to the literature by incorporating ESG to evaluate green supply chain performance, which is the first of its kind. The results would be beneficial when people wish to select supply chain partners. They are also conducive to companies' managers and listed companies when they submit financial reports that need to report ESG performance.

KEYWORDS

ESG, carbon emissions, green supply chain, supply chain performance, index

1 Introduction

Given the adverse impact of global warming, such as flooding and drought, many sectors and countries are implementing various means to reduce carbon emissions. The global supply chain is no exception. This article highlighted the importance of a green supply chain to reduce carbon emissions and the necessity of incorporating ESG into green supply chain performance evaluation. It aimed to explore the relationship between EGS and green supply chain performance. It contributed to supply chain managers' decision-making. A green supply chain comprehensive model was constructed from 200 listed companies and 2,400 financial data.

1.1 The importance of green supply chain to reduce carbon emissions

Climate change has become a global challenge in recent years, and carbon emissions are identified as a risk factor in global warming (Jiang et al., 2022). The World Economic Forum's Global Risk Report suggested that greenhouse gases such as carbon dioxide are essential environmental factors that cause global climate change and are one of the top ten global risks (WEF, 2014). Greenhouse gases threaten environmental sustainability and harm the social economy (Sun et al., 2020; Sun et al., 2022a). Reducing carbon emissions and improving environmental quality have become vital solutions for global sustainable development (Sun and Razzaq 2022). Indirect carbon emissions from many companies' supply chain activities are five times the company's direct emissions (Downie and Stubbs 2013). The supply chain's carbon emission control could contribute to environmental sustainability. According to China's "14th 5-Year Plan for Industrial Green Development (2021–2025)", the green supply chain is also integral to green development. Thus, it is critical to accelerating the green supply chain to reduce carbon emissions.

Green supply chain management is a current mode of management (Chen et al., 2009). It incorporates environmental factors and resource efficiency into the category management and considers the impact of supply chain activities on the environment (Chen et al., 2009; Rabbi et al., 2020). In green supply chain management, product selection, production process, and upstream and downstream suppliers' selection are conducive to environmental management, which is the key to carbon emission reduction (Zhu and Sarkis 2004; Mafini and Loury-Okoumba 2018). All in all, the green supply chain can be beneficial in reducing carbon emissions.

1.2 The necessity of incorporating environmental, social and governance into green supply chain performance evaluation

The environmental dimension of ESG has become a research focus when the greenhouse gas emissions report emerges (Baid and Jayaraman 2022). "E" in ESG refers to the environment, which indicates environmental activities to reduce carbon dioxide emissions and energy consumption and improve enterprises' sustainable development (IIGF 2022). Corporate's ESG performance has become a criterion for assessing the corporate's environment and social responsibility (Shakil 2021). Credit risk and supplier ratings are often used in supplier selection to assess operational performance and financial risk (Sardanelli et al., 2022). Traditional credit rating mainly focuses on the short-term indicators of enterprises. These indicators focus on the past enterprises' performance, which does not include the impact of enterprises on the environment in the evaluation scope (Agami et al., 2012). Therefore, constructing a supply chain performance evaluation model, including environmental impact data, can enhance the evaluation comprehensiveness (Sardanelli et al., 2022). When ESG is used for supply chain performance evaluation, it can overcome the lack of non-financial indicators that might impact our future society, such as environmental impact in the traditional credit rating system. It is conducive to promoting the participation of all supply chain members in the sustainable development, minimising carbon emissions (Sardanelli et al., 2022). Thus, incorporating ESG into green supply chain performance evaluation is necessary.

1.3 Research gaps, questions, objectives, and structures

As mentioned above, traditional credit rating mainly focuses on enterprises' short-term indicators and ignores the long-term impacts of polluting industries. In academia, there are few related studies on ESG's application in green supply chain, not to mention building a green supply performance evaluation model based on ESG. Therefore, this paper contributes to the research on green supply chain performance indicators and ESG can fill the research gap. It may benefit from choosing green partners and managerial decisions and promote the development of green supply chain. It also offers insight into credit rating companies. As ESG has become one main element in listed companies' reports, this study also offers insights into them.

This study's research questions are: 1) What is the impact of ESG on the green supply chain's performance? 2) How to evaluate the green supply chain's performance level comprehensively and objectively?

Specifically, this paper aims to: 1) build a comprehensive evaluation model of the green supply chain based on financial indicators and corporate's ESG performance. It can be used for the selection of upstream and downstream partners and decision-making for managers in the supply chain; 2) use the entropy weight method (EWM) to determine the weight of each evaluation index of ESG, which is used to evaluate the impact on the performance level of the green supply chain; 3) evaluate and verify green supply chain performance level based on the research model.

The paper's structure is listed as follows: the second part of this paper mainly reviews the literature review of ESG, green supply chain management and performance, carbon emissions and EWM; the third part constructs the green supply chain performance evaluation model; the fourth utilises the EWM to calculate and verify the performance indicators of a green supply chain; the fifth part is discussion and findings; the sixth part is the conclusion, research limitations and future research directions.

2 Literature review

2.1 Environmental, social and governance (ESG)

The concept of ESG first appeared in 2006 and attracted the attention of academia, government and business (Atkins 2020). Environmental (E) includes greenhouse gas emissions, air pollutants, energy consumption, and efficiency, etc. (Jayachandran et al., 2013). It also refers to activities that reduce carbon dioxide emissions and energy consumption and contributes to global carbon neutrality goals (IIGF 2022). The company's environmental performance strongly impacts ESG (Tampakoudis and Anagnostopoulou 2020; Wang and Sun 2022). Dong et al. (2018) use carbon productivity and intensity to measure carbon emission performance among the environmental performance indicators. The green revenue share is used to measure enterprises' degree of green development (IIGF 2019). Social (S) factors include supply chain management, customer health and safety, etc. Profitability is used to measure a company's social responsibility. Companies with higher profitability can have more resources and the ability to undertake more social responsibility. Violating societal expectations can lead to increasing costs for the company and affect the company's cash flow (Abdul Rahman and Alsayegh 2021). Return on equity (ROE) and return on investment (ROI) are representative profitability indicators (Rajan et all., 2007; Nguyen and Nguyen 2020). Net sales margin and operating profit growth rate are used to measure the company's cash flow level, and it is significantly positively correlated with profitability (Liu and Ma 2014; Coad et al., 2017). Governance (G) factors include shareholder rights, stakeholder engagement, and relationship governance (NEA, 2012). Shi and Liao (2015) found that in the context of the supply chain, the level of corporate's governance can be measured by operational performance. In the indicators of operational capability, inventory turnover and proportion of products sold are used to measure the company's governance risk (Choi and Ham 2009). Total asset turnover represents the operating quality of the company (Houmes et al., 2018; Porebski and Tomczak 2020; Almomani et al., 2021). The environmental dimension of ESG has become the focus of academia (Baid and Jayaraman 2022). ESG has been considered a vital criterion for companies to assess the environment and social responsibility (Shakil 2021). Raising ESG standards helps companies achieve sustainable development (Whitelock, 2019).

ESG plays an essential role in supply chain management. There is an interaction between ESG performance and supply chain operation management (Dai and Tang 2022). Strengthening corporate governance (G) can improve the supply chain's productivity (Ziolo et al., 2019). When suppliers select partners, the traditional rating indicators only focus on financial ones. Nevertheless, customer satisfaction and product quality might not be affected by financial indicators only. Likewise, companies may ignore some critical strategic environmental related decisions in the supply chain. ESG can overcome the shortcomings of the traditional credit rating system in the supply chain.

Besides, increase in environmental performance awareness would be conducive to enterprises' active participation in sustainable development related works (Sardanelli et al., 2022). ESG was often used in performance-related research (Li et al., 2021). In the context of ESG research, some keywords included financial performance, green, environmental performance, and corporate performance (Jayachandran et al., 2013). Most literature studied ESG scores as a measurement on sustainability in supply chain performance (Rajesh 2020). Li et al. (2021) used CiteSpace to analyze the frequency of ESG-related keywords, and it indicated that there were few related studies on ESG in green supply chain performance research. Therefore, this paper aims to research the relationship between green supply chain performance indicators and ESG and fill the research gap.

2.2 Green supply chain management and performance

Bowen et al. (2001) defined green supply chain management as the effort of enterprises, suppliers and customers for environmental management and technical exchanges to formulate solutions. It ultimately reduces the impact of production processes and products on the environment (Bowen et al., 2001). Therefore, green supply chain management incorporates environmental factors into supply chain management (Rabbi et al., 2020). A green supply chain is not only economically viable but also environmentally friendly (Srivastava 2007; Li and Zhou 2022). Likewise, green supply chain management focuses on products, production processes, and supplier selection (Zhu and Sarkis 2004; Du et al., 2020), but also consider the potential costs and benefits among supply chain members (Zhu et al., 2012). The collective efforts of all stakeholders help companies mitigate the adverse environmental impact of logistics activities in their supply chain (Yang et al., 2013; Sosnowski 2022). Thus, green supply chain management is considered necessary for a company's sustainable development and growth (Wu et al., 2012). As environmental issues, for example, carbon emissions, continue to gain attention, the selection of green partners has become particularly important. Nevertheless, traditional supplier selection does not consider environmental aspects (Yeh and Chuang 2011; Gurel et al., 2015). Thus, strengthening green supply management of chain partners is conducive to promoting the effective integration of the entire supply chain, minimising the impact on the environment (Green et al., 2012; Ghosh et al., 2020). As consumers pay more attention to the environment, green innovation has emerged as an opportunity for green supply chain management to reduce carbon emissions (Sardanelli et al., 2022; Sun and Razzaq 2022).

To effectively integrate financial and non-financial data and improve the reliability of performance evaluation, it is necessary to incorporate environmental and financial data into supply chain performance evaluation (Sardanelli et al., 2022).

Increasing environmental concerns in supply chain management and monitoring green supply chain performance can improve managers' decision-making capabilities and achieve sustainable competitive advantage. The performance evaluation of the green supply chain could be multi-dimensional, including environmental performance, operational performance, and economic performance (Sardanelli et al., 2022). Hervani et al. (2005) believed that the goal of the green supply chain is to reduce the negative impact on the environment and the waste of resources. This process should start by extracting raw materials, transporting, and consuming products. Therefore, the performance evaluation of the green supply chain should focus on the whole process and supply chain stakeholders.

Green supply chain can promote ESG's development and enhance the ESG's attention by companies' managers. Rabbi et al. (2020) proposed a probability model based on a Bayesian Belief Network (BBN) to predict green supply chain performance. Observing the impact of a supply chain performance indicator on the overall environmental perspective was conducive to managers' decision-making. Fernando et al. (2019) studied the impact of offshore green supply chain management on sustainable business performance. They found that green supply chain management can indirectly promote enterprises' sustainable economic, environmental, operational and social performance.

2.3 Carbon emissions

Coping with climate change (You and Kim 2021) is one of the most severe challenges facing human society. In recent years, the adverse impacts of climate change on human lives have become prominent. The emission of greenhouse gases such as carbon dioxide is an essential environmental factor leading to global climate change (WEF, 2014). It is also among the top ten global risks (WEF 2014). Excessive carbon emissions cause a threat to current and future environmental sustainability (Sun et al., 2022b). It also has enormous socioeconomic impacts on supply chain management. Reducing carbon emissions and improving environmental quality have become critical issues for the supply chain's sustainable development (Sun and Razzaq 2022).

Scholars studied the relationship between carbon emission, green supply chain management and ESG (especially "E", environment) (Sun et al., 2022a). Sun et al. (2022b) showed that technological progress in carbon emission was one of the critical factors in addressing environmental concerns and ensuring sustainable economic development. Fiscal decentralization and green investment contributed to environmental sustainability (Sun et al., 2022a). Green innovation also reduced corporate's carbon emissions (Sun and Razzaq 2022). Thus, green supply chain management minimises carbon emission. Green supply chain management was conducive to promoting the effective integration of the entire supply, minimising environmental impact (Green et al., 2012). It can achieve green environment development by supporting and changing consumption patterns (Sun et al., 2022b). Thus, ESG and green supply chain management research benefit carbon emission reduction.

2.4 Entropy weight method

The entropy weight method (EWM) has been widely used in economic evaluation. It is a very successful evaluation metric in calculating target weights (Kumar et al., 2021) and has strong objectivity in the index's weight calculation process (Wei et al., 2008; Kumar et al., 2021). The method has established sufficient consistency in identifying responses and contrasted strengths in decision-making (Kumar et al., 2021). Although EWM is relatively simple to calculate, it is logical (Kumar et al., 2021) and can be used for supply chain performance assessment (Li et al., 2009) and overall performance evaluation of green supply chain (Yu 2015). EWM was widely used in decision-making in supply chain management. It included equipment procurement in supply chain quality performance evaluation (He et al., 2020), supplier paradigm selection (Li et al., 2016), risk assessment of supply chain, etc. (Liu et al., 2022). All in all, EWM can be used to evaluate the performance of the supply chain, which is beneficial to reflect the weight of indicators for managers' decision-making objectively. Yet, no study has incorporated ESG in green supply chain before. Thus, it is applied in this study.

3 Construction of green supply chain performance evaluation model

3.1 Principles for establishing the evaluation index system

Measuring the performance level of the supply chain is the key to achieving efficient supply chain management and improving managers' decision-making (Hervani et al., 2005). Green supply chain performance evaluation is an indispensable prerequisite for evaluation work, reflecting the operation of the entire supply chain. Green supply chain evaluate environmental, economic, and operational performance (Sahoo and Vijayvargy 2020; Sardanelli et al., 2022). Because the performance evaluation indicators cover a wide range and are complex in content, the

TABLE 1 Green supply chain performance indicator system.

Evaluation object	First-level indicator	Secondary indicators	Calculation formula
Green supply chain performance	Profitability	Net profit margin on sales (a1)	Net profit margin on sales = net profits/sales revenue
		Rate of return of investment (a2)	Rate of return of investment (ROI) = income before tax/total investment
		Return on equity (a3)	Return on equity = net income/average shareholders equity
		Operating profit growth rate (a4)	Operating profit growth rate = operating profit growth this year/total operating profit for the previous year
		Carbon intensity (b1)	Carbon intensity = carbon footprint/operating revenue
	Environmental performance	Carbon productivity (b2)	Carbon productivity = operating revenue/carbon footprint
		Green revenue share (b3)	Green revenue share = green revenue/operating revenue
		Inventory turnover (c1)	Inventory turnover = operating revenue/average balance of inventory
	Operational performance	The proportion of products sold (c2)	The proportion of products sold = sales/(total inventory amount + sales amount)
		Total asset turnover (c3)	Total asset turnover = sales/average total assets

construction of the performance evaluation indicator system for green supply chain should follow scientific principles and link theory with practice and operability, independence and integrity (Jin 2021).

3.2 Construction of green supply chain performance evaluation index

As mentioned above, environmental, operational, and economic performance are the main aspects of green supply chain performance evaluation (Sardanelli et al., 2022). Thus, this paper will combine ESG data to construct a green supply chain performance evaluation index based on green supply chain profitability, environmental performance, operational performance (Table 1). Profitability is essential for evaluating a company's present and future performance (Nguyen and Nguyen 2020). It can be used to measure a company's social responsibility (Abdul Rahman and Alsayegh 2021). Since ESG performance has become a criterion for assessing corporate environmental and social responsibility (Shakil 2021), the environmental dimension of ESG has become emphasised (Baid and Jayaraman 2022). To strengthen and enhance the importance of environmental protection and management in supply chain management, it is essential to incorporate environmental indicators into the green supply chain performance evaluation system. Operational performance is a crucial factor affecting supply chain performance (Gunasekaran et al., 2004). It can be used to measure the level of corporate governance (Shi and Liao 2015). The improvement of the operational performance level will increase the financial performance level of the company and then increase the company's profitability. The progress of environmental performance indicates the enterprise's ability to utilise environmental protection technology better, reduce the enterprise's cost and drive the enterprise's operational performance and profitability. Therefore, there is a correlation between profitability, environmental, and operational performance indicators (Wang et al., 2013).

The indicator of profitability, return on equity (ROE) is used to measure a company's success in generating profits for shareholders. The rate of return on investment (ROI) is a measure of a company's ability to generate profits from its investment activities (Ichsani and Suhardi 2015). Both represent profitability indicators (Rajan et al., 2007; Nguyen and Nguyen 2020). Net profit margin on sales can measure enterprise growth (Liu and Ma 2014). The operating profit growth rate promotes the enterprise's development and employment's growth (Coad et al., 2017) and helps achieve the sustainable development of the enterprise.

Concerning the indicator of environmental performance, carbon intensity relates to a company's physical carbon performance and is measured by the ratio of a company's absolute carbon usage to a related business metric (Hoffmann and Busch 2008). It plays a significant role in showing how the company's emissions performance can improve the company (Zhao et al., 2012). Carbon productivity is the economic output per unit of carbon dioxide emissions over time (Y and K 1997), which is considered a key indicator of companies' control of greenhouse gases (Meng and Niu 2012). Dong et al. (2018) use carbon productivity and intensity to measure carbon emission performance. The green revenue ratio is one indicator to measure enterprises' degree of green development (IIGF 2019).

Concerning the indicator of operational performance, inventory turnover is a ratio of a firm's goods sold to its average inventory level. It is commonly used to measure inventory management performance (Gaur et al., 2004), directly reflecting

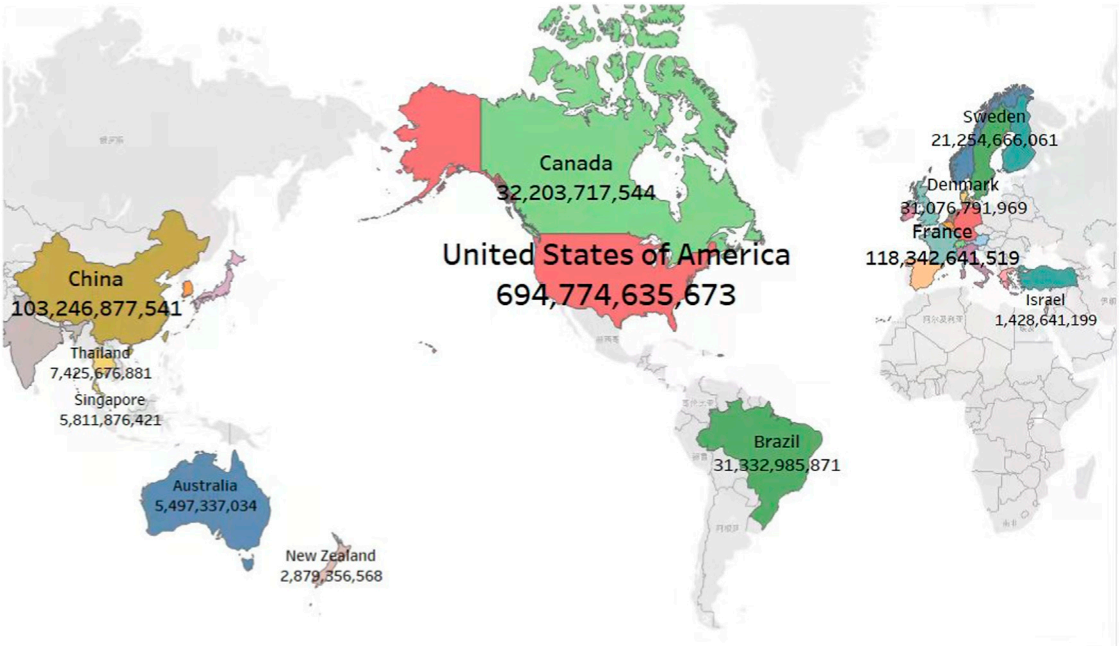

FIGURE 1
Green income of countries worldwide (currency unit: USD).

the company's profit level (Qu and Zhao 2016). The proportion of products sold can reflect the utilisation of supply chain resources, and total asset turnover measures the turnover ratio of all assets owned by a company, which is an indicator to measure the ratio between the scale of asset investment and the level of sales (Nariswari and Nugraha 2020). It can better measure the growth of enterprises (Liu and Ma 2014).

4 The measurement process of performance indicators

4.1 Selection of study samples

This study included 200 companies from the Clean 200 list of global public companies published by Canadian market research firm Corporate Knights and the US nonprofit As You Sow. Companies on the Clean 200 list are leading the transition to a clean energy future by putting sustainability at the heart of their products, services, business models and investments. According to the Clean 200 list released by As You Sow, the United States ranks first in total clean revenue, with 52 companies on the list. These firms mainly come from Information Technology, Industrials and Materials industries. The second is France, with 12 companies on the list, mainly including industrials and information technology industries. China ranked third with 16 companies on the list, mainly in the Industrials and Information Technology and Consumer Discretionary industries, as shown in Figure 1.

4.2 Financial data collection

Investing.com is a real-time market and information expert in the global financial market. It is the second largest financial website globally. It provides comprehensive financial data of global financial products, which is conducive to complete access to sample corporate indicators data (Investing.com, 2022). Therefore, this article obtained the financial data of 200 companies in investing.com *via* Python and received 2,400 operational performance and profitability performance indicators from 2019 to 2021. Finally, it combined with the clean revenue data of the Clean 200 global listed companies released by Corporate Knights and As You Sow, the sample companies' operational performance, profitability performance indicators, and environmental performance indicators were calculated.

4.3 Performance indicator calculation results

According to the data collected by Python and the company's ESG report, this study calculates the results of the profitability

TABLE 2 Performance indicator calculation results.

Indicators	Minimums	Maximum	Medium	Standard deviation	Source of data
Net profit margin on sales	−1.2574	11.2262	0.0667	0.8205	Investing (https://investing.com/)
Rate of return of investment	−12.7045	57.6056	0.944	6.1558	Investing (https://investing.com/)
Return on equity	−1.2376	7.602	0.092	0.63649	Investing (https://investing.com/)
Operating profit growth rate	−30.4082	107.7232	−0.0502	11.1155	Investing (https://investing.com/)
Carbon intensity	0.0005	113.944	0.3507	11.6447	Company ESG report; investing (https://investing.com/)
Carbon productivity	0.0088	1845.2467	2.8512	142.6949	Company ESG report; investing (https://investing.com/)
Green revenue share	0.0992	1	0.5428	0.3058	Company ESG reporte; investing (https://investing.com/); as you sow(https://www.asyousow.org/)
Inventory turnover	0.3016	790	8.5062	81.1846	Investing (https://investing.com/)
The proportion of products sold	0.1534	1	0.9017	0.1242	Investing (https://investing.com/)
Total asset turnover	0.0181	2.6959	0.6149	0.4553	Investing (https://investing.com/)

indicators and environmental performance indicators and operational performance indicators of 200 samples (Table 2). Among the indicators, carbon productivity's standard deviation is 142.6949, indicating a wide gap in carbon emissions among different companies. Likewise, inventory turnover's standard deviation is high (81.1846). This is because the impact of COVID-19 on the inventory of different products has high deviations (Fisher Ke et al., 2022).

4.4 Measured result of entropy weight method

The EWM is a kind of objective weighting method, which can determine the index weight coefficient according to the degree of difference between the evaluation index values. The EWM avoids the interference of human factors when determining the weight coefficient and objectively reflects each evaluation index's importance (Sun et al., 2017). EWM can be used for supply chain performance appraisal (Li et al., 2009) and assessment of overall performance levels for green supply chain (Yu 2015).

Suppose x_{ij} (i = 1,2,3,. . . . . .,n; j = 1,2,. . . . . .,m) is the observed data of the j^{th} index in the i^{th} evaluated object.

(1) Calculate the index ratio of the i^{th} evaluated object on the j^{th} performance indicator.

$$P_{ij} = x_{ij} \Big/ \sum_{i=1}^{n} x_{ij} \tag{1}$$

(2) Calculate the entropy weight of the j^{th} performance indicator.

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^{n} p_{ij} \ln\left(P_{ij}\right) \tag{2}$$

Among them, 0≤e_j≤1.

(3) Calculate the coefficient of difference of the evaluation index x_j.

$$g_j = 1 - e_j \tag{3}$$

(4) Calculation of index weight coefficient:

$$W_j = g_i \Big/ \sum_{j=1}^{m} g_i,\ j = 1, 2, 3....., m \tag{4}$$

Where w_j is the final weight coefficient of each performance indicator.

(5) Weight factor results for performance indicators.

According to the entropy standardised calculation result (p_{ij}) of all indicators (Table 3), the weights of each performance indicator were calculated (Table 4). The operational performance has the highest weight (0.5723), followed by the environmental performance (0.3946) and finally profitability (0.0331). Among the indicator, the highest weight is the proportion of products sold at 0.5273. It indicates a high proportion of products sold, which can have a high green market attractiveness and help reduce carbon emissions (Sun and Razzaq 2022). Utilising supply chain resources has the greatest impact on the overall performance level (Garveya and Nash, 2018). The second is the green revenue share at 0.3796. It measures the degree of green development of the company. It is the ultimate goal of evaluating the performance level of the green supply chain (IIGF 2019). The environmental dimension of ESG

TABLE 3 Results of standardization of performance indicators (pij).

Indicators	Minimums	Maximum	Medium	Standard deviation
Net profit margin on sales	0	0.0056	0.005	0.0004
Rate of return of investment	0	0.0063	0.0051	0.0006
Return on equity	0	0.0059	0.005	0.0004
Operating profit growth rate	0	0.0064	0.005	0.0005
Carbon intensity	0	0.0052	0.0051	0.0005
Carbon productivity	0	0.0051	0.0051	0.0004
Green revenue share	0	0.0106	0.0054	0.0036
Inventory turnover	0	0.0052	0.0051	0.0005
The proportion of products sold	0	0.0423	0.0042	0.0059
Total asset turnover	0	0.0066	0.0051	0.0011

TABLE 4 The results of performance index weight *via* EWM.

Performance indicators	Indicators	ej	gj	wj
Profitability (weight = 0.0331)	Net profit margin on sales	0.999	0.001	0.0058
	Rate of return of investment	0.9983	0.0017	0.0101
	Return on equity	0.9988	0.0012	0.0069
	Operating profit growth rate	0.9982	0.0018	0.0103
Environmental performance (weight = 0.3946)	Carbon intensity	0.9985	0.0015	0.009
	Carbon productivity	0.999	0.001	0.006
	Green revenue share	0.9351	0.0649	0.3796
The Operational performance (weight = 0.5723)	Inventory turnover	0.9984	0.0016	0.0095
	The proportion of products sold	0.9098	0.0902	0.5273
	Total asset turnover	0.9939	0.0061	0.0356

Note: P_{ij}, the proportion of the j^{th} indicator in the i^{th} plan; e_j, Information entropy of each indicator; g_j, information entropy redundancy; w_j, the weight of each indicator.

is the focus of the research (Baid and Jayaraman 2022), and it significantly impacts the performance of the green supply chain. The result also confirms that green supply chain management focuses on environmental management (Zhu et al., 2008; Zhu et al., 2012). The third is the total asset turnover rate (0.0356), indicating that the turnover rate of total assets is an important indicator to measure the company's overall operating quality. Strengthening the asset turnover rate is conducive to improving the utilisation efficiency of assets, thereby improving the overall performance level (Nariswari and Nugraha 2020). Therefore, according to the calculation results in Table 4, the company's green supply chain performance indicator is X = 0.0058*a1 + 0.0101*a2 + 0.0070*a3 + 0.0103*a4 + 0.0090*b1 + 0.0060*b2 + 0.3796*b3 + 0.0095*c1 + 0.5273*c2 + 0.0356*c3.

Among them, X is the evaluation results of enterprise green supply chain performance; a1 is Net Profit Margin on Sales; a2 refers to the Rate of return of Investment; a3 denotes the Return on Equity; a4: Operating Profit Growth Rate; b1 represents Carbon Intensity; b2 indicates the Carbon Productivity; b3 denotes Green Revenue Share; c1 refers to the Inventory Turnover; c2 records the Proportion of Products Sold; c3 denotes the Total Asset Turnover.

Using the above calculation results, this paper randomly selects five companies from different industries in the Clean 200 list, among which Apple Inc.'s GICS Sector is Information Technology, Kering SA's GICS Sector is Consumer Discretionary, Rexel SA's GICS Sector is Industrials, Orsted A/S's GICS Sector is Utilities, and the GICS Sector of Cogeco Communications Inc. is Communication Services. Then, this study calculates the green supply chain performance evaluation results, and the highest is Apple Inc. (5.0611), the second is Kering SA (1.3288), the third is Rexel SA (0.8652), the fourth is Orsted A/S (0.7577), the fifth is Cogeco Communications Inc. (0.6269) (Table 5). These performance evaluation rankings are

TABLE 5 Green supply chain performance evaluation results.

Company	Apple Inc.	Kering SA	Rexel SA	Orsted A/S	Cogeco communications Inc.
Performance evaluation results	5.0611	1.3288	0.8652	0.7577	0.6269
Clean200 global listed companies ranking	1	26	43	71	195

TABLE 6 Green supply chain performance evaluation results.

Company	Steel dynamics Inc.	Outokumpu Oyj	PPG industries Inc.	Umicore SA	Hanwha solutions corporation
Performance evaluation results	1.1301	0.8552	0.7293	0.7197	0.6583
Clean200 global listed companies ranking	39	52	74	76	133

the consistent with the results of the Clean 200 global listed companies released by Corporate Knights and As You Sow.

It then calculates the five companies' green supply chain performance level results in the same GICS Sectors (Table 6). According to the calculation results, the highest is Steel Dynamics Inc. (1.1301), the second is Outokumpu Oyj (0.8552), the third is PPG Industries Inc. (0.7293), the fourth is Umicore SA (0.7197), the fifth is Hanwha Solutions Corporation (0.6583). These performance evaluation results are consistent with the ranking of Clean 200 global listed companies released by Corporate Knights and As You Sow.

5 Discussion and findings

5.1 Effectiveness of green supply chain performance evaluation model

The ranking order of Clean 200 was first used and released in July 2016. It is mainly based on the cleaning income of the evaluated company and whether its business meets the essential criteria of social investors. Through the above empirical analyses and tests, it can be concluded that assessing supply chain performance by constructing and testing ESG and companies' financial data is comparable to the Clean 200 Global released by Corporate Knights and As You Sow in calculating and evaluating the performance of companies in the same industry and across sectors. Incorporating the ESG evaluation index and companies' financial data into the green supply chain performance evaluation model can further strengthen the relationship between ESG and green supply chain performance. It is conducive to increasing enterprises' attention to the ESG and promoting the green development and sustainable development of the enterprises, consistent with the research purpose of this paper.

5.2 Impact of environmental, social and governance on green supply Chain performance

5.2.1 The impact of operational performance on green supply chain performance

According to the above calculation results, it can be concluded that the operational performance (0.5723) has the highest impact on the performance level of the green supply chain. Although there is less research on the relationship between green supply chain performance and ESG, some researchers have found that operational performance comprehensively reflects the governance of each link of the supply chain. Operational performance has the widest impact on supply chain. Strengthening the operational performance can significantly improve supply chain performance (Mafini and Loury-Okoumba 2018; Sahoo and Vijayvargy 2020). When studying the performance level of green supply chain, more attention was paid to environmental indicators, but operational indicators and economic indicators were rarely involved (Rodriguez-Aguilar, 2020). As a result, the evaluation results are one-sided and unrelated with the company's operating conditions and social responsibilities. In order to comprehensively reflect the performance of green supply chain, this study considers all the indicators about ESG (operational, environmental, and profitability indicators) when constructing the research model to calculate the performance level of green supply chain. It is proved that the impact of the operational performance is more important than environmental and economic performance.

Among the indicators of operational performance, the highest weight of the proportion of products sold ratio is 0.5273. Products sold ratio has the greatest impact on the green supply chain performance. It reflects the market acceptance of its products, which is conductive for managers to adjust management strategies. It also avoids the backlog of inventory and resources waste, ensures the most efficient use of supply chain resources, and ultimately achieves green development (Garveya and Nash 2018; Sun and Razzaq 2022). When Wattanutchariya and Kuaites, (2017) did the performance analysis of the rice supply chain, they emphasized the importance of the proportion of products sold ratio. It is consistent with the findings of this paper. The weight of total asset turnover ratio is 0.0356. Its weight ratio ranks third in the weight of the entire green supply chain performance evaluation model. The turnover rate of total assets is an important indicator that measures the company's overall operating quality. It measures the company's governance risk and operating quality (Choi and Ham 2009; Porebski and Tomczak 2020). Strengthening the asset turnover rate is conducive to improving the efficiency of assets, thereby improving the overall performance level (Nariswari and Nugraha 2020). However, some studies prove that excessive asset turnover reduces corporate profitability and financial risks (Houmes et al., 2018; Almomani et al., 2021). In the process of green development, although most of the environmental protection assets are non-current assets, this result is applicable to assets with strong liquidity.

5.2.2 The weight of the impact of environmental performance on green supply chain performance

The overall weight of environmental performance ranks second (0.3946). It has the second highest impact on the performance of green supply chain. Some studies have also demonstrated that environmental management in the supply chain is an essential driver for improving supply chain performance (Park and Choi, 2021). Environmental performance significantly affects green supply chain management (You and Kim 2021). Strengthening green management can improve environmental performance (Wu et al., 2022). Jin-Hee, (2020) found that if green supply chain activities were promoted through environmental regulation, it would improve environmental performance, but there may be a negative impact on overall performance. Because a lot of environmental supervision is required in the early stage of green development, enterprises at this time might experience transformation problems and investment problems. It will lead to a decrease in their overall performance level. Thus, manager should pay attention to their current stage of development when comparing supplier partners.

Among the environmental performance indicators, the proportion of green revenue share (weight = 0.3796) ranks second in the importance of the entire green supply chain performance evaluation index. It indicates the importance of "E" in ESG in supply chain management. The green revenue share is an important indicator that measures the degree of green development of the company. It is the ultimate goal of evaluating the performance level of the green supply chain (IIGF 2019). This result confirms that green supply chain management focuses on environmental management (Zhu et al., 2008; Zhu et al., 2012). Besides, a green supply chain should focus on green development and market acceptance to avoid wasting resources, and help reduce carbon emissions from supply chain activities.

5.2.3 The impact of profitability on green supply chain performance

The overall weight of profitability ranks third (weight = 0.0331). Profitability has the lowest impact on the performance level of the green supply chain. All indicator weights of profitability did not rank in the top three. This also confirms that economic benefits are not the highest standard for measuring performance levels in green development, and managers should pay more attention to ESG. In the early stage of green investment, the company cannot increase profitability in a short time, but has a negative financial impact instead (Buallay et al., 2020). Green supply chain management has a positive impact on the environment but no positive impact on the economy (You and Kim 2021). Nevertheless, companies might be affected by COVID-19, resulting in lower profitability. Under the influence of the new epidemic, the global economy has been severely affected, and the profitability of companies has been reduced (Xiong et al., 2020; Gazi et al., 2022; Papikova and Papik 2022).

In conclusion, operational performance has the most significant impact on the green supply chain performance level, followed by environmental performance, and the third is profitability. Adhering to green development is the key to future supply chain management, and managers cannot place too much emphasis on short-term economic benefits. Improvement in green and quality management can reduce the waste of resources (Wu et al., 2022). Focusing on suppliers' environmental cooperation and green manufacturing minimise supply chain carbon emissions (Mafini and Loury-Okoumba 2018). Strengthening the use of ESG in green supply chain performance evaluation can also increase public attention to the environment.

6 Conclusion

6.1 Research contribution

ESG is the core framework for achieving sustainable development, and it represents the practice and performance of enterprises in environmental, social, and governance aspects. Strengthening ESG management and green development in the supply chain is the key to reducing carbon emissions. It is also an inevitable trend in developing enterprise green supply chain in the future. Despite few previous studies incorporate ESG for evaluating green supply chain performance, ESG has been an important element in financial reporting in listed companies worldwide. The evaluation model incorporating ESG for evaluating green supply chain performance can fill the research gap and offer a new angle to global supply chain management, listed companies and stock markets. Besides, it can also increase enterprises' awareness of ESG. The comprehensive evaluation model of the green supply chain constructed in this paper is validated using real world examples. This model determines the weight of indicators through the EWM, ensuring the results' objectivity. This model can comprehensively evaluate its performance level, benefit the selection of partners and managers' decision-making.

6.2 Research limitation and future research directions

The academic community has not yet reached a consensus on the performance evaluation system of the green supply chain. Although the comprehensive performance evaluation model of the green supply chain constructed in this paper is practical, there are still some limitations in this paper. 1) ESG's environmental performance, social responsibility, and governance might affect each other. But this paper analyses their impact weights on supply chain performance separately, without studying the interaction of these factors based on interaction terms. 2) The performance evaluation indicators constructed in this paper focus on the environment and economic benefits. There are few indicators in the social dimension.

In the future, all these limitations may become a new research agenda. It is also possible to further study the interrelationship between environmental performance, social responsibility, and governance. It can better improve the decision-making of managers and reduce carbon emission.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://investing.com/; https://www.asyousow.org/.

Author contributions

Conceptualisation, HZ, RL, and LZ; methodology, HZ and LZ; software, HZ, LZ; validation, HZ, RL; formal analysis, HZ; investigation, HZ and LZ; resources, HZ; data curation, HZ; writing—original draft preparation, HZ, RL; writing—review and editing, visualisationation, LZ; project administration, LZ and RL; funding acquisition, LZ. All authors have read and agreed to the submitted version of the manuscript.

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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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Corporate social responsibility regulation in capital market and environmental information disclosure of listed companies: A quasi-natural experiment from China

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Based on a quasi-natural experiment generated by the Shenzhen Stock Exchange (SZSE) of China, which issued the *Guidance for Social Responsibility of Listed Companies* (referred to as *Guidance*) in 2006, this paper utilizes a panel dataset of A-share listed companies at Shanghai Stock Exchange (SSE) and SZSE from 2004 to 2008, and employ difference-in-differences (DID) method to investigate impact of the *Guidance* on environmental information disclosure quality (Eidq) of listed companies. The finding shows that exchange's corporate social responsibility (CSR) regulation contributes to improving the Eidq of listed companies. Furthermore, policy effects of the *Guidance* are more significant in eastern region, heavily polluting industries and state-owned enterprises (SOEs). This study provides theoretical evidence and policy implications for the "two-wheel drive" of China's stock market regulation and social supervision, and for the construction of an environmental information disclosure system that is more targeted in terms of region, industry and property rights, and that effectively promotes fulfillment of environmental governance responsibility by listed companies and guides their sustainable development actions.

KEYWORDS

corporate social responsibility (CSR) regulation, environmental information disclosure, listed companies, capital market, shenzhen stock exchange (SZSE), difference-in-differences (DiD)

1 Introduction

This article aims to investigate the impact of stock exchange regulation in capital market on environmental information disclosure quality (Eidq) of listed companies. The *Guidance for Social Responsibility of Listed Companies* (the *Guidance*) issued by the SZSE in 2006 is the first regulatory system in the Chinese capital market that requires listed companies to disclose social responsibility reports and environmental information. The *Guidance* provided natural control and test groups for quasi-natural experiments as it is only for companies listed on the SZSE. We provide theoretical support and practical guidance for the formulation of mandatory environmental information disclosure policies being implemented in China by examining the impact of the *Guidance*'s publication on the Eidq of Chinese listed companies and heterogeneity analysis of region characteristics, industry attributes, and property rights.

From Adam Smith's "invisible hand" to Keynes's "visible hand", the debate on regulatory effectiveness has been discussed for a long time. Most studies demonstrated the positive effect of CSR regulation on corporate environmental activities (Ramanathan et al., 2018; Younis et al., 2021), but others found that institutional regulation is not sufficient to force firms to substantially "green" (He et al., 2020). Existing research on CSR regulatory effectiveness is shown as follows. First, studies focus on macro effects of regulation, such as effects of institutional regulation on green innovation (Liu et al., 2021c; Zhang H. et al., 2022; Ma et al., 2022; Zhao et al., 2022), high-quality economic development (Liu et al., 2021b), inclusive growth (Ge and Li, 2020), and green transformation (Cai et al., 2020). Second, studies majority are based on comprehensive CSR and environmental regulations, such as environmental fees to taxes (Cheng et al., 2022), central environmental inspections (Deng et al., 2022), new environmental protection law implementation (Zhang and Cheng, 2022), emissions trading system (Zhi et al., 2022), environmental information disclosure system (Zhang et al., 2021; Fang et al., 2022) and China's national ecological civilization pilot zone (Hou et al., 2022). Third, regarding CSR system effects of regulators, existing research mainly explores the effects of environmental protection system regulation on corporate energy efficiency (Li et al., 2021), total factor productivity (Tang et al., 2020) and enterprise location choices (Lu and Li, 2020). The role of CSR regulation in driving environmental information disclosure is mainly based on China's new environmental protection law (Zeng et al., 2022) and green finance policies (Wang et al., 2019). As a result, existing literature is biased toward discussing macro effects of CSR regulation, but its impact on micro-organizational behavior is not sufficiently discussed and is mostly limited to the impact on corporate performance, discussing policy effects of overarching institutional arrangements, and specific impact analysis of sector-specific institutional regulation is still in depth. In quasi-natural experimental studies, researchers prefer to examine policy spillovers, and few literatures investigate institutional regulation effects from a particular regulatory sector perspective. Existing literature has not identified the causal relationship between CSR regulation and Eidq, and has failed to explore intensively the role mechanism of regulation on environmental information disclosure behavior of listed companies. This article intends to examine the impact of CSR regulation issued by stock exchange on the probability and quality of environmental information disclosure of listed companies as an external shock event, which can fill research gap on real impact of CSR regulation on "jurisdiction".

This paper employs quasi-natural experiment method to accurately analyze the impact of institutional supervision on the Eidq of listed companies. The empirical results show that the issuance of the *Guidance* positively influences the Eidq of listed companies. Based on the main test, this paper further analyzed the heterogeneity of region characteristics, industry attributes, and property rights. With different levels of economic development and differences in marketization, the degree of influence of institutional regulation on the Eidq of listed companies may vary among regions (Liu XB. and Anbumozhi V., 2009). Heavily polluting industries are the focus of Chinese environmental protection departments, financial regulators, and securities regulators. So the impact of institutional regulation on environmental information disclosure of heavily polluting listed companies will be different compared to non-heavily polluting companies (Zeng et al., 2021). In China, SOEs and non-SOEs fulfill different social responsibilities and attach heterogeneous importance to environmental governance and environmental information disclosure (Jiang et al., 2014). We find that the influence of capital market CSR regulation on Eidq of listed companies in eastern regions, heavily polluting industries, and SOEs is more significant.

This article has the following contributions. First, we opened up a pioneering research perspective. Existing literature rarely studies listed companies' environmental information from a regulatory authority perspective. This paper explores the impact of the *Guidance* on listed companies' behavior from exchanges perspective, provides suggestions for the supervision of China's listed companies, and investigates the relationship between environmental information disclosure of listed companies and regulatory policies. Second, we expanded environmental information disclosure supervision theory. We combine environmental information disclosure supervision and quasi-natural experiments, which enrich supervision theory of environmental information disclosure of listed companies. This paper surveys the effectiveness of the relationship between regulatory authorities and environmental information disclosure of listed companies, to provide helpful decision-making ideas for regulatory authorities to supervise environmental information disclosure effectively.

The rest of this paper is organized as follows. Section 2 introduces the institutional background for the issuance of the *Guidance* and reviews relevant literature. Section 3 discusses theoretical assumptions. Section 4 presents sample selection, data sources and variable definitions. Section 5 reports empirical findings, robustness tests and heterogeneity tests. Section 6 summarizes research findings and policy implications.

2 Institutional background and literature review

2.1 Institutional background

With the SSE, SZSE, and Beijing Stock Exchange (BSE) presently (Kathiravan et al., 2021), China's capital market, which established in 1990, has made tremendous development over the past 30 years, is moving towards the goal of building an international financial center (Ho et al., 2022). However, China's capital market needs to consolidate the "barometer" function of economic development unremittingly, continue to enhance opening level, and steadily improve multi-level capital market system (Yan and Qi, 2021). The regulatory history of CSR and environmental information disclosure in China's capital market can be roughly divided into three stages (Akbar et al., 2021; Huang et al., 2021), namely voluntary disclosure before 2008, a combination of voluntary and mandatory disclosure from 2008 to 2015, and mandatory disclosure from 2015 to the present. In December 2008, the SSE and SZSE simultaneously issued the *Notice on the Work of 2008 Annual Reports of Listed Companies* (Han et al., 2019), which required companies listed on the *SSE Corporate Governance Index*, companies issuing overseas-listed foreign shares, and financial companies to disclose CSR reports, and required listed companies included in the *SZSE 100 Index* to disclose CSR reports, and encourages other companies to disclose CSR reports. In 2002, *China Securities Regulatory Commission* (CSRC) issued the *Code on Governance of Listed Companies*, which clarified listed companies' social responsibility for the first time (Sun et al., 2022). In 2018, CSRC revised the *Code on Governance of Listed Companies* to build a framework for environmental, social and governance (ESG) information disclosure for listed companies in China (Ruan and Liu, 2021). In 2015, the CPC *Central Committee* and the *State Council* published the *Integrated Reform Plan for Promoting Ecological Progress*, which proposed the establishment of a mandatory environmental disclosure mechanism for listed companies (Yang J. et al., 2022). Since then, the construction of a regulatory mechanism for mandatory environmental disclosure of listed companies in China has entered the "fast track" (Du et al., 2022). In 2017, the CSRC and the former *Ministry of Environmental Protection* (MEP) jointly signed the *Cooperation Agreement on Jointly Carrying Out Environmental Information Disclosure for Listed Companies*, which clearly stated that "a mandatory environmental information disclosure system for listed companies and debt-issuing enterprises shall be gradually established and improved" (Dong and Zheng, 2022). In 2017, the CSRC issued the "Guidelines on the Content and Format of Information Disclosure by Companies Issuing Public Securities No. 2: Content and Format of Annual Reports (Revised 2017)", which mandated listed companies or their significant subsidiaries that are among the key emission enterprises announced by environmental protection authorities to disclose environmental information in annual reports. In 2022, the CSRC issued the *Guidelines on Investor Relations Management for Listed Companies*, introducing ESG information disclosure in investor relations management for the first time. In 2022, the SSE issued "No. 9 of the Self-regulatory Guidelines for Listed Companies on the SSE: Evaluation of Information Disclosure Work" and the SZSE issued "No. 11 of the Self-regulatory Guidelines for Listed Companies on the SZSE: Evaluation of Information Disclosure Work", both of which required evaluation of the quality of ESG information disclosure of listed companies.

There were 2,578 listed companies on the SZSE by the end of 2021, with a total market capitalization of about RMB 40 trillion. According to the *World Federation of Exchanges* (WFE), the SZSE respectively ranked third, third and fourth in the world in terms of annual turnover, financing amount, and IPO companies' number. In September 2006, the SZSE issued the *Guidelines*, which became the first regulatory system on social responsibility disclosure in the Chinese capital market. The *Guidelines* consist of eight chapters and thirty-eight articles, which require listed companies on the SZSE to assume relevant social responsibilities while pursuing economic interests and protecting related interests. In terms of environmental protection and sustainable development, Chapter 5, Articles 27 to 31 of the *guidelines* set out requirements for environmental information disclosure by listed companies, which should establish a policy system on environmental governance and protection according to the extent of their impact on the environment, and support the disclosure of corporate environmental information in all aspects. However, the *Guidance* is not mandatory and only encourages listed companies to establish relevant institutional systems to disclose external CSR reports and publish environment-related information. Therefore, based on the profit maximization principle, the proportion of listed companies that perform environmental governance and disclose environmental information will be relatively low.

Overall, the publication of the *Guidance* has prompted a portion of listed companies to engage in environmental governance and disclose environmental information, which provided material for research on the relationship between institutional regulation and environmental information disclosure. In addition, since the regulatory regime is only for the disclosure of social responsibility reports of companies listed on the SZSE, which provided a natural test group and control group for quasi-natural experiments to study the effect of the regulatory regime on the disclosure of environmental information of listed companies based on this policy.

2.2 Literature review

2.2.1 Capital market institutional regulation

Institutional regulatory theory, which originated in developed countries, has been extensively investigated by various scholars (Adler and Posner, 2000). Government and market, being two instruments of resource allocation, perform "visible hand" and "invisible hand" functions in economic development (Wang et al., 2021). Institutional regulation is main external pressure in business operation, which affects enterprises' behavior (Zhang et al., 2015). Government regulation effectiveness has been a highly controversial topic and is influenced by the complexity and scope of regulation (Polishchuk, 2009). Previous research has shown that regulated firms tend to comply with government system (Beyers and Arras, 2020). Institutional regulation is main pusher behind corporate efforts (Ramanathan et al., 2018).

Capital market regulation includes government agency regulation, such as SEC regulation, and market self-regulation, such as exchange regulation (Hart and Moore, 1996). It has been shown that stock markets are responsive to regulatory enforcement in terms of stock price and the degree of response is correlated with the severity of enforcement (Nourayi, 1994). Exchanges are more likely to regulate in a way that optimizes trade-off between investor protection and regulation cost than government agency regulation (Pritchard, 2003). Public objectives of stock market disclosure regulation are to prevent market failures, enhance market confidence, and reduce investment risks (Schulte, 1988). How information providers are regulated depends on the generic properties of information categories they convey to investors and the uncertainty of investors' interests in information suppliers (Stocken, 2022). Environmental regulation needs to be strengthened in Chinese capital market to punish environmental violators (Huang et al., 2017), and company self-regulation is not enough to ensure effective environmental disclosure (Maassen et al., 2004).

2.2.2 Effects of corporate social responsibility and environmental regulatory in capital markets

Existing studies demonstrate that CSR and environmental regulation contributed to environmental investment (Yang Y. et al., 2022), total factor productivity (Ford et al., 2014; Ai et al., 2020), capacity utilization (Du et al., 2020; Yu and Shen, 2020), technological innovation (Porter and linde, 1995; Qi et al., 2021), corporate performance (Unermana and O'Dwyer, 2007), and corporate environmental information disclosure (Zhang et al., 2010; Fang et al., 2021). Capital market disclosure regulation creates market reactions such as changes in stock prices (Ingram and Chewning, 1983; Pham et al., 2020). Environmental disclosure regulation enhances executives' environmental awareness, stimulates changes in production processes (Lee, 2010), and imposes isomorphic effects on environmental disclosure (Stanny, 1998; Anwar et al., 2021; Wilestari et al., 2021). For instance, the Directive 2014/95/EU contributes to Eidq of listed companies (Caputo et al., 2021). Mandatory environmental disclosure regulation can improve social welfare (Cohen and Santhakumar, 2007). Specific normative regulation exerts a greater influence on corporate disclosure than broad government regulation (Mateo-Márquez et al., 2021). However, China's environmental regulation is still weak (van Rooij and Lo, 2010; Wang and Hao, 2012), regulatory enforcement is lax (Chen et al., 2018), and most listed companies are still experiencing passive disclosure of environmental information (Chen et al., 2022).

2.2.3 Institutional regulation and environmental information disclosure of listed companies

External pressure theory and internal motivation theory are two sides of the same coin (Chen et al., 2022). The determinants of corporate environmental disclosure consist of both external and internal factors, with external factors including regulatory pressure, government stress, media concerns, socio-cultural factors and industry aspects, and internal factors including company size, corporate governance, financial performance, social and environmental performance, equity characteristics, executive characteristics, corporate strategy and management factors (Ali et al., 2022).

It remains controversial whether CSR regulation, a compulsory instrument for environmental protection, can improve corporate Eidq (Delgado-Márquez et al., 2017; Liu and Bai, 2022). Performance-impression theory can be employed to explain voluntary disclosure behavior, while pressure-legitimacy theory can be adopted to describe mandatory disclosure behavior (Meng et al., 2013). Most studies demonstrated the significance of external institutional pressures on corporate environmental disclosure (Kerret et al., 2010). With the rising risks associated with climate change, external pressure on corporate environmental disclosure increases (Tollefson, 2007). Studies have found that air pollution negatively affects the probability and qualitative of corporate environmental disclosures (Li et al., 2020; Lin et al., 2021). Strict environmental regulation has greatly contributed to the level of environmental disclosure (Zheng et al., 2020; Wu and Memon, 2022). Legitimacy requirements of national policies and market-incentivized financing demand force listed companies to issue environmental reports (Ng, 2018). Mandatory environmental disclosure regulation has functions such as reflexive, deterrent, and enhancement mechanisms (Liu et al., 2010). Environmental administrative penalties have a significant positive effect on the level of voluntary disclosure of environmental information by enterprises (Ding et al., 2019). It has been shown that negative media coverage significantly enhances the quality of environmental information disclosure of listed companies, and the interaction between public media and local government regulation has a significant positive effect on the quality of corporate environmental disclosure (Xue et al., 2021).

Imperfect regulation is frequently responsible for poor environmental disclosure (Senn and Giordano-Spring, 2020). A certain constraint can improve Eidq (Freedman and Stagliano, 2002). Alciatore and Carol (2006) proved that institutional regulation significantly affects the probability and quality of environmental information disclosure of listed companies, and government regulation significantly contributes to Eidq. Regarding the investigation of the relationship between regulation and Eidq, researchers focus on heterogeneity analysis for region characteristics, industry attributes, and property rights. The degree of influence of regulatory policies on the Eidq of listed companies varies by region, industry, and property rights. For example, the degree of impact of regulatory policies on listed companies varies according to the differences in regional economic development and marketization (Zhao et al., 2018). Industry sensitivity is the main driver of social and environmental disclosure among Chinese listed companies (Liu X. and Anbumozhi V., 2009; Zeng et al., 2010; Dyduch and Krasodomska, 2017; Suarez-Rico et al., 2018). Compared to other industries, heavy-polluting industries are more strictly monitored and more responsive to regulation (Zeng et al., 2021). SOEs are controlled by the state and pay more attention to CSR and environmental information disclosure than non-SOEs (Yekini et al., 2019; Ren et al., 2020; Liu et al., 2021a). Environmental regulations tend to influence SOEs more significantly (Jiang et al., 2014).

In summary, a growing body of existing literature focuses on the impact of institutional regulation on firms, and most studies have demonstrated the effectiveness of institutional regulation as firms comply with regulatory requirements in pursuit of legitimacy (Wang and Chen, 2017). Scholars have verified the effects of institutional regulation on firm behavior, firm value and capacity utilization, which in turn illustrate institutional regulation effectiveness. For example, Yekini et al. (2019) examined environmental information disclosure status of listed companies following the issuance of the "Environmental Information Disclosure Guidelines for Chinese Listed Companies" by the Ministry of Environmental Protection (MEP) in 2010, without using a quasi-natural experiment approach. Ren et al. (2020) and Liu et al. (2021a) use the "Guidelines on Environmental Disclosure of Listed Companies on the SSE" as a quasi-natural experiment, and employ DID model to investigate the impact of mandatory CSR disclosure policies on win-win for firm's environmental and economic performance, and the fulfillment of corporate environmental responsibility. However, limited literature has examined the differences in listed companies' behavior from the exchange perspective of their institutional regulation and implementation effects. The academic community has not identified a causal relationship between exchange CSR regulation and the Eidq of listed companies, and have not investigated in-depth the mechanism of the effect of institutional regulation on the behavior of corporate environmental information disclosure.

Exploring the relationship between institutional regulation and Eidq requires a natural experiment of a specific institutional policy release. Issued in 2006, as the first institutional document of China's stock exchange requiring listed companies to disclose environmental information, the *Guidance* has a landmark influence on CSR policy. To a certain extent, it constrains the environmental governance behavior of listed companies and motivates them to disclose environmental information, providing a direction to study the influence of institutional regulation on the disclosure of environmental information of listed companies. This article uses the *Guidance* to conduct a quasi-natural experiment with the SZSE and SSE as the test group and the control group respectively to investigate the impact of institutional policy regulation on environmental information disclosure of listed companies.

3 Theoretical hypothesis

First, according to the signaling theory, environmental information disclosure helps stakeholders to understand the environmental protection status of enterprises, improves the market's understanding of enterprises' non-financial information, and affects the market evaluation of enterprises, which in turn promotes corporate value (Blacconiere and Patten, 1994; Patten and Nance, 1998). Secondly, according to the legitimacy theory, the survival and development of enterprises must be based on legal contracts, and enterprises must behave in a way that meets compliance requirements. Suppose a company's actions do not meet the contractual requirements of external stakeholders. In that case, its operation legitimacy cannot be guaranteed and the company may face the risk of related litigation (Deegan and Rankin, 1996). So, it is the primary goal of a listed company to make itself visible to outside as legitimate (Tzouvanas et al., 2020). When relevant policies require companies to disclose environmental information, management will consider the economic benefits of environmental information disclosure. If companies want to communicate positive environmental governance information to the public and improve Eidq, they need to invest heavily in environmental protection. Finally, principal-agent theory holds that management needs to bear environmental management cost and benefits uncertainty, and is under great pressure of cost (Frondel et al., 2008). Thus, management may be reluctant to disclose environmental information voluntarily as well as unwilling to improve Eidq. This directly leads to the generally low Eidq in China. Moreover, the environmental information that enterprises choose to disclose only reflects their efforts to manage the environment but does not reflect negative information such as environmental problems existing in firms and the discharge of related pollutants.

Therefore, relevant regulatory systems are needed to restrict corporate behavior. The regulatory authorities require companies to conduct environmental governance and disclose environmental information and related governance to outside through the system. The environmental supervision system can help improve the level of environmental information disclosure by Chinese listed companies, and can stimulate companies to actively disclose environmental information from the perspectives of mandatory constraints and voluntary incentives. As a landmark system for supervision, the publication of the *Guidance* will impact the environmental information disclosure of listed companies. Thus, hypothesis 1 is proposed as follows.

Hypothesis 1. The implementation of the *Guidance* has a positive impact on the environmental information disclosure of listed companies and improved the Eidq.

The uneven economic and technological development of different countries or regions, as well as the different levels of regulatory may lead to various disclosures of environmental information (Liu and Anbumozhi, 2009). China is a vast country, containing different regions with different economic development patterns and levels. Due to geographical advantages, eastern regions in China take the lead in optimizing development, with a more developed economy and a higher degree of marketization. While the central and western regions are restricted in many aspects of development due to environmental resources, transportation, and economic structure, and the level of economic development and marketization is lower than that of the eastern region. In the early days, China developed its economy at the expense of the environment to solve the problem of food and clothing. The high level of economic development has brought about higher environmental awareness, which has driven the regulatory agencies to impose stricter legislation and enforcement. Under this circumstance, enterprises have a stronger incentive to disclose environmental information, and the level of environmental information disclosure is higher (Fan et al., 2020).

After the regulator issues environmental information disclosure system, enterprises may avoid disclosing environmental information or enhance Eidq when illegality cost is lower than environmental treatment cost. In areas with a high level of economic development, the government and the public have a relatively high awareness of environmental protection, leading to high competitive pressure. The cost for companies to disclose environmental information as required may be much lower than economic losses caused by non-compliance. Under competition from government departments, the public, and enterprises, in regions with a high level of economic development, institutional supervision has a more significant impact on Eidq. Thus, hypothesis 2a is proposed as follows.

Hypothesis 2a. Compared with regions with lower economic development levels, the *Guidance* has a more significant impact on the Eidq of listed companies in regions with higher economic development levels.

Listed companies in different industries have distinct degrees of environmental pollution, different levels of attention from government departments, and different degrees of response to institutional supervision (Zou et al., 2015). Since listed companies in China are required to disclose environmental information, especially for heavily polluting industries. In 2003, the former State Environmental Protection Administration (SEPA) issued the *Announcement on Corporate Environmental Information Disclosure*, which mandated heavy polluters to disclose environmental information. As a key target of state regulation, every move of enterprises in heavily polluting industry is monitored. When their environmental governance and information disclosure behaviors fail to meet institutional requirements, it will damage their reputation and affect future development. So enterprises in heavily polluting industry are more sensitive to regulation responses (Zeng et al., 2021). On the contrary, the environmental information disclosure behavior of enterprises in non-heavily polluting industries receives less attention, and failure to disclose environmental information does not lead to serious economic consequences. Therefore, enterprises in heavily polluting industries will disclose more environmental information. The *Guidance* is Chinese first institution on CSR disclosure. Therefore, affected by this system, the Eidq of listed companies in heavily polluting industries is higher than that of non-heavily polluting listed companies. Hypothesis 2b is proposed as follows.

Hypothesis 2b. Compared with non-heavy polluting industries, the *Guidance* has a more significant impact on the Eidq by listed companies in heavily polluting industries.

To date, there are no mandatory requirements for environmental information disclosure for most listed companies in China. The property rights has a significant impact on the Eidq (Liu and Anbumozhi, 2009). According to the property rights, companies are divided into SOEs and non-SOEs. SOEs need to respond to national strategic decisions and help the country achieve non-economic goals while pursuing economic benefits. So, when government departments introduced relevant policies, SOEs always pursue the maximization of both profit and social interest. On the contrary, the requirement for non-SOEs to assume CSR is relatively low, and managers of non-SOEs are more concerned with economic efficiency than CSR and environmental governance. When the investment cost of environmental governance and disclosure is greater than its economic benefits, non-SOEs lack the incentive to engage in environmental governance and disclosure. After the implementation of environmental system, the Eidq of non-SOEs has been weakly improved. Under the dual effects of external institutional pressure and internal governance mechanisms, SOEs are more inclined to disclose high-quality environmental information. Thus, hypothesis 2c is proposed as follows.

Hypothesis 2c. Compared with non-SOEs, the *Guidance* has a more significant impact on the Eidq of SOEs.

4 Empirical strategy

4.1 Sample selection and data sources

To find the impact of the *Guidance* on the environmental information disclosure of listed companies, this paper selects A-share listed companies in the SZSE and SSE from 2004 to 2008 as research samples. Since the *Guidance* is only valid for companies listed on the SZSE and has no impact on companies listed on the SSE, the A-share listed companies in SZSE are test group, and the A-share listed companies in SSE are control group. The *Guidance* began to be implemented in the middle of 2006. This paper selects 2004–2005 as the time before the implementation of the system, and 2006–2008 as the time after the implementation of the system. In addition, based on the original data obtained, companies listed after 2004, listed companies in the financial industry, listed companies with incomplete data, and ST or *ST companies were deleted. Finally, 5,270 observations were obtained. To exclude outliers, the continuous variables are trimmed by the upper and lower 1% quantile. Before 2008, the sample data of the social responsibility report was collected manually from Juchao Information Network (www.cninfo.com.cn), which is the statutory information disclosure platform of SZSE. Environmental information disclosure in social responsibility report of listed companies in 2008 came from CSMAR database, and other financial data came from WIND database.

4.2 Variable definitions

4.2.1 Explained variable

We set explained variable as the Eidq of enterprises. The *Guidance*, the first institutional regulatory policy on social responsibility disclosure of listed companies in China's stock exchanges, has no specific requirements or mandatory disclosure requirements for environmental information disclosure of listed companies, stating that "information on environmental protection of listed companies should be disclosed in social responsibility reports". We draw on Wiseman (1982), Lee (2017) and Fan et al. (2020) to measure Eidq by a scoring method. When a listed company published a social responsibility report and disclosed monetized environmental information, general environmental information, or non-relevant environmental information, Eidq is correspondingly assigned a score of 2, 1, or 0.

TABLE 1 Descriptive statistics.

Variables	Obs	Mean	S.D.	Min	Max
Eidq	5,270	0.0342	0.2212	0	2
Time	5,270	0.6000	0.4899	0	1
Treat	5,270	0.3843	0.4865	0	1
Asset	5,270	21.4589	1.0268	19.1937	24.4735
Lev	5,270	50.1749	17.9744	7.6546	88.6173
Roe	5,270	5.2542	13.6367	−60.9169	40.6274
Age	5,270	2.0625	0.5529	0	2.7726
Boardsize	5,270	2.3112	0.3109	0	2.7726
State	5,270	0.6584	0.4743	0	1
Industry	5,270	0.1973	0.398	0	1
Region	5,270	0.6013	0.4897	0	1

4.2.2 Core explanatory variables

This paper sets whether the experimental variable is an SZSE listed company (*Treat*), if the company is an SZSE listed company, define Treat = 1, otherwise, Treat = 0; whether the time variable is after 2005 (*Time*), if the sample year is after 2005, Time = 1 is defined, otherwise Time = 0.

4.2.3 Control variables

Drawing on Luo et al. (2022), Meng and Zhang (2022), we control characteristic variables such as company size, solvency, profitability, listing ages, board size, and property rights, industry attributes, and company location. Specifically, company size, marked as *Asset*, is measured as the natural logarithm of company's total assets. Solvency, marked as *Lev*, is measured by the ratio of total liabilities to total assets. Profitability, marked as *Roe*, is measured by the ratio of net income to average net shareholders' equity. Listing ages, marked as *Age*, is measured by the natural logarithm of the company's time to market. Board size, marked as *Boardsize*, is measured by the natural logarithm of the number of directors on the board. Property right, marked as *State*, is assigned 1 if it is SOEs, otherwise 0. Industry attributes, marked as *Industry*, is assigned 1 if it belongs to the heavy pollution industry, otherwise 0. Company location, marked as *Region*, is assigned 1 if the company is located in a region with a high level of economic development, otherwise 0.

TABLE 2 Univariate test.

	$\sum_{2005}^{2004} Eidq - \sum_{2008}^{2006} Eidq$
Control group	0.0000
Test group	0.1480
DID	0.1481*** (12.072)

Notes: *, **, *** indicate significance at the 10%, 5% and 1% levels, respectively, and the values in parentheses below the estimated coefficients are t values.

4.3 Empirical framework

When testing the impact of regulatory system implementation, DID method is usually used for regression analysis. Drawing on Bertrand et al. (2004) and Zhang Y. et al. (2022), this paper sets up the following model (1).

$$Eidq_{i,t} = \alpha_0 + \alpha_1 Treat + \alpha_2 Time + \alpha_3 Treat \times Time + \gamma X_{i,t} + \lambda_t + \mu_j + \theta_r + \varepsilon_{i,t} \tag{1}$$

In model (1), *Eidq* represents the quality of environmental information disclosure, *i* represents listed company, *t* represents time, *j* represents industry, *r* represents region, *Time* represents the implementation of the *Guidance*, *Treat* represents whether it is an SZSE listed company, *X* represents control variable, ε is a random disturbance term. When analyzing regression results, this paper is interested in the coefficient of *Treat* × *Time*. If the coefficient of *Treat* × *Time* is significant in model (1), it means that the implementation of the *Guidance* has significantly improved the Eidq by SZSE listed companies and hypothesis 1 gets verified.

5 Empirical findings

5.1 Descriptive statistics

Table 1 reports the descriptive statistics of main variables. The sample includes 1,054 listed companies with a total of 5,270 observations. The mean of *Time* is 0.6000, indicating that the sample share after the implementation of the *Guidance* was 60%. The mean of *Treat* is 0.3843, which means SZSE-listed companies accounting for 38.43%. The average value is only 0.0342, which means that there are few listed companies that disclose environmental information in social responsibility reports.

5.2 Univariate test

According to listing locations, univariate tests are analyzed for test group (companies listed on the SZSE) and control group

TABLE 3 Parallel trend test.

Variables	**(1)**
	Eidq
pre_2	0.0055
	(0.430)
pre_1	0.0055
	(0.433)
current	0.0528***
	(4.157)
post_1	0.0581***
	(4.579)
post_2	0.3457***
	(27.265)
Controls	Yes
Year fixed effect	Yes
Industry fixed effect	Yes
Region fixed effect	Yes
Constant	−0.6212***
	(−9.575)
Observations	5,270
Adj. R^2	0.187

(companies listed on the SSE). As shown in Table 2, before the implementation of the *Guidance*, there was no difference between test group and control group, and all of them had no environmental information disclosure of social responsibility information; after the implementation of the *Guidance*, control group was not affected, and the Eidq of test group improved by 0.148, which initially verified the *Guidance*'s effectiveness.

5.3 Parallel trend test

One of the prerequisites for DID estimation validity is that test group and control group must satisfy parallel trend assumptions before treated (Bertrand et al., 2004). That is, before the *Guidance* implementation, temporal trends in social responsibility report disclosure and environmental information disclosure behavior changes between control group and test group were as identical as possible. While after the *Guidance* implementation, the break of parallel trends was mainly reflected in trend changes existence in the environmental information disclosure behavior of SZSE listed companies relative to SSE listed companies. The premise for performing DID regression is that test group and control group meet trend prior to the publication of the *Guidance*. Therefore, dynamic effect model 2) is used to test parallel trend and dynamic effect.

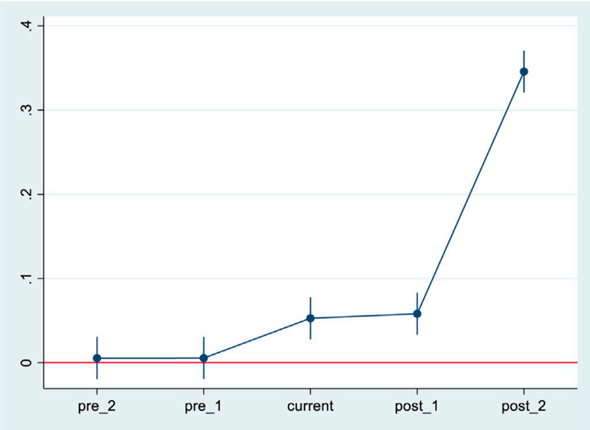

FIGURE 1
Parallel trend chart.

TABLE 4 Baseline results.

Variables	(1)	(2)
	Eidq	Eidq
Time	0.0740***	0.0685***
	(7.268)	(6.361)
Treat	−0.0003	0.0057
	(−0.028)	(0.608)
DID	0.1482***	0.1467***
	(12.308)	(12.303)
Asset		0.0271***
		(8.599)
Lev		−0.0003*
		(−1.904)
Roe		0.0005**
		(2.422)
Age		−0.0067
		(−1.146)
Boardsize		0.0241***
		(2.623)
State		0.0109*
		(1.764)
Year fixed effect	Yes	Yes
Industry fixed effect	Yes	Yes
Region fixed effect	Yes	Yes
Constant	−0.0000	−1.8598***
	(−0.000)	(−7.147)
Observations	5,270	5,270
Adj. R^2	0.114	0.133

$$Eidq_{it} = \alpha_0 + \beta_1 pre_2 + \beta_2 pre_1 + \beta_3 current + \beta_4 post_1 + \beta_4 post_2 + \beta_5 controls + \lambda_t + \mu_j + \theta_k + \varepsilon_{it} \quad (2)$$

Where *i* represents company, *t* represents year, *j* represents industry, and *r* represents region. *Pre_1, pre_2, current, post_1, post_2* are dummy variables. If listed company is in test group before the *Guidance* shock, it is assigned a value of 1, otherwise, 0. If company is in policy shock year and is in test group, *current* is assigned a value of 1, otherwise, 0. If company is after the policy shock and is in test group, *post_1* and *post_2* are assigned a value of 1, otherwise 0. The significance of each dummy variable coefficient can reflect whether there is a common trend between test group and control group.

Table 3 shows that the coefficients of *pre_1* and *pre_2* are not significant. This means that the difference in environmental information disclosure between test group and control group will not change over time before the *Guidance* implementation, which meet parallel trend hypothesis. The coefficients of *current*, *post_1*, and *post_2* are significant, which means that after the implementation of the *Guidance*, the Eidq of listed companies has changed significantly. In 2006, there was a significant change in environmental information disclosure, while in 2007 it increased slowly. In 2008, listed companies' behavior changed significantly, increasing the disclosure of environmental information (Figure 1). Based on institutional theory, there is imitation behavior and resulting institutional isomorphism in corporate disclosure under conditions of legitimacy pressure and uncertainty, and imitation behavior can be specified as frequency imitation of the market average and feature imitation of the market leader (Bernard et al., 2021). This is the reason for the change in the coefficient from 2006 to 2008.

5.4 Baseline results

Table 4 reports Eidq changes before and after the *Guidance* implementation. Column 1) shows the results only considering fixed effects, and column 2) shows the results considering control variables and fixed effects. The regression results show that when only fixed effect is considered, the regression coefficient of DID term is 0.1482, which is significantly indigenous at 1% level. It shows that the implementation of the *Guidance* has had a significant impact on Eidq. Eidq has increased by 14.82%. After considering control variables, DID term is 0.1467, which shows a significance at 1% level. It means that the *Guidance* implementation improved Eidq. Hypothesis 1 is verified. As the regulator and guide of listed companies, the exchange positively influences CSR and environmental disclosure behavior (Ali et al., 2022). The issuance of the *Guidance* affects not only listed companies in SZSE but also listed companies in SSE, which

TABLE 5 Firm fixed effect test.

Variables	(1)	(2)
	Eidq	Eidq
Time	0.0740***	0.0534***
	(7.457)	(3.209)
Treat	0.1111	−0.0722
	(0.864)	(−0.541)
DID	0.1481***	0.1500***
	(12.627)	(12.708)
Controls	No	Yes
Firm fixed effect	Yes	Yes
Year fixed effect	Yes	Yes
Constant	0.0000	−1.8598***
	(0.000)	(−7.147)
Observations	5,270	5,270
Adj. R^2	0.158	0.169

TABLE 6 Heterogeneity test of economic development level.

Variables	(1)	(2)	(3)	(4)
	East regions	East regions	Midwest	Midwest
	Eidq	Eidq	Eidq	Eidq
Time	0.0751***	0.0683***	0.0723***	0.0685***
	(5.967)	(5.151)	(4.219)	(3.733)
Treat	0.0004	0.0042	−0.0023	0.0086
	(0.033)	(0.362)	(−0.152)	(0.549)
DID	0.1531***	0.1529***	0.1416***	0.1384***
	(10.092)	(10.160)	(7.176)	(7.070)
Controls	No	Yes	No	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Region fixed effect	No	No	No	No
Industry fixed effect	Yes	Yes	Yes	Yes
Constant	−0.0031	−0.5207***	−0.0080	−0.8079***
	(−0.334)	(−6.452)	(−0.635)	(−6.757)
Observations	3,169	3,169	2,101	2,101
Adj. R^2	0.123	0.138	0.102	0.126

indicates the possible interaction of regulatory measures from multiple exchanges in the same country or region. That is, CSR regulatory policies introduced by one exchange can have spillover effects on listed companies at other exchanges (Ingram and Chewning, 1983). Although the motivation for environmental disclosure by listed companies in China today is no longer as dependent on institutional pressure as it was in the days when the *Guidance* was issued, it is undeniable that exchange regulation still holds a vital role.

5.5 Robustness checks

5.5.1 Placebo test

The empirical result that the Eidq of listed companies has improved significantly after the implementation of the *Guidance* may be caused by other factors. Drawing on Topalova (2010), We use the samples before the event to conduct a placebo test. This paper selects the listed companies from 2002 to 2005 as the sample, sets the implementation year of the *Guidance* as 2004, and reassigns the samples belonging to 2002 to 2005 to Treat = 0, otherwise, define Treat = 1. Because before 2006, there was no relevant institutional regulation requiring the disclosure of social responsibility and environmental information, so the environmental information disclosure of listed companies was 0. At this time, hypothesis 1 could not be verified, which indicates that research conclusion is robust.

5.5.2 Firm fixed effect test

Regional fixed effects, industry fixed effects, and time fixed effects have been used in the previous section, but they do not fully reflect the impact of the *Guidance* on the quality of individual environmental information disclosure of listed companies. To clarify the specific impact of the *Guidance* on listed companies, we use firm

TABLE 7 Heterogeneity test of industry nature.

Variables	(1)	(2)	(3)	(4)
	Non-heavy polluting industries	Non-heavy polluting industries	Heavy polluting industries	Heavy polluting industries
	Eidq	Eidq	Eidq	Eidq
Time	0.0552***	0.0489***	0.1506***	0.1571***
	(5.379)	(4.529)	(5.046)	(4.853)
Treat	0.0002	0.0060	0.0001	0.0075
	(0.019)	(0.636)	(0.002)	(0.273)
DID	0.1261***	0.1247***	0.2314***	0.2293***
	(10.339)	(10.315)	(6.699)	(6.692)
Controls	No	Yes	No	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes	Yes
Industry fixed effect	No	No	No	No
Constant	−0.0054	−0.5614***	−0.0002	−0.7334***
	(−0.643)	(−8.123)	(−0.009)	(−3.997)
Observations	4,230	4,230	1,040	1,040
Adj. R^2	0.093	0.112	0.184	0.203

TABLE 8 Heterogeneity test of property rights.

Variables	(1)	(2)	(3)	(4)
	Non-state-owned enterprise	State-owned enterprise	Non-state-owned enterprise	State-owned enterprise
	Eidq	Eidq	Eidq	Eidq
Time	0.0519***	0.0855***	0.0482***	0.0791***
	(3.767)	(6.303)	(3.324)	(5.460)
Treat	0.0003	−0.0006	0.0072	0.0022
	(0.022)	(−0.047)	(0.586)	(0.175)
DID	0.0883***	0.1837***	0.0879***	0.1818***
	(5.594)	(11.259)	(5.608)	(11.206)
Controls	No	No	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes
Region fixed effect	Yes	Yes	Yes	Yes
Industry fixed effect	Yes	Yes	Yes	Yes
Constant	−0.0090	−0.0094	−0.4473***	−0.6360***
	(−0.793)	(−0.841)	(−4.229)	(−7.376)
Observations	1800	3,470	1800	3,470
Adj. R^2	0.078	0.135	0.092	0.151

fixed effects to replace toriginal industry and regional effects referencing Meng et al. (2013). Column 1) and Column 2) of Table 5 show that the coefficients of DID term are 0.1481 and 0.1500, and are aboriginal at 1% level, which is consistent with previous results. Hypothesis 1 is still valid.

5.6 Heterogeneity test

The impact of institutional policies on environmental information disclosure differs across region characteristics, industry distribution and property rights, and now the heterogeneity of these three aspects is tested to figure out the impact of the *Guidance* on the Eidq of different types of listed companies.

5.6.1 Impact of region characteristics on the Eidq of listed companies

According to the classification standard of the *National Bureau of Statistics* (NBS) of China (excluding Hong Kong, Macao, and Taiwan), regions classification is as follows. The eastern regions include Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan. These provinces (cities) have good geographical locations and are key areas for national economic development with relatively high levels of economic development. The rest regions belong to the Midwest. The regression results are shown in Table 6. The coefficient of DID term in the eastern region is 0.1529, the coefficient of DID term in the Midwest is 0.1384, and the coefficient of the higher economic development level is more significant. In regions with a higher level of economic development, the *Guidance* has a more significant impact on the Eidq, which is consistent with hypothesis 2a. The level of regional economic development and marketization are important perspectives for analyzing the variability of listed companies' responses to CSR regulation. This finding is consistent with Fang et al. (2022) and Liu and Anbumozhi (2009). To this day, the uneven regional development in China remains. Listed companies in different regions are subject to varying degrees of exchange CSR regulation, which implies the need to strengthen CSR regulation instruments other than exchange regulation, such as local government regulation, social supervision and industry self-regulation.

5.6.2 Impact of industry attributes on Eidq of listed companies

The *Guidance* is aimed at companies listed on the SZSE, and there is no clear distinction between heavily polluting and non-heavy polluting industries. However, the heavily polluting industry has always been regulatory focus. After the publication of system supervision on social responsibility and environmental information disclosure, legality pressure faced by listed companies in heavily polluting industry is particularly prominent. Therefore, their environmental governance and environmental information disclosure behaviors will be different from non-heavy polluting industries. We re-performed the regression analysis by the *Guidance for Industry Classification of Listed Companies* issued by the CSRC in 2001, and the *List of Industry Classification Management of Listed Companies for Environmental Protection Inspection* issued by the General Office of the Ministry of Environmental Protection in 2008 Classification. The regression results are shown in columns 2) and 4) of Table 7. The DID regression coefficients of listed companies in heavily polluting industries and non-heavy polluting industries are respectively 0.2293 and 0.1247, which are significant at 1% level, and are consistent with the baseline test results. Moreover, the coefficient of listed companies in heavily polluting industries is greater than that in non-heavy polluting industries, and the positive effect of *Guidance* on Eidq is more significant. Heavily polluting industries are CSR regulation focus. This finding can guide the design and implementation of mandatory environmental information disclosure system for key industries implemented in China.

5.6.3 Impact of property rights on the Eidq of listed companies

Based on legitimacy theory, SOEs are more responsive to policies in facing exchange regulation compared to non-SOEs. According to ultimate controller, we divided sample companies into SOEs and non-SOEs, and conducted regression analysis on each pair. Table 8 shows that the DID coefficients in the case of considering control variables are 0.1818 and 0.0879, which are significant at 1% level, consistent with the results of main hypothesis test, and the Eidq of SOEs is better than that of non-SOEs, which is consistent with hypothesis 2c. The government and society expect more from state-owned listed companies (Ervits, 2021), which are more responsible and effective in fulfilling CSR (Hu et al., 2018).

6 Conclusions and recommendations

Based on the exogenous impact of the *Guidance*, this paper finds a positive impact of stock exchange CSR regulation on Eidq of listed companies in China. In addition, multiple factors have heterogeneity on environmental information disclosure, the positive impact is more significant in the sub-samples of regions with high economic development levels, heavy pollution industries, and SOEs. Since the *Guidance* does not impose mandatory requirements on environmental information disclosure of listed companies, the proportions of listed companies disclosing environmental information after the implementation of the *Guidance* are still at a low level. Today, listed companies on the SZSE still follow the requirements of the Guidelines for CSR and environmental information disclosure.

Compared to Yekini et al. (2019), Ren et al. (2020) and Liu et al. (2021a), this paper expands the existing literature in the following aspects. First, this paper exploits the CSR regulation data of SZSE for the first time, which expands quasi-natural experiments research on CSR system regulation. Secondly, in an empirical test, we examined the effect of CSR regulation of SZSE on environmental information disclosure of all A-share listed companies by using SZSE listed companies as test group and SSE

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listed companies as the control group, which enhances the refinement of CSR regulation research. Finally, this study particularly emphasizes the practical value of exploring historical policy effects. In 2022, the *Ministry of Ecology and Environment* of China issued the *Reform Plan for the Legal Disclosure of Environmental Information*, which clarified the idea and framework of the system reform based on legal disclosure, focusing on collaborative management, strengthening supervision as a means, and technical support as the guarantee. Mandatory disclosure of environmental information and coordinated management of various departments will be the development trend of environmental governance systems in China and even developing countries.

The policy implications of this paper are as follows. First, the role of the Exchange in CSR and environmental disclosure regulation should be further strengthened. Meanwhile, a single department needs to cooperate with other departments to conduct joint governance to make up for the shortcomings of the system. Second, environmental information disclosure regulation of non-heavily polluting industries and non-state enterprises needs to be strengthened. Third, besides the CSR regulation of the exchange, we should simultaneously improve the "soft regulation" mechanism of local government, industry self-regulation and social supervision of environmental information disclosure of listed companies.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

Author contribution Conceptualization: CZ; Methodology: CZ, YZ; Data curation: YZ, YC; Software: SZ; Formal analysis: CZ, MH; Investigation: CZ, SZ; Writing—original draft: CZ, MH; Writing—review and; editing: CZ, MH, YZ, YC. All authors approved the current study.

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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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Does ESG investment reduce carbon emissions in China?

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This study explores the relationship between ESG investments and carbon emissions in China. Our results show that 1% increase in environmental investments would cause 0.246% decrease in CO_2 emissions and 0.558% decrease in carbon emission intensity. The impact of ESG investment is heterogeneous across the developed and underdeveloped regions. Environmental investments in the advanced eastern region have significantly improved carbon productivity. In contrast, environmental investments in the central and western regions significantly reduced carbon emissions, but they have little impact on carbon productivity.

KEYWORDS

ESG investment, carbon emission, carbon productivity, regional effect, green transition

1 Introduction

Rapid economic development over the past century has led to a series of environmental problems. The "high carbon, high development" model is not sustainable because of the threat of impending climate change. According to Raggad (2020), the greenhouse effect is particularly severe due to the large volume of carbon emissions, which not only adversely affects the ecological balance but also diminishes the health of the economy. In August 2021, the Intergovernmental Panel on Climate Change stated, in its Sixth Assessment Report Group I Working Paper, that global temperatures will rise by 1.5°C–2°C, which will affect agricultural activities and exceed critical the tolerance thresholds of human health, unless carbon dioxide and other greenhouse gas emissions are significantly reduced in the coming decades[1].

To fight against climate change, the European Union has established the world's largest and most mature carbon emissions trading system, assigning a certain amount of carbon emission permits to enterprises (Åihman and Zetterberg, 2005). In the United States, energy security policies have been put forward; the feasibility of carbon tax is under progressive discussion, and a net zero-carbon emission plan has been formulated (Brown and Li, 2019).

1 See details at https://www.ipcc.ch/report/ar6/wg1/#SPM

Japan has made great efforts to improve environmental protection technology, successfully reducing carbon emissions through material recycling. In India, biomass energy, a kind of renewable energy, has been utilized by the government to deal with their energy crisis and minimize their carbon footprint. Although there are technological, economic and infrastructure barriers to developing biomass energy, this can be improved through research and development (Irfan et al., 2022). Thailand also faces environmental challenges, as it relies on non-renewable energy consumption to develop its economy, leading to carbon emissions (Yue et al., 2021). China launched carbon emissions trading pilots in seven provinces in 2013, and it set up a national carbon emissions trading market in 2017. The establishment of carbon emission trading markets in China is crucial to boost ecological conservation and to stay committed to its goal of carbon emission reduction (Wang et al., 2020). As China is currently the world's largest carbon emitter, the ability of domestic companies to effectively reduce carbon emissions is one of the most important factors in achieving global climate goals (Ding et al., 2021). The world needs to consider the energy trilemma: accessible energy affordability, energy security and environmental sustainability. If the world only invests in energy use, the resulting growth will eventually become unsustainable (Khan et al., 2022a). Xie et al. (2022) shows that there is a relationship between natural resources and economic performance. Achieving carbon neutrality and peak emission targets is widely recognized as the only way to achieve sustainable economic development. Furthermore, governments should focus more on sustainable resources since it is crucial to development.

As the concept of ESG has been developed in recent years, increasing research attention focused on ESG development. Rustam et al. (2019) found that higher financial leverage limits the company's ability to disclose ESG information. Baldini et al. (2018) found that country-level characteristics such as political system (legal framework and corruption), labor system (labor protection and unemployment rate), and cultural system (social cohesion and equal opportunities) significantly influence companies s corporate ESG disclosure. In addition, the role of the market also affects the disclosure of comprehensive ESG information. Zhang et al. (2020) studied the interactive effect of three dimensions of ESG information of listed companies on firm value, and concluded that green innovation, environment and ESG information disclosure can positively affect firm value, and its substitution effect on firm value gradually decreases with the increase of firm value.

In this study, we investigated the impact of listed companies' ESG investments on carbon emissions in China. Some studies have focused on the impact of ESG investments on climate change and environmental performance (Jinga, 2021; Peng et al., 2021). Li and Xue (2020) has stated that the implementation of carbon reduction goals relies heavily on the participation by enterprises. A combination of the external political environment, internal development motivation, and the requirement for good community relations prompted companies to focus on green transition. Dong et al. (2021) points out that, to follow the carbon emission restrictions, companies resort to short-term solutions with output control and slower production, which does not conform to the real intention of government policies. The long-term adjustment is what really matters in achieving carbon neutrality. The country should strive to have a low-carbon mechanism by implementing carbon tax, continuous financial aid to lower carbon production, commercializing low-carbon emission technology, etc., (Khan et al., 2022b). Fukushima (2013) documents that reducing carbon emissions is an integral part of corporate ESG investments, regardless of company type. Addressing environmental issues is necessary for conducting business activities. Using the Dumitrescu-Hurlin technique, Ahmad et al. (2021) found that the causality between energy-industry investment and economic performance differs across the regional development levels.

Since China is currently the world's largest carbon emitter, domestic companies' ability of carbon emissions reduction is one of the most important factors in achieving global climate goals[2]. The Hong Kong Exchange required listed companies to disclose ESG reports in 2015, indicating that addressing environmental concerns have become an obligation for enterprises.

Figure 1 shows the distribution of carbon emissions in China in 2014 and 2019. The total carbon emissions remained relatively stable, but their distribution changed significantly. Thus, it is necessary to conduct an in-depth analysis of China's efforts towards the green transition of industries.

This paper contributes to the literatures by investigating the relationship between the ESG investment and the reduction of carbon emissions in China. We focus on the role of regional differences in the relationship between ESG investments and carbon emissions. Regional differences, including both natural resource distribution and economic differences, have significant influence on carbon emissions. The distribution of coal, which is the major fossil fuel used in China, is extremely uneven. However, the reduction in carbon emissions in China is mainly achieved by reducing coal consumption. Richer coal resources allow for a lower cost of resource consumption attributable to local extraction, leading to a weaker incentive for enterprises to develop new technology, to use clear energy, and to improve energy consumption efficiency. Additionally, the unbalanced and inadequate development of regional economies has reduced incentives of local governments for the green transition. Therefore, it is important to analyze the impact of regional differences on carbon emissions. We divide the whole sample into three parts—Eastern, Central, and Western regions, and study the effect of ESG investments on carbon emissions of listed companies in each region, which increases the

2 See more details in Wu et al., 2018.

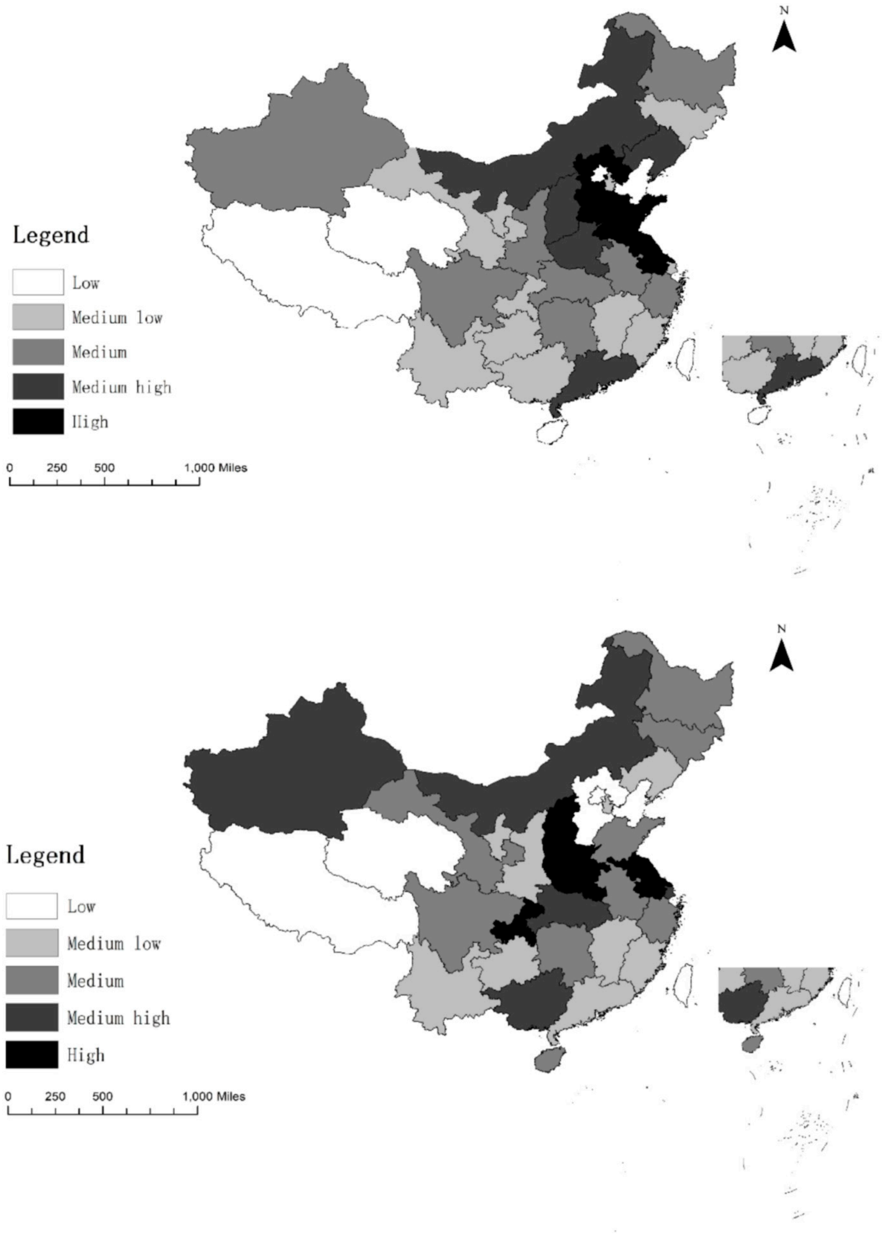

FIGURE 1
Regional distribution of carbon emissions in China in 2014 (top) and 2019 (bottom).

credibility and applicability of the results. This study provides relevant reference in the implementation of the policy, which is in line with the current goal of green transformation and sustainable economic growth.

The rest of the paper is structured as follows: Section 2 provides the data description and analysis; Section 3 introduces the proposed model; Section 4 presents the empirical results; and Section 5 discusses the results and conclusions of the study.

2 Data

2.1 Dependent variables

Based on a study by Wang et al. (2017) and Li and Xue (2020), we selected carbon dioxide emission amount, carbon productivity, and carbon emission intensity as dependent variables. Because carbon emissions cannot be observed, we focused on 14 types of energy: coal, coke, coke oven gas,

TABLE 1 Variable definition.

Types	Variables	Definition
Dependent variables	CO_2	The carbon dioxide emission amount
	CP	Carbon productivity. The ratio of GDP to carbon dioxide emission amount
	CEI	Carbon emission intensity. Carbon dioxide emission amount per unit of GDP, which is the reciprocal of carbon productivity
Independent variables	ESG	Environmental, social and governance investment aggregate score
	Environment	Environmental investment score
	Social	Social investment score
	Governance	Corporate governance investment score
Control variables	TEC	The scientific and technological level proxied by the number of patents
	PGDP	GDP per capita, represent for the economic development level
	COMs	Primary energy consumption, including the coal, oil, natural gas, primary power and other energy
	Open	The openness degree of certain region, proxied by the total imports and exports of regional trade

natural gas, crude oil, gasoline, kerosene, diesel oil, fuel oil, liquefied petroleum gas, blast furnace gas, converter gas, liquefied natural gas, and other natural gas. We then calculated their carbon dioxide emission indices according to Liang et al. (2021). Specifically, we collected 180 balance sheets from 2014 to 2019 and used the coal discount coefficient to estimate carbon dioxide emission index. Data were obtained from the China Energy Statistics Yearbook (2015–2020). Carbon emissions were estimated as follows:

$$CO_2 = \sum_{i=1}^{14} CO_{2,i} = \sum_{i=1}^{14} E_i{}^{*}NCV_i{}^{*}CEF_i \tag{1}$$

where CO_2 represents the estimated carbon dioxide emission amount; E_i is the combustion consumption of energy source i ($i = 1, 2, \ldots, 14$); NCV_i is the net calorific value, represents for the average low-calorific value used to convert various energy consumptions into energy units; and CEF_i is the carbon dioxide emission factor of the various energy sources.

2.2 Independent variables

Our key independent variable is the ESG investment score. ESG scores are estimated based on the announcement of ESG investment and performance of listed firms. These scores can be used to evaluate corporate investment behavior and their contribution to promoting sustainable economic development and fulfilling social responsibilities. We also used environmental, social, and governance scores as independent variables to examine their impact on carbon emissions. We calculate our provincial ESG data as the average ESG investment score of listed firms in each province. The scores were obtained from the SynTao database.

2.3 Control variables

We selected the scientific and technological level, economic development level, primary energy consumption, and degree of openness as control variables. Progress in science and technology plays a vital role in the development of new energy sources, and improvement in new energy processing and conversion efficiency changes the energy consumption structure. The data were obtained from the official website of the State Intellectual Property Office.

We used GDP per capita to represent the level of regional economic development. The Kuznets curve shows the inverted "U" relationship between GDP per capita and environmental degradation (Spangenberg, 2001). China's regional economic development level is unbalanced, which leads to a difference in the time required to cross the turning point among regions. These data were obtained from the China City Statistical Yearbooks.

The consumption of primary energy directly affects carbon emissions (Bertinelli et al., 2007). The lower the energy processing conversion rate (i.e., the greater the proportion of primary energy), the greater the impact on environmental damage and carbon emissions. The data were obtained from the China Energy Statistics Yearbook.

Developed and developing countries are deeply involved in the global value chain and profoundly affect the international carbon transfer network through the trade-clustering effect (Wang et al., 2021). To retain the competitive advantage, some countries relax environmental regulations and the behavior of "race to the bottom line" appears (Revesz, 1997). These results show that the degree of openness significantly affects a country's carbon emissions. We collect these data coms from China Statistical Yearbook. The definitions of the

TABLE 2 Descriptive statistics.

	Unit	N	Mean	SD	Min	Max
CO2	Thousand tons	180	36,054	24,559	3,453	110,603
CP	Hundred million yuan/thousand tons of carbon dioxide	180	3.303	5.941	1.176	58.94
CEI	Thousand tons of carbon dioxide/100 million yuan	180	24.79	68.24	1.278	483.0
ESG	1	180	47.21	2.085	38.75	52.88
Environment	1	180	46.33	2.913	37.66	56.51
Social	1	180	52.20	2.364	42.54	62.69
Governance	1	180	43.08	2.974	31.84	50.72
TEC	1	180	60,339	83,460	619	527,390
PGDP	yuan	180	53,823	23,917	25,202	156,587
COMs	Ten thousand tons of standard coal	180	15,405	8,906	1,820	41,390
Open	Billion yuan	180	618.6	1,165	0.0415	5,888

variables are listed in Table 1 and the summary statistics are shown in Table 2.

3 Methodology

We employ a panel regression model for the empirical analysis. We used the logarithm form of the variables to alleviate the effects of heteroscedasticity. As mentioned above, we chose carbon dioxide emission amount, carbon productivity, and carbon emission intensity as dependent variables. Since the provincial and time effect could hardly be considered as random experiment, we conducted a two-way fixed effect model to evaluate the relationship. The result of Hausman test also support this selection. The model is constructed as follows:

$$\begin{aligned} Y_{ti} = \beta_0 + \beta_1 lnESG_{ti} + \beta_2 lnTEC_{ti} + \beta_3 lnPGDP_{ti} \\ + \beta_4 lnCOMs_{ti} + \beta_5 lnOpen_{ti} + \lambda_t + \mu_i + \epsilon \end{aligned} \quad (2)$$

where Y_{ti} is $lnCO_{2ti}$ *or* $lnCP_{ti}$ *or* $lnCEI_{ti}$, which refers to carbon dioxide emissions, carbon productivity, or carbon emission intensity in province i in year t, respectively; and λ_t and μ_i represent the time and individual fixed effects, respectively. The definitions of variables are listed in Table 1.

Firstly, we test multicollinearity and stationary of the variables. According to Table 3, the VIF values of the explanatory variables are all less than 5, suggesting that there is no serious multicollinearity problems. Table 4 provide the results of unit root test for logarithmic and log first-order difference of the variables. It is clear that most of the variables are first-order stationary. Consequently, the cointegration test should be performed to determine whether there is a stable relationship between the variables. We employ the Kao test to investigate panel cointegration on the variables. Table 5 shows that the cointegration relationships stand in all cases, indicating that our model is not misspecifie.

TABLE 3 VIF test for explanatory variables.

Variable	VIF	1/VIF
TEC	4.45	0.224558
Open	2.98	0.335388
COMs	1.77	0.564112
PGDP	1.76	0.569293
ESG	1.1	0.907685
Mean VIF	2.41	0.414938

4 Empirical results

Table 6 reports the primary results of Eq. 2. In case 1, the primary energy consumption is significant at the 1% significance level because the energy consumption is directly related to carbon emissions. After controlling for the effect of energy consumption, we observe that ESG investment has a significantly negative impact on carbon dioxide emissions. A 1% increase in ESG investment reduces carbon emissions by 0.262%, indicating that ESG investment significantly contributes to alleviating climate change in China.

In Case 2, we adopt carbon productivity as the dependent variable. GDP per capita is highly significant and positive, indicating that carbon productivity is much better in well-developed regions. As energy consumption is significantly negative, suggesting that the under developed regions have not achieved the balance of economic development and environmental protection. However, we observe that ESG investment is positive but not significant, indicating that ESG investments by Chinese enterprises have not achieved progress in relevant green technologies at the current stage. In Case 3, we adopt carbon emission intensity as the dependent variable and obtained similar results. ESG investment is significant and

TABLE 4 Unit root test for variables and their first difference.

Variables	*p*-value
lnco2	0.5795
FD.lnco2	0.0000
C1	1.0000
FD.C1	0.0000
C2	0.0000
FD.C2	0.0000
ESG	0.8962
FD.ESG	0.0000
TEC	0.7121
FD.TEC	0.0000
PGDP	0.7846
FD.PGDP	0.0000
COMs	0.9998
FD.COMs	0.0000
Open	0.0005
FD.Open	0.0000

TABLE 5 Cointegration test.

Method	Inspection form	Statistic	*p*-value
	Dependent variable: CO_2		
	Modified Dickey–Fuller t	3.8493	0.0001
Kao test	Dickey–Fuller t	2.3227	0.0101
	Augmented Dickey–Fuller t	2.6959	0.0035
	Dependent variable: CP		
Method	Inspection form	Statistic	*p*-value
	Modified Dickey–Fuller t	4.9670	0.0000
Kao test	Dickey–Fuller t	5.9080	0.0000
	Augmented Dickey–Fuller t	5.5962	0.0000
	Dependent variable: CEI		
Method	Inspection form	Statistic	*p*-value
	Modified Dickey–Fuller t	4.3822	0.0000
Kao test	Dickey–Fuller t	2.8662	0.0021
	Augmented Dickey–Fuller t	4.5282	0.0000

negative, indicating that an increase in ESG investment tends to reduce or inhibit carbon emissions intensity.

We then distinguish between environmental, social, and governance investments and investigate their impact on carbon emissions. The empirical results are presented in Table 7. Clearly, environmental investment significantly reduced carbon emissions but had no significant impact on carbon productivity. These results are similar to those in Table 6. However, social and governance investments had no significant impact on carbon emissions.

To further analyze the impact of environmental investment on carbon emissions in different regions of China, we refer to the regional division method of the National Bureau of Statistics and divide the sample into three sub-samples: the eastern, central, and western regions[3]. The results are presented in Table 8.

According to Table 8, environmental investments have significant impact on carbon emissions in each region. Specifically, environmental investments significantly increase carbon productivity in the eastern region, and decrease the CO_2 emissions and carbon emission intensity in the western and central region. For better understanding, the results of Table 8 are visualized in Figure 2. Clearly, the impact of environmental investments on carbon emissions differs across regions. These results suggest that environmental investments by enterprises in eastern regions mainly focus on improving carbon productivity, and companies in western and central regions concentrate on reducing carbon emissions.

As the eastern region is the most advanced economy in China, we can conclude that enterprises in the eastern region focus on green innovations in the production process. Compared to the eastern region, the environmental investments of enterprises in the central and west regions significantly reduce carbon emissions. However, such investments do not improve carbon productivity. These results suggest that advanced provinces in China have achieved balance between economic development and environmental protection. China is undergoing a green transition in its industries, and it has obtained substantial positive results from ESG investment. Since the

TABLE 6 The effect of ESG total investments on carbon emissions.

	CO_2	CP	CEI
ESG	−0.262**	0.247	−0.519*
	(−2.14)	(0.74)	(−1.87)
TEC	0.016	−0.208**	−0.145**
	(0.55)	(−2.55)	−2.16)
PGDP	−0.083	1.519***	−0.825***
	(−0.83)	(5.55)	(−3.65)
COMs	0.852***	−0.632**	1.042***
	(9.29)	(−2.52)	(5.04)
Open	−0.001	−0.061	−0.060*
	(−0.09)	(−1.60)	(−1.92)
Constant	3.926***	−8.122**	4.639*
	(3.32)	(−2.51)	(1.74)
Individual FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Observations	180	180	180
R-square	0.580	0.602	0.775

Notes: *, **, and *** indicate significance level at the 10%, 5%, and 1% respectively.

3 China National Bureau of Statistics Information Disclosure (stats.gov.cn)

TABLE 7 The effect of Environmental, Social, and Governance investments on carbon emissions.

	CO_2	CP	CEI	CO2	CP	CEI	CO_2	CP	CEI
Environment	−0.246***	0.243	−0.558***						
	(−2.83)	(1.01)	(−2.86)						
Social				−0.111	0.067	−0.176			
				(−1.05)	(0.24)	(−0.69)			
Governance							−0.034	−0.041	−0.013
							(−0.44)	(−0.55)	(−0.07)
TEC	0.022	−0.213***	−0.133**	0.018	−0.165**	−0.184***	0.017	−0.008	−0.185***
	(0.74)	(−2.62)	(−2.01)	(0.62)	(−2.20)	(−2.65)	(0.57)	(−0.27)	(−2.65)
PGDP	−0.076	1.512***	−0.804***	−0.089**	0.712***	−0.136	−0.094**	−0.094**	−0.144
	(−0.77)	(5.53)	(−3.62)	(−2.36)	(7.31)	(−1.50)	(−2.50)	(−2.57)	(−1.61)
COMs	0.856***	−0.636**	1.056***	0.896***	−0.788***	0.927***	0.883***	0.890***	0.910***
	(9.45)	(−2.54)	(5.19)	(9.69)	(−3.30)	(4.19)	(9.55)	(9.91)	(4.12)
Open	0.001	−0.063*	−0.057*	0.006	−0.075**	−0.078**	0.007	0.001	−0.075**
	(0.04)	(−1.66)	(−1.85)	(0.42)	(−2.12)	(−2.35)	(0.48)	(0.06)	(−2.28)
Constant	3.688***	−7.919**	4.301*	2.889***	2.884	−2.554	2.749***	5.226***	−2.958
	(3.25)	(−2.52)	(1.68)	(3.22)	(1.24)	(−1.19)	(2.98)	(5.84)	(−1.34)
Individual effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	180	180	180	180	180	180	180	180	180
R-squared	0.590	0.604	0.782	0.585	0.649	0.751	0.582	0.632	0.750

Notes: *, **, and *** indicate significance level at the 10%, 5%, and 1% respectively.

TABLE 8 The effect of regional environmental investments on carbon emission in the East, Middle, and West regions.

		East			Middle			West	
	CO_2	CP	CEI	CO_2	CP	CEI	CO_2	CP	CEI
Environment	−0.104	1.730**	0.118	−0.329*	−0.013	−1.044**	-0.411***	0.296	−0.631*
	(-0.45)	(2.13)	(0.40)	(−1.96)	(−0.06)	(−2.26)	(−2.91)	(1.47)	(−1.81)
TEC	0.070	−0.233	−0.058	−0.012	0.047	0.168	−0.000	−0.189***	−0.252**
	(1.08)	(−1.03)	(−0.69)	(−0.22)	(0.65)	(1.12)	(−0.01)	(−2.76)	(−2.12)
PGDP	−0.217	2.423***	0.084	0.007	1.104***	−1.212***	0.179	0.747**	−1.048*
	(−1.01)	(3.21)	(0.30)	(0.05)	(6.16)	(−3.28)	(0.84)	(2.45)	(−1.99)
COMs	0.773***	−1.795*	0.367	0.884***	−0.642***	1.235***	1.037***	−1.272***	0.471
	(2.89)	(−1.92)	(1.07)	(8.26)	(−4.50)	(4.19)	(4.94)	(−4.24)	(0.91)
Open	0.026	−0.118	0.026	−0.017	0.016	0.003	−0.019	−0.014	−0.055
	(0.42)	(−0.56)	(0.34)	(−0.43)	(0.31)	(0.03)	(−1.04)	(−0.53)	(−1.20)
Constant	4.772	−11.654	4.301*	3.408**	−5.432***	5.698	0.102	4.995	13.789*
	(1.65)	(−1.15)	(1.68)	(2.57)	(−3.07)	(1.56)	(0.03)	(1.11)	(1.78)
individual effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
time effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	72	72	72	54	54	54	54	54	54
R-squared	0.515	0.650	0.851	0.796	0.850	0.836	0.649	0.832	0.844

Notes: *, **, and *** indicate significance level at the 10%, 5%, and 1% respectively.

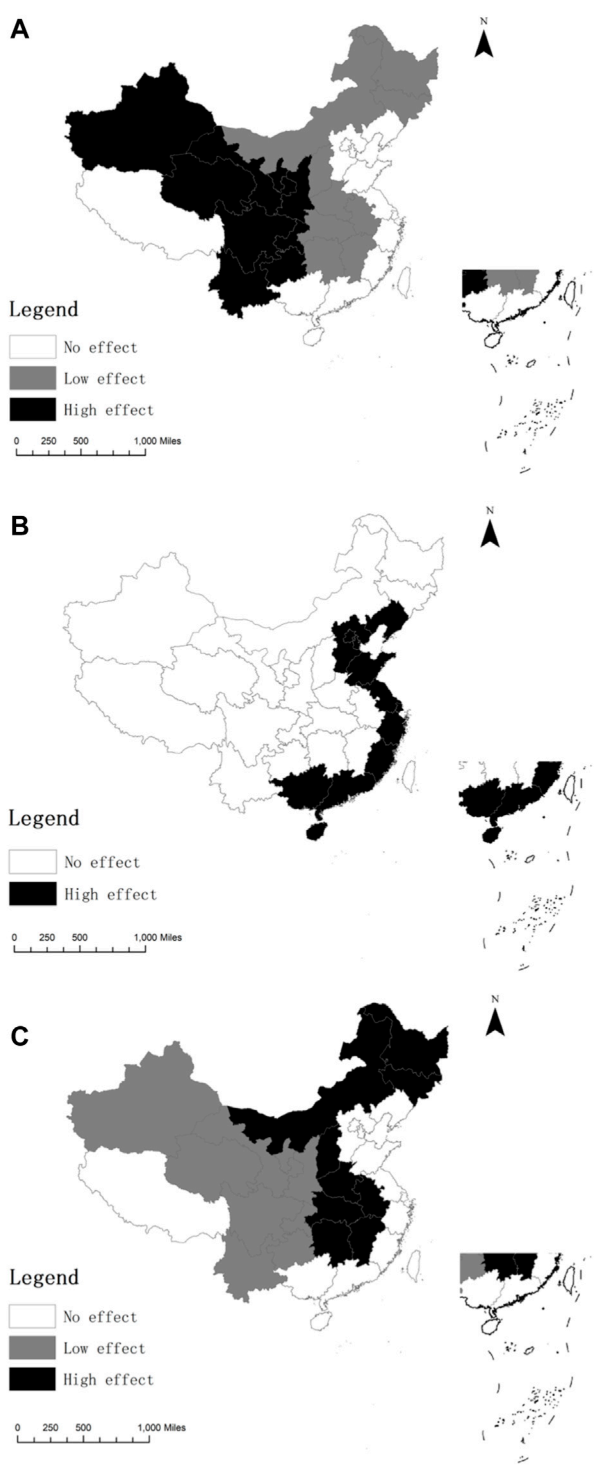

FIGURE 2
(A). The impact of Environmental investments on carbon emissions **(B)**. The impact of Environmental investments on carbon productivity **(C)**. The impact of Environmental investments on carbon emission intensity.

effect of ESG investments is different across regions, environmental economic policies should take into account the levels of economic development.

5 Conclusion

In 2021, the Chinese government put forward the goal of "achieving carbon peak by 2030 and carbon neutrality by 2060". The requirements of sustainable development have changed the idea of "high pollution, high economic development", and have been forcing green transition to enterprises.

This study investigates the impact of ESG investments by Chinese listed firms on carbon emissions. We find that Chinese enterprises' ESG investments significantly reduce carbon emissions, but the effect differs across regions. Enterprises in the eastern region focus on improving their carbon productivity. In the central and western regions, firms concentrate on reducing the amount of carbon emissions.

Overall, China still has a long way to go to meet its climate change targets. The responsibility for reducing carbon emissions requires technological progress in the production process, which has not been realized in the current stage. Future research could focus on specific industries, and investigate the mechanism of how ESG investments can reduce carbon emissions.

Data availability statement

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

Author contributions

YC: Methodology, data collection, empirical analysis, writing, and conceptualization. CZ: Methodology, and empirical analysis. YH: Methodology, and writing. ST: Conceptualization, writing, formal analysis, and supervision. XC: Writing, supervision, and funding.

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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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Can performance-based budgeting reform improve corporate environment in ESG? Evidence from Chinese-listed firms

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Finance is a pillar industry of national governance. It also provides a solid guarantee for achieving the official Double Carbon target. The question of how to forefront the role of environmental governance in the reform of fiscal and taxation systems, whilst also motivating enterprises to enhance Environment in Environmental, Social, and Governance (EESG) considerations is worth investigating in depth. This study takes A-share listed companies in China from 2001 to 2020 as examples. The effect of Performance-Based Budgeting (PBB) reform on the EESG of these enterprises is empirically examined through quasi-natural experiments using a multi-time difference-in-difference model. We find that PBB significantly optimizes the EESG of the enterprises. The placebo test, the difference-in-difference method, and a series of other robustness tests all support this conclusion. Furthermore, it is suggested that the environmental governance effect of PBB is more significant in areas with heavy financial pressure and stronger government audit. The environmental governance effect of the PBB reform is significant for enterprises with government contracts, strong green innovation capabilities, or high financing constraints. The mechanism test is performed, and the results suggest that the influence mechanism of this environmental governance role lies in the fact that PBB has improved environmental protection subsidies and enhanced fiscal transparency. Through the economic consequences test, we find that enterprise EESG can bring economic benefits to enterprises, which is reflected in the improvement of enterprise return on total assets, price-to-book ratio, and total patent authorization. This study enriches literature on the economic consequences of PBB, and has significance in deepening current fiscal and tax system reform, vigorously optimizing the major strategy of carbon peak and carbon neutrality.

KEYWORDS

ESG, environment in ESG, fiscal and tax system, performance-based budgeting, DID, China

1 Introduction

Beyond meeting their financial objectives, many firms have striven to integrate a wide variety of Environmental, Social, and Governance (ESG) goals into their business models over the past few years (Gillan et al., 2021). ESG is an acronym that dates back to 2004 when a report commissioned by the UN called for "better inclusion of environmental, social and corporate governance (ESG) factors in investment decisions."[1] Analysis by asset manager Pimco suggests that from May 2005 to May 2018 ESG was mentioned in fewer than 1% of earnings calls, while by 2021 it was mentioned in almost a fifth of earnings calls.[2] According to Bloomberg, global ESG assets are expected to exceed $53 trillion by 2025, this accounts for approximately over a third of the $140.5 trillion in projected total assets under management.[3]

With the rising use of ESG, corporate ESG has become an increasingly important topic that has received considerable attention and research effort from academic researchers in a wide variety of disciplines (e.g., finance, economics, accounting, and management). The question of how to motivate and improve corporate ESG performance is a key subject of these studies. Academic researchers have started to explore a wide spectrum of management characteristics-, firm-, market-, as well as country-level determinants of corporate ESG over the past few decades. The first refers to the level of management characteristics, including female directors (Dyck et al., 2022), young CEOs (Borghesi et al., 2014), and overconfident CEOs (McCarthy, Oliver and Song, 2017). The second refers to the firm level, including institutional Investors (Dyck et al., 2019), family businesses (Abeysekera and Fernando, 2020), and state-owned enterprises (Hsu, Liang, and Matos, 2021). The third refers to the market level, including import competition (Xu and Wu, 2021), cross-listing (Boubakri et al., 2016), and banks (Houston and Shan, 2022). The fourth refers to the country level, including economic development (Cai, Pan, and Statman, 2016) and the legal system (Liang and Renneboog, 2017). However, empirical inquiries have received limited attention from the position of government policy.

The fiscal policy implemented by the government is a vital tool for intervening and stimulating the behavior of micro-enterprises. It is also the foundation and an important pillar of national governance. National governance capacity largely originates from budgetary capacity (Allen, 1990). An essential cornerstone of building a modern budget system is to implement performance-based budgeting (PBB), which refers to "the systematic use of performance information to inform budget decisions, either as a direct input to budget allocation decisions or as contextual information to inform budget planning, and to instill greater transparency and accountability throughout the budget process by providing information to legislators and the public on the purposes of spending as well as the results achieved." [4]PBB refers to an elastic concept, including program evaluation, spending reviews, and performance management. It links resources to results through injections of information on performance into the stream of budget work. It also becomes part of a process that facilitates monitoring of social trends and progress, while improving managerial accountability and citizen participation in budget decisions (Schick, 2014).

In the spirit of New Public Management, PBB has attracted the interest of academics and practitioners (Mauro, Cinquini and Grossi, 2017). There is a rich body of academic research on PBB, focusing on the connotation, realization path, factors, and incentive and restraint mechanisms of PBB (Hou et al., 2011; Schick, 2014; Park, 2019; Sung and Sungkyu, 2021). However, scholars have rarely paid attention to the economic consequences of PBB. For instance, countries with a higher share of ministries using performance targets in budget negotiation tend to have lower government debt and higher GDP growth rates (Kwon, 2018). In addition, PBB affects the managerial performance of government officials (Yuhertiana and Fatun, 2020). Budgeting use based on performance in improving the quality of financial reporting of organizations in the Iranian Province of Ardabil takes on a positive and meaningful significance (Shahvalizadeh and Fouman Ajirlou, 2020). However, most of the existing research on the economic consequences of PBB has focused on the government level and few studies have examined it at the micro-enterprise level. Environmental responsibility accounts for a vital part of corporate ESG. In this setting, the question of how PBB shapes enterprise environment in Environmental, Social and Governance (EESG) behavior is further explored in this paper.

China is the research context for this study, first, because it has an ambitious goal to achieve peak carbon by 2030 and carbon neutrality by 2060. Efforts are being made to achieve green government procurement, fiscal policy support, tax incentives for carbon emission reduction, building a carbon emission trading market, and promoting the upgrading of industrial structure to ensure carbon peak and carbon neutrality as scheduled. Second, as the largest developing country, China is still in a stage of economic transformation. Compared with other developed countries, the management behaviors of Chinese companies are more easily affected by government policies. Third, China is currently carrying out a comprehensive reform of budget performance management. In 2003, the

1 "Who Cares Wins" https://www.ifc.org.

2 https://www.ft.com/content/5ec1dfcf-eea3-42af-aea2-19d739ef8a55

3 https://www.gobyinc.com/2022-another-historic-year-for-esg/

4 Blazely A. OECD Best Practices for Performance Budgeting [J]. Organisation for Economic Co-operation and Development−2018. https://one.oecd.org/document/GOV/PGC/SBO, 2018, 7.

Third Plenary Session of the 16th Central Committee of the Communist Party of China proposed the establishment of a budget performance evaluation system, thus starting the pace of China's budget performance reform. These factors mean that China is an interesting research context for exploring the impact of PBB reform on corporate EESG.

China's PBB reform can be divided into two stages. The first was the project-based budget performance management stage between 2003 and 2017. The main feature of this stage was that the scope of performance management was limited to general public budgets. The main content of the project, performance evaluation results, and budget arrangements are not organically combined. The second was the comprehensive performance-based budgeting management stage, from 2018 to the present. The main feature of this stage is that the scope of performance management has been expanded to government fund budgets, state-owned capital operating budgets, and social insurance fund budgets; departmental and unit budgets are the main content of performance evaluation, and performance evaluation results are linked to budget arrangement mechanisms. From the perspective of local governments, in 2004 the Guangdong Provincial Government of China implemented the PBB reform, the first example of it being piloted by local government in China. In 2009, the Jiangsu Provincial Department of Finance conducted a performance evaluation of 22 projects at the provincial level with an investment of 14.5 billion yuan. Local governments have successively issued relevant documents for the implementation of PBB in light of the actual conditions of their regions, gradually expanding from the provincial government level to the city and county government level, and from focusing on project expenditure to gradually transitioning to the budget performance of units and departments. Thus, the progress of reforms by China's local governments in batches and years has provided a good quasi-natural experiment scenario for us to study the economic consequences of PBB.

This study takes China's A-share listed companies from 2001 to 2020 as a sample and uses a difference-in-difference (DID) identification strategy to analyze the effect of the PBB reform on the enterprise EESG. It found that the PBB reform has significantly improved enterprise EESG. Placebo tests, difference-in-difference-in difference, and a range of other robustness tests were undertaken and support these conclusions. Furthermore, the effect of the PBB reform on the enterprise EESG is more obvious it is found that in areas with high financial pressure and strong government auditing. The environmental governance effect of the PBB reform is more significant for enterprises that have government contracts, have strong green innovation capabilities, and have high financing constraints. The result of the mechanism test reveals the influence mechanism of this environmental governance role (i.e., PBB reform has increased environmental protection subsidies and fiscal transparency). The result of the economic consequences test indicates that the enterprise EESG can bring economic benefits to the company, which is reflected in the improvement of the company's return on assets, price-to-book ratio, as well as total patent authorization.

Compared with previous studies, the marginal contribution of this study is mainly reflected in the following three aspects. First, in terms of research perspectives, prior literature is more focused on the effect of the PBB reform on economic development, government behavior, and other macro-level factors. In contrast, this study discusses the environmental governance effect of the PBB reform from a micro-perspective, which is helpful for understanding the effect of fiscal and tax system reform on micro-market entities and its mechanism and enriches research on macroeconomic policy and micro-enterprise behavior. Second, at the level of empirical identification, compared with existing research, the PBB reform is adopted as a quasi-natural experiment for empirical tests. There are fewer impurities in the research scenarios, and concerns about endogeneity are reduced to a greater extent, meaning the empirical test evidence is more convincing. Third, at the level of policy enlightenment, this study provides new evidence to evaluate the effect of PBB policy. The findings of this study can provide insights into the policy effects of the PBB reform while providing an important reference for China to deepen fiscal and tax system reform.

The rest of the paper is organized as follows. In Section 2, our hypotheses are developed. In Section 3, the data and sample construction processes are outlined. In Section 4, the relationships between PBB and the enterprise EESG, robustness analyses, heterogeneity test, mechanisms test, and the real consequences of enterprise EESG are examined. In Section 5, we draw our conclusions.

2 Hypothesis development

PBB is expected to produce and use performance information to guide the budgeting process and affect the allocation of resources, directly or indirectly, to manage the efficiency and effectiveness of governments and their agencies, facilitate budgetary decision-making and allocation of resources, achieve cost savings, and enhance transparency and accountability (Curristine, 2005). ESG stresses that companies will integrate a wide variety of ESG goals into their business models (Gillan et al., 2021). Building on budget-maximization and principal-agent theory, we analyze the impact and internal mechanism of PBB on the enterprise EESG.

The first impact is that the compensation effect–PBB implemented by the government reduces the information asymmetry between taxpayers and the government, the financial department, and the budget department. PBB widens the spatial of government environmental subsidies and boosts the efficiency and effectiveness of the subsidy program, which ultimately promotes enterprise EESG.

Management needs to balance the cost and income when making an ESG investment (CAI et al., 2016). When ESG outcomes can be perfectly measured, directly subsidizing the ESG outcome is more effective to improve enterprise ESG; and when ESG cannot be reliably measured, regulators can indirectly improve ESG outcomes by subsidizing the financial performance of firms with socially desirable technologies (Bonham and Riggs, 2022). PBB can reduce the information asymmetry between taxpayers and the government, financial departments, and budget departments, effectively reduce agency conflict, and broaden the space for government environmental subsidies.

Relying on principal-agent theory, there are two main types of principal-agent relationships in the field of government budgets. First, taxpayers entrust the government to provide public services by providing tax revenue. Budget-maximization theory argues that bureaucrats do indeed seek to maximize their budgets because increased budgets gave bureaucrats greater access to salary, people, and power (Niskanen, 1971; Niskanen, 1975). In contrast, it is difficult for taxpayers to supervise the use and efficiency of government budgetary money, and there is a severe principal-agent problem between taxpayers and governments. Second, there is a principal-agent relationship between the financial department and the budget department. The finance department is responsible for the disposition and management of budget funds, and the budget department accounts for the use of budget funds to provide public services. Compared with the financial department, the budget department is more aware of the authenticity, effectiveness, and efficiency of the use of its budget funds. Therefore, the budget department has an incentive to pursue the maximization of the department budget with its information superiority.

On the one hand, PBB directly reduces information asymmetries between the tax payer and the government. PBB establishes an information transparency mechanism by publicly disclosing information, such as budget implementation and performance evaluation. The more information the budget discloses, the less the politicians can use fiscal deficits to achieve opportunistic goals (Benito and Bastida, 2009). By easing the information asymmetry, principals will detect malfeasance or failure to deliver public services on the part of agents and will enact punishment, thus deterring the abuse of public power and helping to channel government resources in a fair and efficient manner (Besley, 2006). PBB provides output and outcome data that can be linked with input data in a way that provides transparency as to the efficiency and effectiveness of spending, so that budget officials and parliament can monitor and steer the limited budgetary resources to where they matter most in a given political context (Shaw, 2016), which provides a restrictive tool to contain the maximization of a government's budget. Thus, PBB can reduce the waste of budget resources, improve the use efficiency of government budget funds, increase the government's support for the sustainable development of enterprises, and increase environmental subsidies for enterprises, thus stimulating the EESG of enterprises.

On the other hand, PBB directly reduces information asymmetries between the financial department and the budget department and enables inefficient or even invalid use of budget resources to be addressed in good time. Because the budget targets approved for the current year are larger than the actual budget resources needed by the department, at the end of the budget year, to use budget resources in a timely way without reducing the budget targets for the next year, many organizations whose budgets are due at the end of the fiscal year may face an incentive to rush to spend resources on low-quality projects at the end of the year (Liebman and Mahoney, 2017). By providing more information about the production costs of public services to the legislature as budget sponsors, the legislative adoption of PBB can mitigate the information asymmetry between bureaucrats and the legislature, which leads to more effective control of budgetary slack by budget sponsors (Sung and Sungkyu, 2021). After PBB is implemented, the financial department can monitor the budget implementation of a department in actual time and promptly judge the use of funds. In the process of budgetary execution, if a the efficiency of budget item use is relatively low and it is difficult to meet the budget plan goal, then the financial department can reduce or withdraw invalid investments in good time, enabling them to instead allocate precious budget resources to more efficient areas.

After the completion of budget implementation, the financial department must evaluate the performance of funds used by the budget department (e.g., funds relevance, effectiveness, efficiency, and economy). Ex-post evaluations of budget items are conducted on a rolling basis, and performance information is systematically fed back into next year's budget preparation. The inefficient and ineffective budget items are reduced, efficient and effective budget expenditure items are simultaneously increased, and budget funds can be redirected to support priority goals. PBB is capable of reducing the waste of budget resources, increasing the efficiency of budget fund allocation, and finally expanding the financial space for the government to stimulate the EESG of enterprises.

PBB reform is capable of deepening the connection between the implementation effect of budget projects and the allocation of budget funds, thus increasing the use efficiency of government subsidy projects, achieving a more accurate and scientific compensation effect, and enhancing the EESG performance of enterprises. For parliaments, performance budgeting more clearly expounds on the purposes of spending, and what goods and services will be delivered in exchange for the resources that they have voted on, as well as a means of holding officials to account for the achievement of results. For finance ministries, performance budgeting provides novel types of information that help them make resource allocation decisions based on evidence of what works, plus tools to make line ministries more accountable for the effectiveness and efficiency of spending (Blazely, 2018). China has issued numerous documents and policies over the past few years to enhance accountability for PBB. For instance, in 2018, the Ministry of Finance issued a policy on *implementing the opinions of the CPC Central Committee and the State Council on the comprehensive implementation of PBB*, which emphasizes that: "In accordance with the principle of rewarding the good and punishing the bad, the government should give priority to stabilizing projects with high performance, and all inefficient and ineffective funds should be reduced or canceled, and funds transferred to vital areas of public financial expenditure for support. Accountability should be held for departments and their responsible persons whose budget execution deviates significantly from performance objectives." Accordingly, PBB will increase the efficiency and effectiveness of environmental subsidy projects and can give more support to enterprises to invest in ESG, thus improving the EESG performance of enterprises. Meanwhile, the guiding effect of PBB has improved financial transparency, reduced regional corruption, improved the business environment, and reduced the institutional transaction costs of enterprises, thus saving funds for enterprises and enabling them to implement investment in EESG.

Opinions on the comprehensive implementation of PBB issued by the CPC Central Committee and the State Council in September 2018 indicate that it is necessary to vigorously improve the openness and transparency of performance information, take the initiative to report to the People's Congress at the same level and disclosing these results publicly, meaning they consciously accept the supervision of the People's Congress and wider society.

PBB is capable of improving the quality of financial reporting of the public sector in terms of comparability, timeliness, and understandability (Shahvalizadeh and Fouman, 2020), increasing fiscal transparency in the government, raising the function of the public sector, fostering greater accountability, and fighting against the corruption (Cai et al., 2016). The higher the levels of regional corruption, the greater the obstacles to enterprise in terms of financing channels, procedures, processes, and others, and the larger the financing cost. Moreover, the rent-seeking behavior of officials brings more rent-seeking costs to enterprises, thus encroaching on the original investment resources in the EESG of enterprises. The improvement of government transparency can optimize the business environment, helping to form a novel "qin qing" government business relationship, meaning enterprises have more energy and resources to engage in production and operation activities. Decker (2020) has suggested that the Army's PBB programs are beneficial to enhancing quality performance. Facilities participating in PBB programs enhance performance after program implementation, relative to comparison facilities.

PBB is capable of improving the quality of public services, enabling enterprises to enjoy more convenient, fast, and high-quality services, meaning they can respond more directly to market demand, and reduce institutional transaction costs. Thus, PBB saves funds for enterprises, meaning they can carry out ESG activities, as it lowers the cost involved in implementing EESG. Formally, our first hypothesis is presented as follows.

Hypothesis 1: PBB motivates enterprise EESG.

Since it undertook tax reform, China's central and local governments have seen a rise in wealth and a decline in power. With the gradual implementation of fiscal and tax system reforms (e.g., the reform of the income tax sharing system, the abolition of agricultural tax, and the replacement of business tax with value-added tax), the original financial resources of local governments continue to be squeezed and rigid expenditure (e.g., infrastructure, people's livelihood security, and education) continue to increase. The recent COVID-19 pandemic has involved repeatedly waves, and the policy of reducing taxes and fees has been vigorously implemented. Under this superposition effect, the local government's financial pressure is highlighted. With increasing financial pressure, local governments need to consider how to make good use of existing budget resources and increase the efficiency of fiscal expenditure to solve the contradiction between revenue and expenditure. Increasing the efficiency of fiscal expenditure can effectively avoid the distortion of resource allocation by the government's "grabbing hand." Higher expenditure efficiency usually causes lower corruption and abuse of funds (Xu et al., 2020). Compared with local governments that face low levels of fiscal austerity, government officials facing a high level of fiscal austerity use more budget performance information (Bjørnholt et al., 2016). Under larger financial pressure, the budget resources become relatively scarce. To ensure public services are at an acceptable level, local governments should tap into potential through budget performance management, thus reducing the unnecessary waste of resources, promoting PBB, and the corresponding reform may more significantly affect the enterprise EESG.

As the "immune system" of the national governance system, government audit is an important tool for local governments to improve the efficiency of fiscal expenditure (Xu et al., 2020). China's Budget Law emphasizes that audit departments of governments at and above the county level should supervise budget implementation and final accounts in accordance with the law. Specifically, an audit can play a greater supervisory role in budget implementation, results application, and other links. On the one hand, in the process of budget implementation, the audit department can check the budget implementation status of the budget department or the project at any time, and verify the matching degree with the performance objectives. For budget units and projects with poor performance, a timely request from the financial department to cut or terminate the use of funds to reduce the loss and waste of funds, and play a supervisory role. On the other hand, after the budget, the audit department can reevaluate the budget department or projects; review the authenticity, reliability, and rationality; and audit whether or not assessment indicators are unscientifically set, or if there is poor operability and other problems. At the same time, the audit department can also check whether the budget department prepares the budget for the next year based on the performance evaluation results of the previous year, and whether the results of the budget performance evaluation have been fully utilized. When the audit department is conducting an economic responsibility audit on the head of the budget department, it can reevaluate the performance of the relevant responsible persons; find out their waste of budget funds, fraud, and inadequate performance of budget performance work; and timely hold them accountable. In addition, the audit can also further improve the quality of financial reporting in the public sector, enhance the transparency of the public sector, alleviate the information asymmetry between taxpayers and the government, and improve the public's trust in the government. In other words, in the areas with a stronger government audit, PBB plays a more significant role in environmental governance. Accordingly, this study proposes the second hypothesis:

Hypothesis 2: The incentive effect of PBB on the enterprise EESG is more significant in areas with greater financial pressure and stronger government audit.

Companies with government contracts are affected by PBBs. On the one hand, government customers can play a supervisory effect to support the development of enterprises and enhance the resources and motivation of enterprises to implement EESG. Compared with ordinary corporate customers, creditors use fewer contracts and performance pricing terms (Cohen et al., 2022). When loans to corporate suppliers with key government customers, because signing with key government customers face low demand uncertainty, which enables companies to generate more revenue from the investments of specific customers, profit margins increase with government customer concentration (Cohen and Li, 2020). Compared with similar enterprises, companies with large government customers have higher capital capitalization, capital spending, and higher bank credit (Goldman, 2020). On the other hand, China's Government Procurement Law stipulates that government procurement refers to the behavior of state organs at all levels using financial funds to purchase goods, projects, and services. China's Budget Law stipulates that all government revenue and expenditure should be included in the budget. The government procurement funds belong to the budget expenditure, and the signing, implementation, and settlement of the government contracts will be affected by PBB. Thus, this study concludes that for enterprises with government contracts, PBB will have a greater incentive effect on their EESG.

Green innovation of enterprises can reduce environmental pollution and save energy, while achieving environmental and social benefits, and improving the core competitiveness of enterprises (Li and Xiao, 2020). Green innovation can improve the existing production process or develop a new process to reduce harmful substances and the emission of pollutants, and increase the efficiency of energy. Moreover, green innovation emphasizes the integration of environmental protection concepts into the product of raw material selection, design, production, packaging, after-sales service, and other links to improve the performance of environmental and social responsibility (Xie and Zhu, 2021). The level of green innovation represents the environmental governance ability of the enterprises. Accordingly, this study concludes that enterprises with strong green innovation ability pay more attention to environmental protection, and PBB has a greater incentive effect on their EESG.

The resource-based view considers that the heterogeneity of resources and capabilities can explain the performance differences between enterprises. In particular, those valuable, rare, and high-cost resources of imitation have the greatest potential to create economic rent, and the resources owned by enterprises are the important factors in their decision-making. Enterprise initiative to implement EESG investment is affected by the enterprise's inherent resources. In particular, enterprises with a weak resource base have a low willingness to carry out EESG investments. Moreover, the income brought by the enterprise environment in ESG investment has positive externalities, and enterprises cannot enjoy all of the income of their investment. The management will conduct a cost-income analysis of ESG investment (Cai et al., 2016), such that government intervention should stimulate companies to invest in EESG. As a policy tool, PBB increases the efficiency of fiscal expenditure and expands the space for government subsidies and tax incentives. For enterprises with high financing constraints, their internal resources are insufficient to support enterprises to carry out large-scale EESG investments, and they are more dependent on government support. Thus, PBB for enterprises with higher financing constraints has a greater incentive effect on EESG. In brief, our third hypothesis states that:

Hypothesis 3: For enterprises with strong government contracts, strong green innovation ability, or high financing constraints, the environmental governance effect of PBB is more significant.

3 Materials and methods

3.1 Data and sampling

In this study, listed non-financial companies in China from 2001 to 2020 were selected as the research samples. The

TABLE 1 Year of implementation of PBB reform by region.

Year of implementation	Region
2004	Guang Dong
2005	Zhe Jiang
2009	Hai Nan, Jiang Su
2011	Bei Jing, Tian jin, Shang Hai, An Hui, He Nan, Xin Jiang, Si Chuan
2013	Fu Jian, Shan Dong, Liao Ning, Hu Bei, Jiang Xi, Shan Xi, Chong Qing, Gui Zhou, Shan Xi, Guang Xi, Yun Nan
2015	Hei Longjiang, Ji Lin, Nei Menggu, Xi Zang, Qing Hai, Gan Su, He Bei, He Nan, Hu Nan
2018	Ning Xia

provincial-level data, financial data, and data of the environment in ESG originated from the China Research Data Service platform (CNRDS). In addition, we deleted samples with negative values of assets, cash, MB, and so on, and all continuous variables were winsorized at 1% to reduce the effect of variable outliers in the sample. Accordingly, this study ended up with 40,959 annual company samples.

3.2 Definitions of variables

3.2.1 Explained variable

The dependent variable is "Enterprise Environment in ESG," which is denoted as EESG. This study uses the CNRDS database to get the total score of the EESG index, in which the highest score is 8 and the lowest score is 0. The specific sub-indicators are as follows. First, if the company has developed or applied innovative products, equipment, or technology that are beneficial to the environment, then the value will be 1; otherwise, the value will be 0. Second, if the company has adopted policies, measures, or technologies to reduce emissions of waste gas, waste water, waste residue, and greenhouse gases, then the value will be 1; otherwise, the value will be 0. Third, if the company has used policies and measures of renewable energy or circular economy, then the value will be 1; otherwise, the value will be 0. Fourth, if the company has policies, measures, or technologies to save energy, then the value will be 1; otherwise, the value will be 0. Fifth, if the company has green office policies or measures, then the value will be 1; otherwise, the value will be 0. Sixth, if the company's environmental management system has passed ISO 14001 certification, then the value will be 1; otherwise, the value will be 0. Seventh, if the company has received environmental recognition or other positive evaluation, then the value will be 1; otherwise, the value will be 0. Finally, if other enterprise environmental advantages are not covered in these indicators, then the value will be 1; otherwise, the value will be 0. Because there is a time lag for enterprises affected by policies, $t + 1$ stage treatment will be applied to EESG index numbers.

3.2.2 Explanatory variable

Unlike existing research, this study suggests that the year when the respective region implemented PBB reform is neither the year when each region issued the PBB document nor the pilot year but should be the year of large-scale promotion and implementation, such that the implementation of the reform can have a significant impact on the local government.

This study obtains the actual implementation year through field research, interviews with government officials, and consulting the websites of the Ministry of Finance and the financial departments of local governments. For instance, Beijing issued the Interim Measures for the Management of Performance Evaluation of Budget Expenditure of Municipal Departments of Beijing in 2006. The reform of the government performance budget was piloted in 2002, but it covered the whole process from 2011. Thus, this study takes 2011 as the year for the implementation of the PBB reform in Beijing.

There is a lag in the implementation of the PBB reform. This means that the PBB reform is implemented in the current year, which will have a substantial impact on the enterprise EESG in the next year. For instance, If the province or city where enterprise i is located implements PBB in the t year, then the explanatory variable of enterprise i in the t + 1 year is set to 1, otherwise it is set to 0. The specific implementation year of the respective region is shown in Table 1.

3.2.3 Control variable

Control variables are assigned to enterprise and provincial levels in accordance with existing literature on enterprise ESG. Enterprise-level variables involve enterprise age, size, sales growth rate, the proportion of tangible assets, R&D intensity, return on assets, book-to-market ratio, cash asset ratio, asset-liability ratio, liquidity, independent directors, duality, institutional investors, and ownership concentration. Enterprise Age measures an enterprise's experience in implementing EESG. According to the theory of enterprise life cycle, enterprise development is similar to the growth curve in biology, which goes through a process from prosperity to decline. In different stages, the economic, market, and technological environment faced by enterprises and the strategies adopted are different to some extent. Size measures the size of an enterprise. Large enterprises have stronger R&D capability, risk resistance ability, and financing ability, which is more conducive to

TABLE 2 The definitions of the main variables.

Types of variables	Variables	Variable name	Definitions
Dependent variable	EESG	Environment in ESG	The total score of environment in ESG index, $t + 1$ stage treatment
Independent variable	Revolution	Performance-based budgeting reform	If the province or city where enterprise i is located implements PBB reform in the t year, then the explanatory variable of enterprise i in the $t + 1$ year is set as 1, otherwise it is set as 0
Control variables—enterprise level	Lnfirmage	Enterprise age	The natural logarithm of firm age
	Lnasset	Size	The natural logarithm of total asset
	Salegrow	Sales growth rate	(Sales revenue$_1$—sales revenue$_0$)/sales revenue$_0$
	PPE	Proportion of tangible assets	Fixed assets/total assets
	RDI	R&D intensity	R&D expenditure/sales revenue
	ROA	Return on assets	Net profit/Total assets
	MB	Book-to-market ratio	Ending total market capitalization/total assets
	CF	Cash asset ratio	Cash/total assets
	LEV	Asset-liability ratio	Total liabilities/total assets
	Liquidity	Liquidity	(Current assets—Current liabilities)/Total assets
	Indiratio	Independent directors	Number of independent directors/number of directors
	Duality	Duality	If one person concurrently holds the position of general manager and chairman, it will be 1; otherwise, it will be 0
	Institution	Institutional investors	Shareholding ratio of institutional investors
	S1	Ownership concentration	Shareholding ratio of the largest shareholder
Control variables—provincial level	GDPper	Condition of the economy	Number of GDP per capita
	PD	The population density	Total population/area under jurisdiction
	UR	Urbanization rate	Urban population/total population
	SF	Fiscal self-sufficiency rate	Ratio of fiscal revenue to fiscal expenditure
	EDUA	Human capital	Education per capita
	OD	Degree of openness	Total imports and exports/GDP

the implementation of EESG. However, a scale that is too large can easily cause bureaucracy and more rigid management, while small enterprises are more flexible. Sales growth rate, return on assets, R&D intensity, and book-to-market ratio reflect the enterprise's future growth opportunities. Enterprises with more future growth opportunities will have more optimistic development prospects and more opportunities for R&D investment. Investors and creditors may be more optimistic about the company's expectations, which increases the company's financing ability. Therefore, the future growth opportunities of enterprises are also an important factor influencing the implementation of EESG. The proportion of tangible assets measures a firm's borrowing capacity. Compared with intangible capital, physical capital is more often used as collateral for debt financing because the market for physical capital is more transparent and its value can be easily assessed from a creditor's point of view. Therefore, the proportion of tangible assets can measure the borrowing ability of enterprises, and the financing ability of enterprises is related to the fund source of EESG investment and affects the EESG output of enterprises. The cash asset ratio reflects the impact of cash holdings on EESG. The implementation of EESG investment requires a large amount of capital to promote, and the sustainability of EESG activities depends on the cash flow status of enterprises. The asset-liability ratio reflects the level of debt that a company has taken on and the possibility of further borrowing. When issuing loans, banks need to examine the debt-to-asset ratio of borrowers to assess the future solvency and current loan scale of enterprises. Liquidity also reflects the current solvency of the company. Corporate financing capacity is closely related to EESG. Provincial-level variables, including economic status, population density, urbanization rate, financial self-sufficiency rate, human capital, and degree of opening to the outside world, are selected. The specific meanings are listed in Table 2.

3.3 Model setting

Government PBB reform is gradually implemented in different provinces and cities by year, which is a quasi-natural experiment with multiple shocks. To accurately measure the effect of government PBB reform on the enterprise EESG, this study builds a multi-time difference-in-difference (DID) model

TABLE 3 Descriptive statistics.

Variables	N	Mean	Median	Standard deviation	Min	Max
EESG	40,959	1.2082	0.0000	1.8037	0.0000	8.0000
Revolution	40,959	0.6482	1.0000	0.4776	0.0000	1.0000
Lnfirmage	40,959	2.7448	2.8332	0.4266	1.3863	3.5264
Lnasset	40,959	21.8919	21.7239	1.3034	19.2191	25.9357
Salegrow	40,959	0.4461	0.1323	1.3448	−0.7347	10.2817
PPE	40,959	0.2357	0.2008	0.1734	0.0021	0.7414
RDI	40,959	0.0332	0.0252	0.0401	0.0000	0.2268
ROA	40,959	0.0512	0.0412	0.0414	0.0016	0.2195
MB	40,959	0.6434	0.6548	0.2391	0.1068	1.1330
CF	40,959	0.0850	0.0696	0.0698	0.0000	0.4105
LEV	40,959	0.4428	0.4368	0.2144	0.0519	1.0375
Liquidity	40,959	0.2680	0.2235	0.1962	0.0000	0.8085
Indiratio	40,959	0.3592	0.3333	0.0756	0.0000	0.5714
Duality	40,959	0.2314	0.0000	0.4217	0.0000	1.0000
Institution	40,959	0.3392	0.3272	0.2375	0.0000	0.8646
S1	40,959	0.3574	0.3368	0.1520	0.0900	0.7498
GDPper	40,959	4.6395	4.6659	0.3013	3.7752	5.1724
PD	40,959	6.1345	6.2364	0.9788	2.5955	8.2760
UR	40,959	0.5976	0.5975	0.1204	0.3430	0.8909
SF	40,959	0.6417	0.6728	0.1805	0.2527	0.9259
EDUA	40,959	0.1238	0.1240	0.0565	0.0359	0.3170
OD	40,959	0.5425	0.5129	0.4110	0.0511	1.5344

(Bertrand and Mullainathan, 2003). The basic model is as follows:

$$EESG_{i,t} = \alpha + \beta Revolution_{i,t} + \gamma Control_{i,t} + \chi_i + \delta_t + \epsilon_{i,t} \quad (1)$$

where $EESG_{i,t}$ represents enterprise environment in ESG, and $Revolution_{i,t}$ represents government performance-based budgeting reform, which is a dummy variable. If the province or city where enterprise i is located implements the government PBB reform in the t year, then the value of enterprise i in the t + 1 year will be 1; otherwise, it will 0. $Control_{i,t}$ represents control variables affecting enterprise EESG; χ_i, δ_t, and $\varepsilon_{i,t}$ represent industry fixed effect, year fixed effect, and random disturbance term, respectively. β is the effect of PBB reform on enterprise EESG. When β is positive, PBB reform improves enterprise EESG.

4 Results and discussion

4.1 Descriptive statistics

The descriptive statistics are listed in Table 3. The highest EESG score is 8, while the lowest is 0, and the average value is 1.2082. This suggests that the EESG score of the sample enterprises is not high, and there is still considerable room for improvement. Meanwhile, 64.82% of the samples were affected by PBB reform during the sample period. The descriptive statistics of other variables are listed in Table 3.

TABLE 4 PBB reform and enterprise EESG.

Model	(1)	(2)
Explained variable	EESG	EESG
Revolution	0.1805*** (0.0308)	0.1147*** (0.0321)
Firm controls	No	Yes
Province controls	No	Yes
Industry FE	Yes	Yes
Year FE	Yes	Yes
N	40,959	40,959
adj R^2	0.0790	0.2640

Notes: The standard errors are reported in parentheses. ***, **, and * denote significance at the 1, 5, and 10% level, respectively.

4.2 Baseline results

Table 4 provides the baseline results from estimating model (1) with different model specifications. In column 1, we include industry fixed effects and year fixed effects to control for the

TABLE 5 Dynamic effect.

Model	(1)
Explained variable	EESG
Before3	0.0418 (0.0504)
Before2	0.0553 (0.0484)
Before1	0.0739 (0.0467)
Current	0.0752 (0.0461)
After1	0.0750* (0.0428)
After2	0.1583*** (0.0430)
After3	0.0768** (0.0391)
After4	0.1180*** (0.0402)
After5	0.1298*** (0.0354)
After6	0.1316*** (0.0389)
After7	0.1491*** (0.0343)
Controls	Yes
Industry FE	Yes
Year FE	Yes
N	40,959
adj R^2	0.2640

Notes: The standard errors are reported in parentheses. ***, **, and * denote significance at the 1, 5, and 10% level, respectively.

industry-varying and time-varying characteristics of firms. In column 2, we add both control variables and fixed effects to estimate the effect of PBB reform on the enterprise EESG. In all columns, the coefficient estimates on enterprise EESG are positive and significant at the 1% level. Specifically, the results suggest that the PBB reform significantly improves the enterprise environment in ESG and verifies research Hypothesis 1. We label the more comprehensive specification in column 2 as our baseline model. Our findings support the positive incentive effect of PBB reform, the effect is also consistent with evidence found in prior research on the promotional effect of PBB (Kwon, 2018; Decker, 2020). The possible explanation for this is that PBB widens the spatial of government environmental subsidies, and boosts the efficiency and effectiveness of the subsidy program. Meanwhile, PBB improves financial transparency and reduces the institutional transaction costs of enterprises, ultimately promoting enterprise EESG.

4.3 Endogeneity test

From a theoretical perspective, the PBB reform is taken as a pure exogenous shock. This study adopts the double difference method to test the effect of the PBB reform on the enterprise EESG, which can avoid endogeneity problems to a large extent. However, to guarantee the robustness of empirical results, we adopt the following endogenous inspection: Dynamic Effect Test and Entropy Balancing Matching + Dual Difference Method Test.

4.3.1 Dynamic effect test

We follow Beck et al. (2010) and examine the dynamics of the relation between PBB reform and enterprise EESG. We do this by including a series of dummy variables in the standard regression to trace out the year-by-year effects.

$$EESG_{i,t} = \alpha + \beta_1 before3_{i,t} + \ldots + \beta_4 current_{i,t} + \ldots + \beta_{11} after7_{i,t} + \gamma Control_{i,t} + \chi_i + \delta_t + \epsilon_{i,t} \quad (2)$$

We consider an 11-year window, spanning from 3 years before PBB reform until 7 years after PBB reform. We include year dummy variables for the 3 years before the reform, the current year, and the 7 years after the reform. Dummy variables are constructed as follows: when the sample time is 3 years before the exogenous shock, we built the Before3 variable with a value of 1 and 0 in other cases; when the sample time is 2 years before the exogenous shock, we built a Before2 variable and assigned 1. The others were treated similarly.

Table 5 reports the estimation results. As depicted in Table 5, the regression coefficients before the reform and the current reform year are not significant. The regression coefficient is significantly positive in the years after the reform, which suggests that the PBB reform can significantly optimize the enterprise EESG.

4.3.2 Entropy balancing matching

Selection bias may exist in the DID method, meaning that there is no guarantee that the experimental group and control group will have the same individual characteristics before the policy implementation and there are large individual differences in samples of this article. Therefore, we further use the entropy balancing matching method to match the enterprise of the experimental and control groups, and use the difference-in-difference method to regression the matched samples. Compared with the PSM matching method that is commonly used in previous literature, the Entropy Balance Matching method shows the following advantages. First, a high degree of covariable balance can be achieved by setting moment conditions (i.e., the treatment group and the control group balance on sample features). Second, valuable information is retained in the pre-processed data. In PSM matching, unmatched samples are deleted, thus causing large information loss. Third, the matching method exhibits a strong versatility. In the absence of pre-processing, researchers can apply any other standard statistical model, thus suggesting a low model dependence. Fourth, it has strong computing performance and fast computing speed (Hainmueller, 2012). Based on these advantages, entropy balance matching is adopted to solve the possible selection bias of samples, and PSM matching is applied to the comparison in the robustness test.

The basic steps of entropy balance matching are presented as follows. First, the moment conditions are set for the feature variables that may be biased, such that the samples of the treatment group and the control group are balanced, and the weight of each sample is obtained. Second, the weight is used for regression analysis. In this study, all of the enterprise-level control variables are selected as characteristic variables for processing. The matching results suggest that the mean, variance, and skewness of the characteristic variables of the enterprises in the treatment group and the control group are significantly similar after the entropy balance matching method is used, and the enterprises in the treatment group and the control group become balance[5].

Based on the samples matched by entropy balance, the difference-in-difference method is adopted to empirically test the relationship between the PBB reform and the enterprise EESG. After differences in characteristic variables are excluded, the PBB reform can still promote enterprise EESG, and endogenous problems can be significantly reduced. This suggests that the conclusions of this study are reliable (the empirical test results are presented in the Supplementary Appendix).

4.4 Robustness tests

To check the robustness of our baseline model, we provide a set of additional analyses using different subsamples, methods, models, and different measures of variables.

4.4.1 Difference-in-difference-in-difference method

The difference-in-difference-in-difference model is employed for empirical estimation to reduce the estimation bias caused by other factors for the grouping of the treatment group and the control group. Enterprises EESG may differ between the two groups because highly polluting enterprises are more likely to attract the attention of government environmental regulation. The difference-in-difference-in-difference method is adopted to test the robustness of the main regression relationship. To be specific, the group for enterprises in high-pollution industries is set to 1; otherwise, it is 0, and the Revolution_Group variable is set. Under the setting of the triple difference in the difference model, the PBB reform will more significantly increase the EESG of high-pollution enterprises, which is consistent with the benchmark regression result and verifies the robustness of the conclusion[6].

4.4.2 Placebo test

A placebo test is performed to exclude the possible effect of unobservable factors on the regression results of this study. If the main regression result is caused by unobservable factors, then the regression result will not change after the sample mismatch.

To be specific, this study randomly selects a group of sample enterprises from the sample pool (the number of samples is consistent with the number of sample enterprises affected by PBB reform) as the pseudo-treatment group and the remaining samples as the pseudo-control group.

Model (1) is employed for pseudo-treatment group and pseudo-control group samples and repeated regression 1,000 times. The distribution of estimated coefficients fluctuates significantly around 0. The proportion of significantly positive and significantly negative estimated coefficients is significantly low, and there is no virtual processing effect. As revealed by the results, the research conclusion of this study is still valid after excluding the effect of unobserved factors[7].

4.4.3 Other robustness tests

The following series of robustness tests are performed in this study. First, the EESG metrics we used in the baseline regression may not accurately measure a firm's EESG. Other ESG Indicators are adopted in the robustness test. At present, Hua Zheng ESG Rating Data is widely used in China's listed companies. In this evaluation system, a three-level indicator system is built in accordance with the core connotation and development experience of ESG. To be specific, this system comprises three first-level indicators, 14 second-level indicators, 26 third-level indicators, and over 130 underlying data indicators. All Chinese A-share listed companies are assigned a nine-level ESG rating of "AAA-C." Therefore, the ESG data of Hua Zheng will be used to replace the EESG index in the benchmark regression. The test results show that our research conclusions are not affected by the measures of replacing the explanatory variables.

Second, we use firm fixed effects to control for firm characteristics that do not change over time. Simultaneously, we conduct a test by further including province–year fixed effects to control for any potential province varying shocks. In addition, we change robustness to clustering of industry and year, which would solve the possible bias of standard errors in OLS estimation and reflect the real variability of the estimated coefficients. The test results show that our conclusion still exists.

5 The matching results are shown in Supplementary Tables A1, A2 in the Supplementary Appendix.

6 The empirical test results are shown in Supplementary Table A3 in the Supplementary Appendix.

7 Distribution of estimated coefficients and statistical analysis of regression results are shown in Supplementary Figure A1 and Supplementary Table A4 in the Supplementary Appendix.

TABLE 6 PBB and enterprise environment in ESG (Heterogeneity Analysis).

Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Explained variable	EESG									
Grouping	Low fiscal pressure	High fiscal pressure	Weak government audit	Strong government audit	Without government procurement contracts	With government procurement contracts	Low innovation level	High innovation level	Low financing constraints	High financing constraints
Revolution	0.0526 (0.0558)	0.1374** (0.0537)	0.0985** (0.0500)	0.2094*** (0.0452)	0.1101*** (0.0329)	0.4000** (0.1551)	0.1107*** (0.0336)	0.2413** (0.1017)	0.0624 (0.0393)	0.1755*** (0.0504)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
IndustryFE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	20,554	20,405	21,691	19,268	39,842	1,117	35,272	5,687	20,513	20,446
adj R^2	0.3230	0.2310	0.3080	0.2300	0.2630	0.3430	0.2390	0.3730	0.1180	0.2770
Empirical *p*-value	0.0980		0.0380		0.0580		0.0680		0.0450	

Notes: The standard errors are reported in parentheses. ***, **, and * denote significance at the 1, 5, and 10% level, respectively. Empirical *p*-values were used to test the significance of differences in regression coefficients between groups, and were obtained by 1,000 times Bootstrap.

Third, this study will eliminate interference from concurrent policies. The PBB reform and other fiscal and taxation reforms (e.g., reform to replace business tax with value-added tax) will eliminate double taxation and reduce the corporate tax burden, thus motivating enterprises to perform the environment in ESG. There may be a time overlap between the two policies, such that this study only retains samples of manufacturing enterprises to make an empirical test, to eliminate the possibility of such interference. Furthermore, China revised the Environmental Protection Law in 2014, and the new Environmental Protection Law came into effect in 2015. Therefore, to exclude the interference of environmental protection laws, we exclude the data from 2015 to 2020. It is tested that the conclusion of this paper is still robust after excluding the interference of other policies.

Finally, we change the matching method, and we use the traditional PSM Matched samples to eliminate individual differences in the samples. The test results show that the research conclusions of this paper still exist after changing the matching method.

In conclusion, the robustness test results all support the conclusion that the PBB reform significantly improves the enterprise EESG. This suggests that the conclusion of this study is relatively reliable and the effect of the external environment will not lead to significant changes in the conclusion of this study[8].

8 The empirical test results are shown in Supplementary Table A5 in the Supplementary Appendix.

4.5 Cross-sectional analyses

To further understand the specific effects of the PBB reform, this study analyzes the effect of heterogeneity from the government level and enterprise level.

4.5.1 Heterogeneous impact on fiscal pressures in different localities

At present, the tide of anti-globalization and the COVID-19 pandemic are overlapping with each other, and geopolitical risks such as the conflict between Russia and Ukraine have slowed the global economic recovery. With the domestic economy trending downward and the implementation of tax and fee reduction policies, the financial pressure on local governments in China has increased sharply. PBB reduces the government expenditure growth rate and financial deficit level (Lee and Wang, 2009). Therefore, we investigate the effect of the PBB reform on the enterprise EESG from the perspective of financial pressure, where fiscal pressure is equal to the difference between local fiscal expenditure minus local fiscal revenue divided by local fiscal revenue. Groups are divided by median into high and low financial stress. The regression results in Table 6 suggest that the regression coefficient of column (1) is not significant, while the regression coefficient of column (2) is significantly positive at the 5% level. The coefficient equality test reveals that the difference achieves statistical significance, with an empirical *p*-value of 0.098. The regression results show that in the region with great financial pressure, the PBB reform can more significantly motivate the enterprise EESG. This verifies Hypothesis 2. The possible reason for this is that government revenue is limited in financially stressed areas so that the government will more actively promote the reform of PBB, increase the efficiency of fiscal capital stock of spending, and allocate limited resources to areas more conducive to high-quality economic development, thus stimulating the enterprise EESG.

4.5.2 Heterogeneous impact on government audit in different localities

As the "immune system" of the national governance system, a government audit is an important tool for local governments to improve the efficiency of fiscal expenditure (Xu et al., 2020). Therefore, we investigate the impact of PBB reform on enterprise EESG from the perspective of a government audit and use the proportion of the fiscal expenditure that should be turned over to the current fiscal expenditure in the audit to indicate the local government audit. According to the median, two groups of high and low audit intensity are divided. The regression results in Table 6 suggest that the regression coefficient of column (3) is 0.0985, which is significant at 5%; and the regression coefficient of column (4) is 0.2094, which is positive at the significance level of 1%. The coefficient equality test reveals that the difference achieves statistical significance, with an empirical p-value of 0.038. The regression results show that in areas with high government audit intensity, PBB reform is more effective in promoting enterprise EESG. This verifies Hypothesis 2. The possible explanation is that the audit can play a more important role in governance in stronger strength of the government audit, and can more effectively supervise the use of unreal and non-compliant financial funds by the government. In addition, the audit can put forward the corresponding budget preparation, implementation, and other links of risk control suggestions. The quality of financial reports of the public sector can be improved, and the information asymmetry between taxpayers and the government can be reduced. Therefore, a government audit can strengthen the environmental governance effect of PBB reform and has a greater incentive effect on enterprise EESG.

4.5.3 Heterogeneous impact on enterprises with government procurement contracts

Dhaliwal et al. (2016) show that the concentration of corporate customers is positively associated with the cost of equity, while the concentration of government customers is negatively associated. Cohen and Li (2020) document that demand uncertainty decreases with the concentration of government customers but increases with the concentration of corporate customers. Cohen et al. (2022) find that government strictly monitors its corporate suppliers, and it can be a better monitor than a major corporate customer. Meanwhile, government procurement expenditure is an important part of budget expenditure. Therefore, we investigate the impact of PBB reform on enterprise EESG from the perspective of government procurement, and we group enterprises according to whether or not they have government procurement contracts. As can be seen from the regression results in Table 6, the regression coefficient of column (5) is 0.1101, positive and significant at 1%; the regression coefficient of column (6) is 0.4, positive and significant at 5%. The coefficient equality test reveals that the difference achieves statistical significance, with an empirical p-value of 0.058. The regression results show that for enterprises with government procurement contracts, the environmental governance effect of the PBB reform is stronger. Therefore, the empirical test results verify Hypothesis 3. The possible reasons for this are as follows: on the one hand, government customers can exert supervision effect and enhance the resources and motivation of enterprises to implement EESG, while on the other hand, government procurement funds are budgetary expenditures (i.e., the signing, execution, and settlement of government contracts will be directly affected by the PBB reform).

4.5.4 Heterogeneous impact on an enterprise's green innovation level

The level of green innovation represents the environmental governance ability of enterprises. We anticipate that the enterprises with strong green innovation ability pay more attention to environmental protection, and PBB has a greater incentive effect on their EESG. Therefore, we investigate the effect of the PBB reform on the enterprise EESG from the perspective of an enterprise's green innovation level. In accordance with the median, enterprises are divided into two groups of high and low green innovation, and green innovation is measured by green invention patent authorization. The regression results in Table 6 suggest that the regression coefficient of column (7) is 0.1107, which is significant at 1%; and the regression coefficient of column (8) is 0.2413, which is positive at the significance level of 5%. The coefficient equality test reveals that the difference achieves statistical significance, with an empirical p-value of 0.068. The regression results show that for enterprises with higher green innovation levels, the environmental governance effect of budget performance management reform is stronger. This confirms Hypothesis 3. The possible explanation for this is that enterprises with a high level of green innovation have higher investment intention for EESG and a stronger ability to achieve enterprise EESG, and the PBB reform has a more obvious incentive effect on enterprise EESG.

4.5.5 Heterogeneous impact on corporate financing constraints

The resource-based view believes that the heterogeneity of resources and capabilities can explain the performance differences between enterprises. The management will conduct a cost-income analysis of ESG investment (Cai et al., 2016). Enterprises implementing EESG investment will be restricted by financing constraints, and we expect that enterprises with lower financing constraints will have better EESG performance. Therefore, we further investigate the effect of the PBB reform on the enterprise EESG from the perspective of enterprise financing constraints. Based on Hadlock and Pierce (2010), the SA index is used to measure financing constraints. SA = 0.043*Size^2 − 0.040*Firmage − 0.737*Size, where Size is the enterprise size, measured by the logarithm of the total assets. Firmage indicates when the organization was established, indicating the time it has been operating. Enterprises are divided into two groups with high and low financing constraints in accordance with the median. As can be seen from the regression results in Table 6, the regression coefficient of column (9) is not significant, while the regression coefficient of column (10) is significantly positive at 1%. The coefficient equality test reveals that the difference achieves statistical significance, with an empirical p-value of 0.045. Regression results show that for enterprises with high financing constraints, the environmental governance effect of the PBB reform is stronger. This verifies Hypothesis 3. The possible reason for this is that PBB reform can reduce the local government's financial pressure; make more room for government subsidies, and tax and fee cuts; and reduce the financing constraints of the enterprise. For enterprises with more limited financial resources, government subsidies and tax and fee cuts will have a greater impact, and therefore these enterprises are more vulnerable to the effect of the PBB reform.

4.6 Mechanism analysis

Through this empirical test of the relationship between the PBB reform and the enterprise EESG, we find that the PBB reform can significantly optimize the enterprise EESG. However, the following question is raised: What is the mechanism of the PBB reform affecting enterprise EESG? We will conduct two tests to shed light on which underlying theoretical mechanism best explains our findings. The first is the compensation effect. The PBB reform reduces the information asymmetry between the taxpayer and the government, and between the financial department and the budget department. The allocation of budget resources is more efficient. The government is capable of implementing more environmental subsidies, reducing the cost of EESG implementation, and enhancing the performance of enterprise EESG. The second is the guiding effect. The performance-based budget management reform has increased regional financial transparency, reduced the regional corruption, optimized the business environment, reduced institutional transaction costs for enterprises, and saved funds for the enterprise EESG activities. The moderating effect model is built to accurately measure the mechanism, which is presented as follows:

$$\begin{aligned} EESG_{i,t} = \alpha + \beta_1 Revolution_{i,t} + \beta_2 Moderator_{i,t} \\ + \beta_3 Moderator\_Revolution_{i,t} + \gamma Control_{i,t} + \chi_i + \delta_t \\ + \epsilon_{i,t} \end{aligned} \tag{3}$$

TABLE 7 Mechanism analysis.

Model	(1)	(2)
Explained variable	EESG	EESG
Esubsidy_revolution	0.0071*** (0.0025)	
Revolution	0.0618* (0.0359)	
Esubsidy	0.0065*** (0.0020)	
Transparency_revolution		0.0453*** (0.0151)
Revolution		−0.0382 (0.0598)
Transparency		−0.0254** (0.0106)
Controls	Yes	Yes
Industry FE	Yes	Yes
Year FE	Yes	Yes
N	40,959	40,959
adj R^2	0.2660	0.2640

Notes: The standard errors are reported in parentheses. ***, **, and * denote significance at the 1, 5, and 10% level, respectively.

where $Moderator_{i,t}$ represents moderating factor and $Moderator\_Revolution_{i,t}$ represents interaction item between government PBB reform and moderating factor. When β_3 is positive, the positive effect of the PBB reform on the enterprise EESG increases with the increase of the moderator.

4.6.1 Compensation effect: PBB reform and an enterprise's environmental protection subsidies

Our proposed mechanism assumes that the environmental protection subsidy implemented by local governments provides resources for enterprises to invest in environmental protection and compensates their environmental protection costs. The data of environmental protection subsidy originate from the government subsidy data, which is manually sorted and obtained by the author. The results in Table 7 indicate that the regression coefficient of the interaction item is significant at 1%, which suggests that the positive effect of the PBB reform on the enterprise EESG increases with the increase of environmental subsidies. The empirical results suggest that environmental subsidy is the internal mechanism of budget performance reform to optimize the enterprise EESG.

4.6.2 Guiding effect: PBB reform and regional financial transparency

Our proposed mechanism assumes that the PBB reform has increased fiscal transparency, reduced regional corruption, optimized the business environment, and reduced institutional transaction costs for enterprises, thus guiding enterprises to implement more EESG. The data on financial transparency originate from the China Financial Transparency Report released by the Shanghai University of Finance and Economics, in which the weights of the respective item are presented as follows. The weight of the general public budget is 25%; government-managed funds account for 8% of the

TABLE 8 Economic consequence test.

Model	(1)	(1)	(1)
Explained variable	***ROA***	***FPB***	***Patent***
Revolution	0.0028*** (0.0005)	0.1656*** (0.0305)	0.1924*** (0.0197)
Controls	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
N	40,959	40,959	40,959
adj R^2	0.5640	0.1700	0.5930

Notes: The standard errors are reported in parentheses. ***, **, and * denote significance at the 1, 5, and 10% level, respectively.

budget; state capital operations account for 2% of the budget; social security funds account for 19% of the budget; 4% of the budget for special accounts; the weight of assets and liabilities of government departments accounts for 9%; the weight of the department's budget is 15%; state-owned enterprises account for 15%; and the weight of the respondents' attitude is 3%. The results in Table 7 indicate that the regression coefficient of the interaction item is significant at 1%, which suggests that the positive effect of the PBB reform on the enterprise EESG increases with the increase in fiscal transparency. The empirical results reveal that fiscal transparency is the internal mechanism of the PBB reform to promote enterprise EESG.

In summary, through the compensation effect, the increase in environmental subsidies caused by PBB reform would alleviate financing constraints faced by enterprises implementing EESG investment. Through the guide effect, PBB reform will promote transparency of local government, and will bring about a series of improvements in the business environment and the quality of public services, thereby reducing the institutional transaction costs of enterprises and guiding enterprises to increase EESG investment.

4.7 Additional analysis

In the preceding sections, this paper has shown that PBB has a positive impact on enterprise EESG. However, a question remains about whether there is an economic benefit arising from PBB pushing enterprises for greater EESG. In this section, we examine what economic consequences PBB brings to an enterprise. We postulate that an enterprise's improved EESG will enhance their brand and reputation effect, improve the consumer's satisfaction with their product quality and safety, increase the supplier's willingness to cooperate with them in the long term, and improve the investor's and creditor's confidence in their future performance. We learn from Dai et al. (2021), and we use the return on assets, price-to-book ratio, and the average value of total patent authorization of an enterprise in the next 3 years as indicators to measure the enterprise performance. Compared with the benchmark regression, the control variables of the economic consequences test deleted the control variables at the provincial level and kept the control variables at the enterprise level. As shown in Table 8, the regression results show that the regression coefficients are positive at the significant 1% level. Our findings demonstrate that PBB can further boost the future firm performance after improving firm EESG, which also implies that the implementation of ESG investment can improve firm performance. This is consistent with evidence found in prior research by Zhang and Lucey (2022), who found that ESG performance improves firm performance by alleviating financial constraints.

5 Conclusion and policy implications

The global economy is currently reviving but still faces many uncertain factors as the pandemic persists and geopolitical risks increase. The question of how to shape the behavior of local governments, stimulate the enterprise EESG, and promote high-quality economic development through the reform of the fiscal and taxation system is a topic worth in-depth discussion. Taking China's A-share listed companies from 2001 to 2020 as a sample, and based on quasi-natural experiments and using a multi-time difference in the difference model, this study empirically examines the effect of performance-based budgeting reform on the enterprise EESG, thus enriching the literature on the effect of macroeconomic policies on the behavior of micro-enterprises, and providing micro-evidence for the evaluation of the effectiveness under the performance-based budgeting management policy in the reform of China's fiscal and taxation system.

The main conclusions of this study are as follows. First, the performance-based budgeting management reform has significantly optimized the enterprise EESG. This conclusion is still true after using the following endogenous and robustness tests: the dynamic effect test, entropy matching method, difference-in-difference-in-difference method, placebo test, adjustment of measurement indicators, and so on. Second, the effect of the PBB reform on the enterprise EESG is more obvious in places with heavy financial pressure or strong government auditing. For enterprises with government contracts, strong green innovation capabilities, or high financing constraints, the environmental governance effect of the PBB reform is more obvious. Third, the result of the mechanism inspection indicates that the influence mechanism of this environmental governance role is that the PBB reform has improved environmental protection subsidies and improved financial transparency. Finally, through the economic consequences test, we find that the enterprise EESG can bring economic benefits to the enterprise, which is reflected in the improvement of the enterprise's return on assets, market net market rate, as well as total patent authorization.

The research conclusion of this study reveals that the reform of PBB can affect the government's behavior and economic development at the macro-level while penetrating the behavior of microeconomic subjects and stimulating the enterprise EESG. The suggestions are presented as follows. First, local governments at all levels should further improve performance-based budgeting management, enhance the transparency of budget performance information, optimize the linkage mechanism between budget performance evaluation results and budget arrangements, increase the efficiency of the utilization of budget funds, and channel resources to support the green and sustainable development of enterprises. Second, enterprises should bear environmental and social responsibility autonomously; integrate the concept of environmental protection from the selection, design, processing, packaging, after-sales service, and other links of products; and increase the green content of products to serve the green development strategy, thus contributing to the realization of the dual carbon goal for China.

We expand the factors at the government level for the research on corporate ESG. In future research, an in-depth study can be conducted at the government level, especially in countries or regions with economies in transition as the research background. In such countries or regions, the level of government intervention in the economy is higher. At the government level, we can attempt to explore the effect of government factors on corporate ESG in terms of industrial policy, fiscal policy, monetary policy, as well as tax policy.

Data availability statement

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

Author contributions

Conceptualization, SH; investigation, XW; visualization, SH; writing—original draft preparation, SH and XW; project administration, SH and XW; funding acquisition, SH and XW.

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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.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.982160/full#supplementary-material

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Modularity clustering of economic development and ESG attributes in prefabricated building research

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One major change in the modern construction industry worldwide in recent years is moving toward prefabricated buildings (offsite construction) to achieve sustainable development. Despite an increase in attention to ESG due to global stock markets' requirements and prefabricated buildings aid industries in achieving the ESG goal, few or even no research investigated the ESG attributes of the prefabricated buildings. Additionally, ESG subitems in different industries receive varying attention. Developed countries are primarily subject to ESG rules, but ESG laws in developing countries are at their infant stages. No study examined the effects of economic progress on prefabricated buildings' ESG attributes. The research gaps are filled by visualising and clustering the WoS and Scopus articles' keywords, themes, and authors' locations. This article also studied the evolution of this field. Based on the science map modularity cluster analysis, cost control is the most concerned issue in developed and developing countries. There are far more articles related to sustainability and environmental aspects of prefabricated buildings. Although the governance aspects of prefabricated buildings have not been thoroughly studied, inadequate governance increases bond yields. Therefore, future research on prefabricated buildings may expand to governance aspect to benefit industry and academia.

KEYWORDS

prefabricated building, science mapping, modularity cluster analysis, construction management, ESG, economic development

1 Introduction

The rapid development of urbanisation in developing countries, policy guidance, digital technology, and building information model (BIM) technology has fastened the development of prefabricated buildings in recent years (Abanda et al., 2017). Building construction has increased to almost 4 billion square meters annually since 2013, and it is anticipated that this rapid growth will continue for decades, with 33 billion more square meters added by 2040 and another 17 billion by 2060 (Abergel et al., 2017). The traditional methods of building design and construction are changed to prefabricated, which mainly depends on in-plant manufacturing and site assembly of building components (Chang et al., 2018). Due to its standardised architectural design, high-quality building part production, quick onsite building assembly, easy disassembly, and appropriate building reuse, the prefabricated building holds promise for the sustainable transformation of the construction sector (Chang et al., 2018).

Besides, the construction industry is always perceived as a traditional labour-intensive industry with high energy consumption, low efficiency, low digitalisation and industrialisation (Barbosa et al., 2017). Countries like the United States (Razkenari et al., 2020), Europe (Pan and Sidwell, 2011), and China have labour force shortages. Prefabricated or offsite buildings, semi-finished components made by offsite construction and combined onsite to form complete buildings (Jiang et al., 2019), can solve the abovementioned problems by reducing the use of materials, energy, and construction time (Razkenari et al., 2020), improving the construction environment and quality (Hanafi et al., 2018), and minimising the negative impact of traditional construction activities on the environment and society (Li et al., 2014). As the prefabricated building is part of the supply chain in buildings and infrastructures' production, its performance also affects a company's governance. Indeed, developing prefabricated buildings has important implications for construction industry companies' environmental, social and governance (ESG) performance.

Because of the high environmental and social awareness (especially in developed countries), customers expect businesses, including construction firms, to invest time and resources in sustainable practices. A focus on the impact of ESG disclosures on corporate financial performance has caused an overall increase in ESG disclosures and reporting globally. Disclosure of non-financial information is now required in many European nations. Other nations were inspired to adopt obligatory ESG disclosure policies for sustainable development by this change from voluntary to required disclosure. Disclosing non-financial information has become more popular worldwide in all industries for several reasons, including raising awareness, educating consumers, mitigating risks related to corporate performance, and achieving sustainability (Singhania and Saini, 2021).

While there is an increase in attention to ESG due to listed companies' requirements in many stock markets Worldwide, prefabricated buildings help industries achieve ESG, few studies or even no research investigated the ESG attributes of the prefabricated buildings per previous research. Furthermore, different levels of economic development pay extra attention to various ESG subitems in various industries; therefore, environmental performance, social performance, and financial performance are different (Wang et al., 2016). It is expected that the coverage of ESG and prefabricated building in different levels of economic development research may be higher in developed countries due to more financial resources for research and ESG regulations mainly covered by developed countries (Singhania and Saini, 2021). Nevertheless, no research investigates the impact of economic development on ESG coverage in prefabricated building research.

Bibliometric analysis is a widely used and rigorous technique for investigating and analysing many pieces of literature published worldwide. As quantitative research of bibliographic material (Merigó and Yang, 2017), bibliometric analysis enables the exploration of the subtleties of a particular field's evolutionary history while illuminating its emerging areas (Donthu et al., 2021). In bibliometric analysis, a knowledge map is a graph showing the many entities and concepts in the real world and their connections. This study utilised CiteSpace per previous research (Wang and Lu, 2020) to systematically explore the ESG attributes in the prefabricated building industry. It visualised the knowledge map of prefabricated buildings for ESG-relevant academic research with the aims to:

(1) Compare the research productivity of prefabricated buildings in developed and developing countries.
(2) Review the existing research in prefabricated buildings that threw light on the environment, social and governance (ESG), and suggest future academic research direction.

This research found that developed countries have far more prefabricated buildings research (except China), echoing the results of (Singhania and Saini, 2021). The findings of the environmental aspect of the prefabricated building are more than the social and governance aspect. In the following sections, Section 2 lists the literature review, Section 3 is the research method, Section 4 sheds light on the research results, Section 5 is the discussion, and Section 6 concludes the article.

2 Literature review

2.1 Prefabricated building

Jaillon and Poon (2009) defined prefabrication as a building that could be delivered in pieces and assembled or that needed to

TABLE 1 Research that reviewed prefabricated buildings (note: ESG were not included in all these studies).

Reviews	Research focuses that were different from this study
Li et al. (2014)	Review to obtain the five sub-research categories
Liu et al. (2021)	List the research, with more emphasis on engineering
Yu et al. (2021)	Technical overview of thermal and environmental Performance in China
Hosseini et al. (2018)	Scientometric evaluation is based on a meta-perspective.
Jin et al. (2018)	Review for identifying the latest research topics, performance of offsite construction projects
Wang et al. (2021a)	China's prefabricated building policies review
Zhang et al. (2021)	Building information model for prefabricated construction

be built entirely in a factory. Li et al. (2014) stated that prefabricated buildings refer to "various materials joined together to form a component of the final installation procedure". Navaratnam et al. (2019) emphasised modular volumetric units. Taylor (2010) listed most of the definitions for offsite construction before 2009. The most commonly cited definition is by Goodier and Gibb (2007), which described the process of manufacturing and preassembly of a certain number of building components, modules, and elements before their shipment and installation on construction sites. Hosseini et al. (2018) traced the early development process of "offsite construction" and did not distinguish between the two concepts in critical literature reviews. This study analysed prefabricated buildings (or offsite construction) by throwing light on ESG. While these two concepts sound different, we critically comment on the related review studies in prefabricated buildings or offsite construction in Table 1.

From Table 1, previous relevant critical comments focus on prefabricated building, rarely on its relationship to ESG, providing a new research gap.

2.2 Environmental, social, and governance and sustainable development of construction management

The sustainable business emphasises global and local environmental, community, societal, and economic responsibilities at the industry and corporate levels. The idea has been highlighted as a new way for a successful business. Approximately 2/3 of institutional investors anticipate that environmental, social, and governance (ESG) issues will become the industry standard (Managers, 2019). ESG refers to the "configuration of principles of environmental, social, and governance responsibility; processes of environmental, social, and governance responsiveness, and politics, programs, and observable outcomes as they relate to the firm's society relationships" (Velte, 2019).

Environmental governance is creating and implementing policies and procedures to protect the environment from damages caused by enterprises' activities and ongoing environmental performance monitoring. It is composed of a solution to carbon emission, resource depletion, climate change and ecosystem pollution (Patil et al., 2021). Businesses that use ESG put more emphasis on growing their marketing and profitability while giving the public's environmental concerns and the reduction of environmental consequences equal weight.

Social governance refers to the regulations and rules that business organisations adopt to improve relations with the stakeholders while ensuring the companies' prosperity, rights, wellbeing, employee and animal welfare, good community relation and protection of the interests of shareholders (Patil et al., 2021). How businesses are governed may be affected by institutional (business in society) and organisational (individual firm-level activities) nexus. Corporate governance could be described as "the creation of institutions that promote trust among stakeholders (including employees, consumers, suppliers, and communities).

All management and the board issue relevant to management, including agenda issues, board meetings, attendance, board diversity, and corruption, are all included in the governance factor (Sharma et al., 2020). Governance at the organisational level addresses the principal-agent problem that results from the separation of management and capital. Governance effectiveness aids in lowering sovereign bond yield spreads; nations that are more corrupt must pay higher yields when issuing bonds (Crifo et al., 2017).

Construction companies' environmental, social, and governance (ESG) elements are frequently assessed by aggregating project sustainability performance. The construction industry has been developing a future strategy for improving their ESG scores, emphasising ESG integration, despite controversies on ESG factors' practical impact on the organisation's performance or profits (Siew, 2017). However, stakeholders' needs for information on ESG management are not satisfied in the construction industry (Hadro et al., 2022). Evidence from Italy shows that the construction industry scored the highest ESG when it disaggregates the accrual and real earnings management proxies (Gavana et al., 2022). In construction management and operations, construction companies should emphasise collaborative ESG activities to gain favourable public business reputations, for example, lowering CO2 emissions and construction waste and improving safety and health (Butković et al., 2021). While there are quite a number of research on ESG, there is still a research gap that review the prior research about prefabricated building's contribution on ESG.

2.3 Developed countries and developing countries

Economists usually adopt United Nations' Human Development Index (HDI) to measure human development in a country. Any score of 0.80 or higher is classified as a developed country, and any lower is developing (Center, 2021). Developed countries are countries that are developed in terms of economy and industrialisation. Developed countries have better housing and living conditions and industrial, infrastructural, and technological advancements. One finance research found that existing empirical articles mainly focus on environmental factors when examining industrialised countries and on social or governance aspects only when analysing underdeveloped or rising nations (Crifo et al., 2017). It is sensible to speculate that there are different levels of studies on ESG attributes in the development of prefabricated buildings or offsite construction and most only study one aspect of ESG only. If most research comes from the developed countries, we speculate that most research focuses on environmental aspect only, similar to the abovementioned finance research.

3 Research methods

A systematic literature review provides an in-depth understanding of a research domain. The literature review process is listed in Figure 1. We adopted the bibliometric science map modularity cluster analysis approach for this research. Similar approach was adopted to study construction safety research (Zeng and Li, 2022) and tourism (Zeng et al., 2022). Pritchard (1969) pioneered the concept of bibliometrics. Historically, bibliometric research has mainly focused on intelligence, archives, and other fields. Big data bibliometric tools have become popular in various disciplines recently, assisting researchers in tracking and analysing research foci and development over time (Chen, 2014; Jie, 2016). CiteSpace knowledge visualisation software has become one of the most popular knowledge map-drawing tools. Chen (2006) explained its basic principles: "a picture is worth thousands of words, clear at a glance." It is considered a knowledge-map tool with a high level of information visualisation (Chen and Chen, 2003).

CiteSpace extracted titles, keywords, abstracts, and references of the articles and performed statistical and cluster analysis of all the information. We excluded the review article to avoid having a review label appear in the cluster analysis, which often overrides the display of other research information. It is an excellent tool for reviewing research in specific fields. While the Web of Science (WoS) covers the most important and influential academic research results worldwide (Hosseini et al., 2018), Scopus is the world's largest abstract and indexing academic database. Scopus and WoS are two central databases covering the best journals worldwide and complement each other as neither resource is all-inclusive (Burnham, 2006). Merging the two databases and removing the duplicates allowed us to include the best articles related to prefabricated buildings and offsite construction.

For papers published in the WoS and Scopus, we searched for subjects such as "offsite construction," "offsite construction," "prefabricated buildings," "prefabricated building," and "prefabrication building, "modular building" and "building industrialisation." All search terms are in double quotation marks. In the WoS core collection, we checked the boxes for articles, proceeding papers, and early access and obtained 275 terms. We checked the boxes for articles and conference papers in Scopus and got 794 items. We obtained 1069 records from the two databases. We cleaned the data and removed duplicates by using CiteSpace. We obtained 954 unique records and observed a significant increase in articles from 2000 onwards. From 2000 to 2020 (the search date is 28 October 2020), there were 855 prefabricated building articles, all shown in Table 2. As in most fields, the number of studies has increased yearly since 2015, 647 from 2015 to 2020. (CiteSpace identifies all data.)

In the result maps, we obtained two parameters, modularity and silhouette, according to Chen (2014) and Li and Chen (2016): The Modularity (Q) value is an evaluation index of network modularity. The higher the value, the better the clustering effect. The value range of Q is (0, 1); $Q > 0.3$ means that the structure of the network community is significant (Li and Chen, 2016). Silhouette (S) is a parameter used to assess clustering homogeneity; the closer the value is to 1, the higher the homogeneity; $S > 0.7$ has high reliability, and $S > 0.5$ can be considered good clustering (Li and Chen, 2016). In addition, the betweenness of centrality or centrality is an essential parameter. The node is crucial if the centrality value is more significant than 0.1. The higher the centrality value, the greater the node circle, and the article is critical in this field. On the science map, nodes represent keywords, articles, categories, countries, journals, authors, or other information. The larger the circle is, the more influential the node is. The

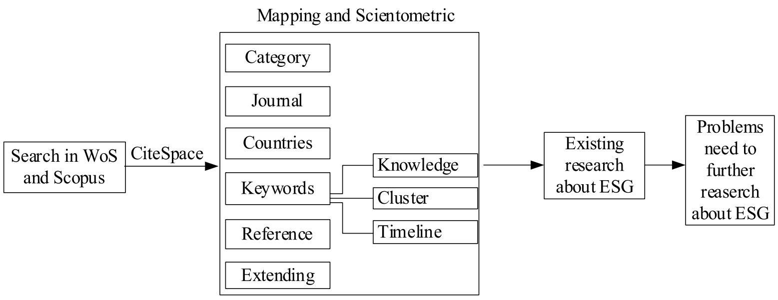

FIGURE 1
Description of the four-step process.

TABLE 2 Data sample source.

Items	Details
Database	Scopus, web of science core collection
Search type	Subject (including topic, abstract, keywords)
Search subject	offsite construction, prefabricated buildings, prefabricated buildings, offsite construction, prefabrication building, modular, building industrialisation
Category	article, proceedings paper, or conference paper
Search quantity	Scopus records:794 (articles: 444, conference papers: 354)
	WoS records: 275 (articles: 178, proceedings papers: 99, early access: 4)
Retained quantity	Scopus records: 681; WoS records: 273
Duplicated remove	95
Total unique records	954 (1963–2020)
Analysis unique records	855 (2000–2020) (articles: 760, proceedings paper: 95)

line indicates that there is a specific connection between these nodes.

4 Research results

4.1 Research category, journals and countries

Regarding the research results of knowledge mapping of research category analysis, this study found no results per WoS database for topic words such as "prefabricated building or offsite construction and ESG" (Figure 2). Most of the results concentrated on construction and building technology, engineering, environmental, Environmental sciences & ecology, and science and technology. Among the three areas of ESG, most focus on the environmental (E). For example, Green and sustainable science and technology, environmental sciences, energy and fuels, and environmental studies. Social (S) includes architecture, and urban studies, while G (governance) includes management.

Figure 3 is a knowledge mapping of journals, showing the prominent journals in this field, excluding the engineering technology journal. The *Journal of Cleaner Production* and *Building Environment* may be the most concerned the environmental or social studies, and the *Journal of Construction Engineering and Management* is most concerned with prefabricated buildings. Figure 4 shows that developed countries and regions, such as the United States, Australia, the United Kingdom, Canada, and Hong Kong, had more prefabricated research. China, Brazil, India, and Malaysia are developing countries with the most prefabricated research. Details about countries of top centrality are shown in Table 3.

4.2 Keywords analysis

4.2.1 Keywords knowledge mapping

In Figure 5, the keyword nodes "prefabricated building" and "offsite construction" display high centrality. Many

TABLE 3 Top centrality for countries of the research.

Count	Centrality	Year	Countries	Developing/Developed countries
251; 145	0.44; 0.05	2002	China; Peoples R China	Developing
51; 44	0.42; 0.17	2000	United States; United States	Developed
78	0.12	2008	Australia	Developed
54	0.09	2008	Canada	Developed
21; 57	0.09; 0.08	2003	England; United Kingdom	Developed
12	0.07	2004	Spain	Developed
6	0.07	2011	Serbia	Developed
32	0.06	2002	Italy	Developed
15	0.05	2009	South Korea	Developed
7	0.05	2002	Russian Federation	Developed
6	0.05	2002	Japan	Developed
24	0.04	2000	Poland	Developed
16	0.03	2002	Singapore	Developed
20	0.02	2012	Brazil	Developing
11	0.02	2004	Germany	Developed
10	0.02	2002	France	Developed
8	0.02	2003	India	Developing
3	0.02	2016	Taiwan (CN)	Developed
24	0.01	2010	Hong Kong (CN)	Developed
10	0.01	2006	Sweden	Developed

FIGURE 2
Knowledge mapping of research category analysis.

studies on engineering technology, such as "walls," "timber," "brick," and "thermal insulation" are relevant to management in the top 100 keywords, as shown in Table 4. Others include "supply chain," "residential building," "housing," and "productivity." We may consider these as the social aspect-related keywords. The environment aspect-related keywords include "carbon emission," "energy conservation," sustainable development, "life cycle assessment," and "building information model". There is a lack of governance-related studies.

4.2.2 Keywords clusters analysis

The keyword cluster mapping analysis is shown in Figure 6. In this cluster analysis, the modularity (Q) value is 0.677 > 0.3,

FIGURE 3
Journal analysis.

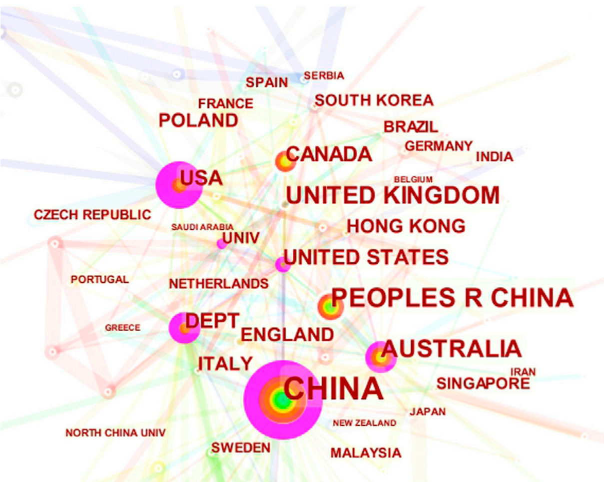

FIGURE 4
Study of countries analysis.

and the silhouette (S) value is 0.827 > 0.7. That means the cluster is significant. According to the results of this significant clustering, we can screen out the literature and main research topics that need to be reviewed. The top terms are calculated and listed in Table 5. The terms "prefabricated building" and "offsite construction" or similar keywords used for the retrieval were removed manually.

4.2.3 Evolution of the prefabricated building studies

This study reviewed articles from 2015 to 2020; the total number of articles was 647 for 2015–2020, accounting for 75.6% of the total volume of 855 from 2000 to 2020 (Figure 7). Most shed light on the technology. For management, "life cycle assessment" appeared in 2012, and "offsite construction" focused on the research of "model" and "design". In 2016, research on "prefabrication concrete" appeared. The concepts of "sustainability building industries" and "cost-benefit analysis" were proposed in several articles, and research on "developing" and "barriers in China" appeared almost simultaneously, cited more frequently as the "capital cost" in 2017. After 2018, research directions became more diverse, such as "preformation," "optimisation," "BIM," "environmental benefit," "influencing factor," "simulation," and "implementation." However, researchers have concentrated on other aspects of prefabricated buildings, such as "energy consumption," "carbon emission," "benefit evaluation," "policies," and "risk assessment" or "risk management" since 2019.

4.3 Reference analysis

The research source and evolution can be carried out through the analysis of reference information. The total number of terms cited by 855 papers is 18972, including some of their citations. According to the time evolution of the primary references (Figure 8), we can obtain the citation relationship and the evolution process of the research in this field. Pan, Gibb (2012) proposed strategies for building companies' management using offsite technology. Mao et al. (2013) compared greenhouse gas emissions between offsite prefabrication and conventional construction methods in two cases. Zhang et al. (2014) discussed the challenges faced by industrialised residential buildings in China.

The top co-cited reference is in Table 6, and we obtained the top topic in this field. Jaillon and Poon (2014) studied the life cycle design of prefabricated buildings in Hong Kong. Tam et al. (2015) studied prefabrication implementation in Hong Kong. Arashpour et al. (2015) discussed the optimisation of process integration and multi-skilled resource utilisation in offsite construction. For example, Mao et al. (2016) analysed the cost, and Kamali and Hewage (2017) studied the performance criteria for the sustainability evaluation of offsite construction. These are highly cited papers related to management.

4.4 Extending research

According to the expansion method (Chen et al., 2012), the first group papers (855) were cited by the second group papers. Then we analysed the second group of papers to find the trend of the first group and obtained a new research point. So, based on the 855 papers (first group), we got the citing papers in WoS and Scopus. By removing duplicates,

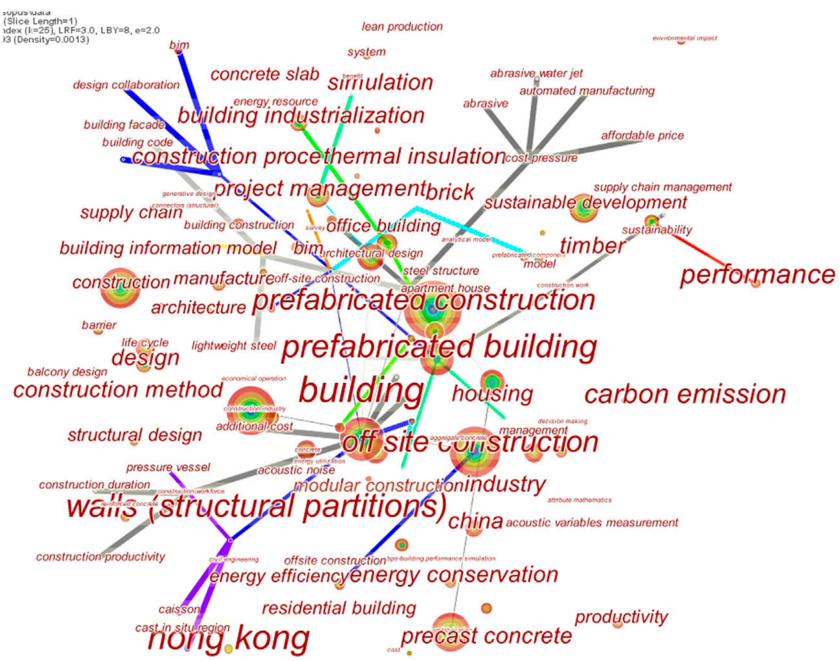

FIGURE 5
Knowledge mapping of keywords.

TABLE 4 Top centrality for keywords related to management.

Count	Centrality	Year	Keyword
76	0.05	2012	Sustainable development
25	0.04	2009	Supply chain
14	0.04	2013	Lean production
63	0.03	2009	Project management
26	0.03	2017	Barrier
34	0.02	2017	Life cycle
24	0.02	2014	Sustainability
23	0.02	2015	Building information model (BIM)
18	0.02	2015	Construction cost
16	0.01	2017	Life cycle assessment

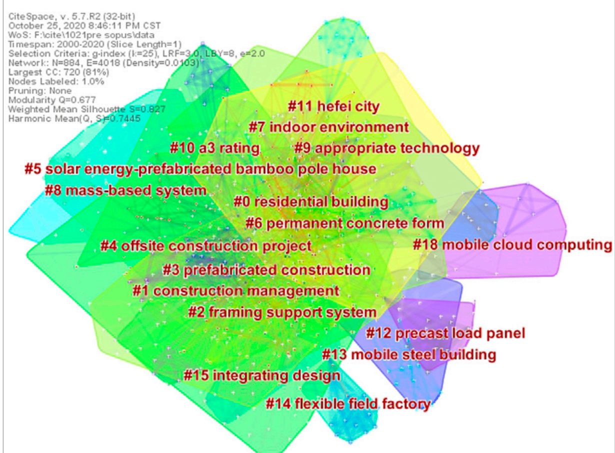

FIGURE 6
Keywords cluster mapping analysis.

3022 records (second group) were obtained. The second group paper reference analysis is shown in Figure 9. The modularity (Q) value was 0.8897 > 0.3, and the silhouette (S) value was 0.96 > 0.7. That means the cluster was extremely significant.

The nodes were the articles of the first group papers. According to the cluster analysis results, the label of cluster #4 in Figure 9 was "developing countries." That means developing countries, especially China, published so much research in the 2010s. Clusters #6 and #13 indicated that developed countries' extending research focused more on "carbon footprints" and "augmenting output."

Goodier and Gibb (2007) from the United Kingdom, Pan et al. (2007) from the United Kingdom, Tam et al. (2007) from Australia, Jaillon and Poon (2009) from Hong Kong, Blismas and Wakefield (2009) from Australia, Aye et al.

TABLE 5 Top term of Keywords cluster analysis.

ID	Silhouette	Mean (Year)	Top term
9	0.980	2019	Safety risk; multi-objective optimisation; considering risk correlation
3	0.708	2016	China; dynamics; building policies; engaging stakeholders; multi-skilled resources; simulation; attitudes; constraints; stakeholder; overcoming barrier; collaborative management
1	0.726	2016	Supply chain; information flow; materialisation stage; evaluation
8	0.909	2015	Case study; community; factors; china; cost; environmental performance; behaviour analysis; comprehensive benefit
19	0.860	2014	Residential prefabricated buildings; indoor environment; terms; optimisation; residential prefabricated building
5	0.891	2014	Case study; china; estimation; residential project
13	0.989	2013	Flexible field factory; construction industry
2	0.694	2013	Comparison; barriers; conventional methods; quality control

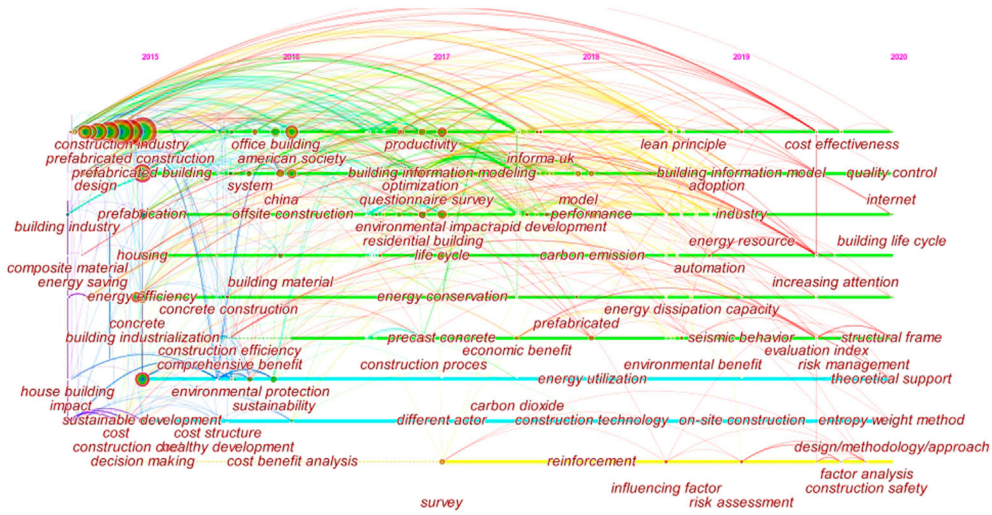

FIGURE 7
Keywords timeline analysis.

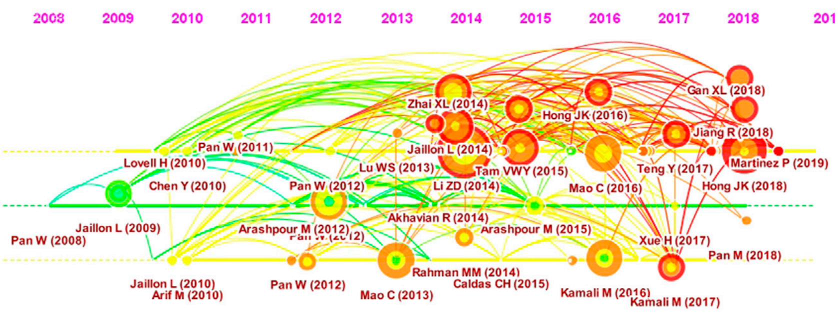

FIGURE 8
Cited references timeline analysis.

TABLE 6 Top 10 for the papers' reference co-cited analysis.

Count	Centrality	Cited references	Topic	Countries
23	0.02	Pan et al. (2012)	Strategies for integrating the use of offsite production technologies	United Kingdom
21	0.02	Mao et al. (2016)	Cost analysis for sustainable offsite construction based on a multiple-case study in China	China
13	0.02	Kamali and Hewage (2017)	Development of performance criteria for sustainability evaluation of modular versus conventional construction methods	Canada
11	0.02	Arashpour et al. (2015)	Optimisation of process integration and multi-skilled resource utilisation in offsite construction	Australia
23	0.01	Hong et al. (2018)	Barriers to promoting prefabricated construction in China: A cost–benefit analysis	China
18	0.01	Kamali and Hewage (2016)	Life cycle performance of modular buildings: A critical review	United Kingdom
17	0.01	Jaillon and Poon (2014)	Life cycle design and prefabrication in buildings: A review and case studies in Hong Kong	Hong Kong
16	0.01	Mao et al. (2015)	Comparative study of greenhouse gas emissions between offsite prefabrication and conventional construction methods: Two case studies of residential projects	China
14	0.01	Tam et al. (2015)	Best practice of prefabrication implementation in the Hong Kong public and private sectors	Hong Kong
11	0.01	Gan et al. (2018a)	Overcoming barriers to offsite construction through engaging stakeholders: A two-mode social network analysis	China

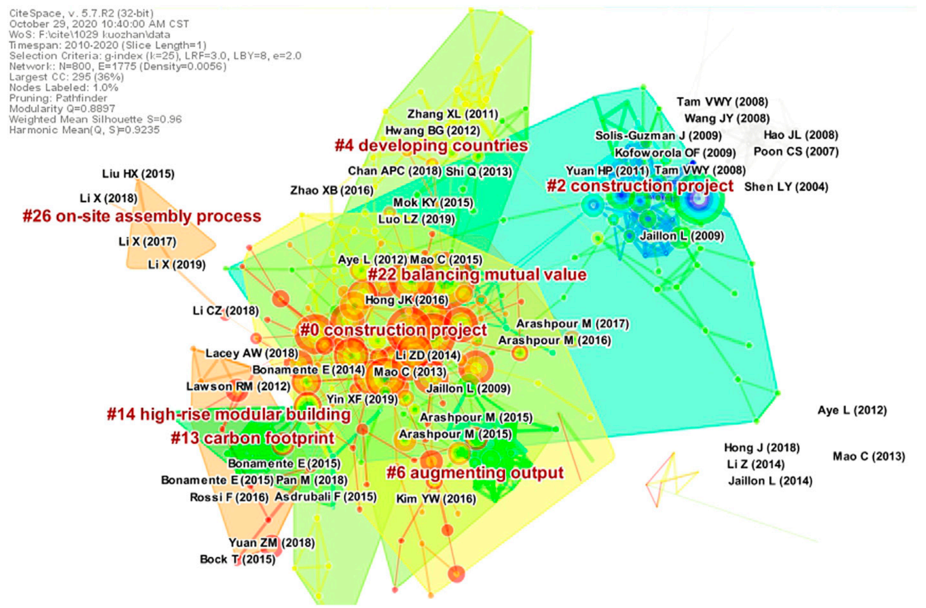

FIGURE 9
Co-cited of extending research cluster analysis.

(2012) from Australia, Mao et al. (2013) China, Li et al. (2014) China, Jaillon and Poon (2014) from Hong Kong, Mao et al. (2015) China, Hong et al. (2016) from China, and Arashpour et al. (2017) from Australia had high citations, implying that these studies received increased attention. That is to say, in developed countries and regions (Australia, Hong Kong), the research on offsite construction was conducted earlier, while developing countries (China) are rapidly promoting such buildings as a form of building in the 2010s.

5 Discussion

5.1 Environmental, social, and governance in prefabricated building industry

5.1.1 Environment

There is a high expectation of prefabricated buildings concerning sustainability. Most articles have mentioned this keyword, highlighting it in the literature analysis. Gallo et al. (2021) investigate the evaluation of sustainable parameters in Hong Kong. Arashpour et al. (2017) compared the environmental, economic, and social aspects of traditional site construction and preassembly life cycle sustainability. Wasim et al. (2020) studied industry management techniques that promote sustainable development. For "sustainability", most studies concern applications of sustainable technology, so the research on the product management features was not too much. Pham et al. (2020) also mentioned sustainable construction development in Vietnam. Wu et al. (2021a) summarised that the sustainability of prefabricated buildings or offsite construction must be combined with environmental, economic, social, and technological development.

5.1.2 Social

"Supply chain management" is a top topic of management research. Xue et al. (2018) revealed the stakeholders' collaborative management in the supply chain. Luo et al. (2020) analysed the problems and experiences of prefabricated building production, transportation, and supply chain management in Hong Kong. Arashpour et al. (2017) studied the theorised supply chain configurations in offsite construction. Liu et al. (2018) studied the establishment of the maturity model of the industrial supply chain relationship for prefabricated buildings. Wang et al. (2020) studied a blockchain-based framework for improving supply chain traceability and information sharing for a prefabricated building. Government guidance plays a significant role in the supply chain (Steinhardt and Manley, 2016; Jing et al., 2020; Wang et al., 2021a). The supply chain for prefabricated buildings is still developing; it is not a mature industrial chain in most countries, and collaborative stakeholder management goes a long way.

"Barriers" are the top centrality keyword related to management, a critical study topic. Prefabricated buildings are still concentrated in low-rise buildings (O'Neill and Organ, 2016), and the high cost is an obstacle to developing prefabricated buildings in the United Kingdom (Goodier et al., 2005). Mao et al. (2015) revealed that "government regulations and policies," "technological innovation," "industry supply chain," "cost," and "market demand" are the main obstacles to the development of prefabricated buildings in China. They continue to find the driving path of development in China (Mao et al., 2018). Yuan et al. (2020) studied the design process's obstacles to solving technical, economic, and management barriers. Liu et al. (2018) studied Chinese policies, knowledge, and standardisation barriers in China. Developers are not actively promoting prefabricated buildings (Wang et al., 2021b), and stakeholders play games (Zhang et al., 2020) (Wu et al., 2021b), even in the USA, where they also face those barriers (Razkenari et al., 2020). At present, the development of prefabricated buildings in developing countries still mainly relies on the government's strong push and needs the cooperation of stakeholders. Researchers in developing and developed countries still study how to overcome those barriers.

"Safety risk" is one main topic in 2019. In this cluster, Darko et al. (2020) found that technology application is the most critical factor in reducing construction risk in prefabricated buildings. Chang et al. (2020) studied the system to avoid the safety risks of prefabricated construction. Ahn et al. (2020) explained why offsite construction can help reduce safety risks on construction sites. Many researchers, as well as industry practitioners, believed that offsite construction methods are associated with a lower level of worker safety risks than traditional onsite construction methods. Zhao et al. (2020) analysed projects' impacts on environmental protection in China. He suggested that the degree to which benefits of offsite construction help reduce safety risks at construction sites needs future study in all countries.

5.1.3 Governance

Among the three elements in ESG, there is a lack of governance study linked to prefabricated buildings. Given the scale and complexity of contracts, competitive bidding procedures, the need to interact with both public and private players, and the need to prevent bribery, corruption, and anti-competitive behaviour, governance has long been a hot topic in the sector (Roberts, 2021). Nevertheless, it is pretty surprising that governance almost disappeared in literature. Prefabricated construction governance issues have not yet been properly investigated, yet bad governance in all businesses may raise bond yields. Future studies on prefabricated buildings may be applied to other academic fields, leading to real-world implications.

According to the keyword knowledge maps, cluster analysis maps, and timeline analysis maps, we obtained the primary top keywords and studied issues for prefabricated buildings, or offsite construction of their product management attributes to get the

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TABLE 7 The primary study of related topics in recent years.

Keywords	Count	D/L	Main literature
Sustainable/ Sustainability	123	41/36	Kamali and Hewage (2017) Canada; Hu, Chong et al. (2019) Australia; Wu, Luo et al. (2021a) China; Wasim, Han et al. (2020) Australia; Pham, Kim et al. (2020) Vietnam; Gallo, Romano et al. (2021) Italy
Supply chain	72	21/31	Luo, Shen et al. (2019) HK; Luo, Jin et al. (2020) HK; Arashpour, Bai et al. (2017) Australia; Liu, Su et al. (2018) China; Kim, Han et al. (2016) Canada; Masood, Lim et al. (2021) New Zealand; Lin, Lyu et al. (2021) Australia; Zhai, Fu et al. (2019) HK; Jing, Zhang et al. (2020) China
Barriers	93	30/42	O'Neill and Organ (2016) United Kingdom; Mao, Liu et al. (2018) China; Gan, Chang et al. (2018b) China; Gan, Chang et al. (2018a) China; Tan, Chen et al. (2019) China; Zhang, Pu et al. (2020) China; Zhang, Lee et al. (2018) HK; Razkenari, Fenner et al. (2020) United States; Luo, Xue et al. (2021) China; Wu, Qian et al. (2021b) China; Wang, Wang et al. (2021b) China; Sun, Wang et al. (2020) China
Life cycle assessment	84	19/21	Hao, Cheng et al. (2020) China; Bortolini, Formoso et al. (2019) Brazil; Minunno, O'Grady et al. (2018) Australia; Tumminia, Guarino et al. (2018) Italy
BIM	114	37/39	Tan, Chen et al. (2019) China; Abanda, Tah et al. (2017) United Kingdom
Cost	254	51/69	Hong, Shen et al. (2018) China; Xue, Zhang et al. (2017) China; Li, Shen et al. (2014) China; Nahmens and Bindroo (2011) United States; Said and Bartusiak (2018) United States; Bortolini, Formoso et al. (2019) Brazil; Hao, Cheng et al. (2020) China; Tavares, Gregory et al. (2021) EU; Wu, Qian et al. (2021b) China; Lou and Guo (2020) China
Safety risk	28	8/9	Darko et al. (2020) HK; Chang et al. (2020) China; Ahn et al. (2020) Australia; Zhao et al. (2020) China; Yuan et al. (2021) China

Note: D is the article count of developed countries; L is the article count of developing countries.

primary information about ESG. In Table 7, we summed up the total research in the core collection of WoS (all search terms are in double quotation marks, 2016.1.1–2021.12.31); the count referred to the article numbers; the country attributes of the paper were calculated according to WoS automatic classification, and the relevant country numbers were obtained. Some articles belong to more than one country, so the sum of developed and developing countries is greater than the count.

According to Table 7, we can see that in recent years, developed countries have been a bit more concerned about sustainability than developing countries, and both conducted more cost-benefit analyses that showed developed countries attach greater importance to the environmental and social benefits of ESG more than developing countries. Developing countries studied more about the barriers and supply chain than developed ones, which means more concern about governance. Most studied BIM technology did not focus on safety risks. We list the primary and latest research literature about management and discuss the details in Table 8.

5.2 Prefabricated buildings, building information model and costs saving

Though "BIM" is still in its infancy, it can combine building information model (BIM) with safety risk data to automatically evaluate construction safety concerns and aid architects in making speedy design decisions (Luo et al., 2022). BIM technology supports the development of prefabricated buildings, and to some degree, the development of prefabricated buildings is inseparable from BIM technical assistance (Yin et al., 2019; Akbarieh et al., 2020). BIM is currently critical in driving other innovative techniques and is being pushed by the government to improve building industrialisation (Abanda et al., 2017). However, whether BIM technology is the main factor restricting the development of prefabricated buildings still needs further research, and the quantitative benefits of BIM for prefabricated buildings need to be further studied. In "life cycle assessment" research, Bortolini et al. (2019) considered that building information model (BIM) could solve the complex problem of scheduling and reduce costs. BIM and digital technology are the ultimate solutions to the development of the construction industry (Akbarieh et al., 2020). Hammad et al. (2019) demonstrated prefabricated buildings' improved social, environmental, and economic benefits. Hao et al. (2020) studied the life cycle carbon emissions of prefabricated buildings with BIM. Therefore, BIM technology has always been associated with the life cycle assessment of prefabricated buildings and is an essential factor in the promotion of the development of prefabricated buildings. Yet, one of the previous research suggested that BIM is not economically feasible for usage in China's prefabricated buildings (Xu et al., 2019). A summary of the top research is shown in Table 8.

"Construction cost" is the top centrality keyword related to management. It is about governance. Based on the construction industry conditions in Japan and the United Kingdom, Barlow et al. (2003) concluded that information technology significantly reduces construction costs. Li et al. (2014) revealed strengthening construction management and problem-solving efficiency. Hong et al.

TABLE 8 Existing research and need for future research.

Topic	Existing research	Problems need to further research
ESG	Environment and social aspect of prefrabricated buildings	Governance of prefrabricated buildings
Sustainable/ Sustainability	1. Environment, economy, and society of prefabricated buildings; 2. Technological development	The sub research topics in environment, economy, and society
Supply chain	1. Model of the industrial supply chain 2. Not mature industrial chain in most countries; 3. Stakeholder relationship	1. Stakeholders' collaboration
Barriers	Technical, economic, and management	1. Qualitative or quantitative analysis of all barriers 2. How to overcome those barriers in all countries
BIM	BIM technology supports the development of prefabricated buildings	Quantitative benefits of BIM
Cost	The cost of prefabricated buildings is not lower than the traditional buildings	How to reduce the cost under different countries' situations
Safety risk	Lower safety risks than traditional onsite construction methods	The degree or quantitative benefits offsite construction help to reduce safety risks on sites

(2018) considered the benefits of prefabricated buildings, established a cost analysis framework, analysed the actual cases, and put forward countermeasures. Nahmens and Bindroo (2011) concluded that the existing system in the United States had not formed a large-scale business. Said and Bartusiak (2018) concluded that local businesses have certain advantages in the regional competition for industrialised housing in the United States. Currently, the costs of prefabricated buildings are not lower than those of traditional buildings, which have limited their large-scale business in both developed and developing countries. Whether the carbon emission of prefabricated buildings (concrete) is better than that of traditional buildings still needs to control the transportation distance parameter (Hao et al., 2020, Almashaqbeh and El-Rayes, 2021). Moreover, cost control remains a research focus, and how to reduce the cost still needs more research under different countries' situations.

6 Conclusion

ESG report has become one major requirement for many listed companies. Whether these companies comply with these requirements might affect the stock prices. While many listed construction companies operated their plants and made their prefabricated units and bibliometrics have been done in many research areas, bibliometrics study on prefabricated buildings' attributes of ESG is rare, not to mention systematic review on this area. This study fills the academic void and figures out prefabricated buildings and offsite research knowledge map and proposes further research about prefabricated buildings that achieve the goal of ESG. Besides, while developed countries are more concerned with the environmental aspect than developing countries, there were substantially less research on the governance aspect. The results might have managerial implications that we may research on the means to motivate the prefabricated industry to work more on the governance aspect of ESG.

Prefabricated building is not mature in the construction supply chain in most countries, especially developing countries and is dependent on government policies and collaborative stakeholder management. As most of these developing countries have immature legal and management systems, more studies about governance in prefabricated buildings are needed. A similar rationale is needed for the safety aspects of prefabricated units. While technical, economic, and management barriers might be related to ESG, a lack of comprehensive study implies that there is room for improvement. Developing a future strategy for ESG rating improvements and integrating ESG in prefabricated buildings may be one of the future directions that academia has not yet studied, but worth to do so in the future to enhance industry awareness in this area where the financial sector has already taken action long ago.

This research also has practical implications. Given the current listed companies' requirements in ESG reporting in the financial sector, this study suggests the construction industries to enhance governance aspects that could benefit industry practitioners who might list their companies in the stock market. A similar idea holds for academia. The current review is limited to the selected literature sample published in WoS and Scopus, and only English journal articles were included. It might have excluded some of the latest studies published in other languages. As one of our research indicated that local language research might allow us to see other angles in housing price research (Li et al., Forthcoming 2022), similar research might be conducted to study prefabricated buildings.

Detailed focus groups and surveys may be taken to see the professionals' perspectives on ESG and prefabricated buildings in the future. So that we may also know more about practitioners' extrinsic and intrinsic motivations in ESG and prefabricated buildings knowledge sharing (Li and Poon, 2011).

Author contributions

RL: Conceptual idea, write, review and edit the manuscript. BL: Conceived and designed the study, completed the paper in English. XZ: Conceived and designed the study, revised the important intellectual content. JZ: Gave valuable research advice and revised the manuscript. RP: Provided a comprehensive English revision. LS: Part of literature review, proof and editing.

Conflict of interest

Author Bo Li is/was employed by Jinke Property Group Co., Ltd.

The remaining 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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Regional Response of Low Carbon Investments to the COVID-19 Pandemic: The Case of Stock Markets in Seeking Carbon Neutrality Goals

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Low carbon investments are significant in climate change and sustainable economic growth. The research considers the impact of the COVID-19 pandemic on low carbon investments using environmental, social, and governance (ESG) factors in different regions to find the correlation between various markets and the impact of the pandemic. Our research employs the method of covariance/correlation analysis to investigate the relationship between low carbon investments in different regions. We also check the main parameters of descriptive statistics. We use the method of bivariate regression analysis to assess the impact of the COVID-19 pandemic on the performance of ESG stock indices in Emerging, European, and Global markets. The main findings reveal that the global prevalence and mortality risk of COVID-19 infection have a significant adverse effect on the performance of Emerging, European, and Global ESG stock markets. In contrast, the effect of COVID-19 cases reported deaths caused by COVID-19 infection to appear to be mixed. Our research shows that the correlation between the European ESG stock market and other ESG markets is exceptionally low or negative in the 1-year horizon. In contrast, tendencies in other markets are similar. So it means that the European ESG stock market is a good tool for diversification and risk mitigation during critical moments. Our results can be used in practice for portfolio management purposes. Institutional and other investors can use these results for low carbon portfolio management and risk mitigation.

Keywords: ESG, stock market, climate change, COVID-19, sustainable and responsible investments (SRI)

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INTRODUCTION

The COVID-19 pandemic can be named a black swan event that stifled the global economy. Unexpectedly emerged, COVID-19 resulted in complete social isolation within different countries and negatively influenced everyday life and business (resulting in employment and industry-wide shutdowns), causing many more adverse economic effects. The coronavirus pandemic and quarantine measures dramatically shocked the global economy with the deepest production slump since World War II. All scenarios of Covid's impact, which is modeled by experts, on the economy are pessimistic. The pandemic claimed many human and economic sacrifices, in the total sense of the word: a high number of deaths lost jobs and employees, closed businesses, and collapsing economies. Macrofinancial measures designed to support a sustainable economy, applied too late or inappropriately, can increase social inequality and income imbalances. In some countries, exceptionally high public dissatisfaction is caused by the tightening of the second wave of COVID-19: There is more than just social discontent and racial unrest (Harris and Missy, 2020).

The current pandemic is a real test for the world economy and institutions of regulation of the global economy. Lots of researchers (e.g., McKibbin and Fernando, 2020; Bouey, 2020; Levine, 2020; Bakas and Triantafyllou, 2020; De Grauwe, 2020; Beck, 2020; Zandi, 2020; Abiad et al., 2020, Ramelli and Wagner, 2020; Lee, 2020) analyze and find the impact of the COVID-19 pandemic on the economy and other spheres. For example, some authors (Jordà et al., 2020) compare the COVID-19 pandemic issues with other crises. Studies that analyze the possible economic consequences of COVID-19 for world trade, economies of individual countries (Bouey, 2020), and separate sectors of the economy have appeared in a brief time (Levine, 2020).

Increased financial markets' volatility reflected difficulties in estimating the extent of the economic damage and predicting the situation's development, and the downturn's consequences could be felt over many years. COVID-19 shock could be compared to the 2007–2008 Great Financial Crisis. Despite its impact caused to financial markets, no doubt being evident and significant. This recent phenomenon should be researched in more detail.

Despite high volatility in stock markets and a big economic shock due to the COVID-19 pandemic, the importance of climate change and sustainable economic growth cannot be forgotten. Climate change now is a topic that must be discussed a lot because it significantly affects people's broad economy, community, and lives. Every day we can hear lots of announcements about natural disasters leading to losses. About half of the losses are insured. However, most of the losses are taken by others. Climate change is a significant risk that must be managed. The growing trend of catastrophic events forces us to be involved in this process and lowers the negative effect of climate change. Climate change plays a crucial role in our lives and strongly impacts economics. Climate change becomes a source of financial risk, and exposure to this type increases every day as the number of catastrophic events grows every minute. Financial institutions must take active action in risk management by adding value to the activities that lower climate risk. Central banks play an especially crucial role in the financial system; therefore, these institutions should take responsibility for climate risk mitigation. All the mentioned financial institutions.

Some authors analyze sustainability and environmental, social, and corporate governance (ESG) factors issues related with a business level and focus on the effects to company value and financial results (Egorova et al., 2022; Saygili et al., 2022; Engelhardt et al., 2021; Abdi et al., 2020; Badía et al., 2020; Bhaskaran et al., 2020; Buallay, 2020; Cordazzo et al., 2020; Drempetic et al., 2020; Garcia and Orsato, 2020; Hoang et al., 2020; Jamprasert et al., 2020; Li and Wu, 2020; Modugu, 2020; Oehmke and Opp, 2020; Oprean-Stan et al., 2020; Peng and Isa, 2020; Rajesh and Rajendran, 2020; Sabatini, 2020; Sadiq et al., 2020; Schumacher et al., 2020; Sharma et al., 2020; Sichigea et al., 2020; Tampakoudis and Anagnostopoulou, 2020; Tommaso and Thornton, 2020; Veenstra and Ellemers, 2020; Widyawati, 2020; Larcker and Watts, 2020; Mukanjari and Sterner, 2020; Palma-Ruiz et al., 2020; Pasquini, 2020), while others try to investigate the risks, benefits, and challenges related with investments in financial instruments, especially stock and bond markets (Aw et al., 2020; Amanjot, 2020; Andrew, 2020; Ardia et al., 2020; Cunha et al., 2020; Dorfleitner et al., 2020; Engle et al., 2020; Fiskerstrand et al., 2020; Garefalakis and Dimitras, 2020; Glossner et al., 2020; Gougler and Utz, 2020; Hübel and Scholz, 2020; Jens, 2020; Kaiser, 2020; Kocmanová et al., 2020; Krueger et al., 2020; Meher et al., 2020; Mercereau et al., 2020; Mercedes, 2020; Mirchandani and Rossetti, 2020; Ng and Rezaee, 2020; Rehman and Vo, 2020; Rui et al., 2020; Siri and Zhu, 2020; Vostrikova and Meshkova, 2020; Yongjun and Yupu, 2020; Zaghum et al., 2020; Ziolo et al., 2020; Khajenouri and Schmidt, 2021; Adams and Abhayawansa, 2022). Our research contributes to those scientific works related to investments, but we add more value to COVID-19 pandemic analysis and find regional stock market responses. We think that this study will help to take investment decisions having in mind regional aspects as we try to show the correlation between different markets in the COVID-19 pandemic.

Empirical studies are more focused on the country level. Studies related to China and US financial markets are oriented to investigate movements in the Shanghai Stock Exchange and New York Stock Exchange. These results make it possible to conclude the existing positive and robust relationship between fluctuations in analyzed financial markets and the number of confirmed COVID-19 cases (Sansa, 2020).

This study fills the gap in the research on the regional level. It gives a broad view of ESG investments, including Emerging Markets, Europe, and Global markets, as it is essential for institutional investors in COVID-19. Our research problem is whether low-carbon investments' performance varies among different regions? Lately, lots of low carbon investment options have been launched, and these investments demonstrate excellent performance compared to traditional investments. Financial institutions and retail investors can use different funds to achieve their maximum goals of seeking carbon neutrality.

This research will help institutional investors such as pension funds, central banks, and other financial institutions mitigate market risk using regional factors. Institutional investors usually do not take a company-level risk and implement investment strategies using more diversified instruments. So focusing on low or negative correlation markets, institutional investors will be able to manage market risk in a sustainable and responsible stock market.

The relevance and popularity of sustainable and responsible investments get more popular every day. Everyone must add value to lower climate risk because human emissions of carbon dioxide and other greenhouse gases can be considered the key driver of climate change. Numbers show that global temperatures have risen sharply over the last few decades, and the main concern is how to solve the problem not to increase climate risk in the future. The relevance of this topic increased a lot during the pandemic period. Lots of financial institutions started to add value to climate risk management. Central banks started to work on this issue more actively, implementing socially responsible investments into their strategies. Still, at the same time, financial institutions faced significant issues in managing market risk and portfolio diversification challenges and how to implement new investments into the existing investment portfolio.

Financial institutions must take an active role in stopping climate change. Sustainable and responsible investments play a crucial role in adding value for taking efforts to decrease climate risk worldwide. Lots of financial intermediaries take part in risk management.

Different authors have analyzed if sustainable and responsible investments can generate higher profitability compared to investments not having sustainability and responsibility factors. But despite the mentioned facts, sustainable investments are getting more popular day by day. Analyzing investments, we usually have a return, which can be achieved by taking a risk position. Yue et al. (2020) found no unmistakable evidence confirming that sustainable funds can generate higher returns than traditional piers or benchmark indexes. Let's consider participation in climate risk management and adding value to climate change. We cannot think only about profit factors and can just pay more attention to social factors. Lewis and Juravle (2010) pointed out that sustainable investments got popularity because of "the profitability of investments, company scandals, globalization, geophysical and environmental changes, changes in public opinion, political climate." Kurtz (2020) found that "approximately 50% of assets under management (AUM) in Europe, Canada, and Australia were managed under a responsible investment policy." The numbers increase every day. Due to reputational risk management, SRI investments attracted more attention from institutional investors. Urwin et al. (2009) pointed out that "sustainable investment can help pension funds and other financial institutions use a more effective portfolio management style."

McKibbin and Fernando's (2020) research is one of the earliest systematic studies of the potential economic cost of COVID-19. The authors explored scenarios of the impact of a pandemic on the macroeconomic and financial markets. They suggested that even a controlled short-term outbreak significantly impacts the global economy. The result of the COVID-19 pandemic is previously unknown intense mixed and negative shock of supply and demand, harming production. As it is argued by De Grauwe (2020), double-shocks will lead to multiple "domino effects." Companies with high fixed costs face bankruptcy, wherefore banks lending to these companies will also experience severe problems and difficulties, which makes a banking crisis possible. Abiad et al. (2020) show the main channels of influence of COVID-19: a temporary decline in domestic consumption and investment, shrinkage of the tourism, manufacturing, and trade sectors, supply overruns, health consequences, and changed expenditures on health care.

A direct sign of the economic impact of the pandemic is a loss of trust from consumers and investors. Rational anticipation of future COVID-19 cases and the associated impact on the economy and society are among the most reasonable arguments for this rapid and sharp market decline. Ramelli and Wagner (2020), using a sector-level decomposition of stock price moves, argue that markets initially focused on the trade impact of the pandemic, also suggesting concerns about supply chains. Having analyzed the first impact of COVID-19 sentiment on the US stock market, Lee (2020) notes that the impact of COVID-19 varies depending on the industry. Mamaysky (2020) argues that the information environment played a first-order role in markets' crisis response—the crucial influence of innumerable headlines in mass media results in adverse investors' expectations. Considering that in February and March 2020, reliable data on the real coronavirus pandemic's economic impact were not available, speculations "about future disastrous economic consequences and associated negative impacts on corporate profitability" (Mamaysky, 2020) significantly affected investors' sentiment. Recent research concerns the impact of this pandemic on the global financial sector. It claims that adverse effects of tax capacity in the financial system will not occur at once. Therefore, there is time to make justified decisions (Beck, 2020; Zandi, 2020). However, side effects in the markets are sudden. As a result, it is necessary to focus on potential financial system disruptions and combine confidence in financial markets.

As this topic is among the most discussed topics nowadays, it is exciting to analyze how sustainable and responsible investments were affected by the COVID-19 pandemic. We think that all the scientists agree that the COVID-19 pandemic strongly influences the economy, but what about the stock market when we see new highs in some regions and what about sustainable and responsible investments. There are scientific works analyzing the impact of COVID-19 on the stock market in broad (e.g., Lööf et al., 2022; Lee, 2020; Albulescu, 2020a; Albulescu, 2020b; Ashraf, 2020; Al-Awadhi et al., 2020; Bloom et al., 2005; Demers et al., 2020; Ding et al., 2020; Dottling and Kim, 2020; Kapecki et al., 2020; Zhang et al., 2020, Zaremba et al., 2020; Czech et al., 2020, and Akhtaruzzaman et al., 2022), but there is a lack of scientific discussions relating to the impact on sustainable investments in the field of the stock market in different regions. Lately, we can find some more research made on ESG investments and COVID pandemic in specific countries. Jun et al. (2022) analyzed China market, and Takahashi and Yamada (2021) focused on Japanese stock market. Korean stock market using social responsible factors was analyzed by Lee et al. (2022). Pisani and Russo (2021) made a research on ESG funds having MSCI Europe index as a benchmark.

The primary purpose of this research is to find if the COVID-19 pandemic impacted sustainable and responsible investments and if there were any differences in different regions, including Emerging Markets, Europe, and Global markets.

We add value to the scientific literature by analyzing the impact of the COVID-19 pandemic impact on sustainable and responsible investments in different regions. Our results showed lots of differences between ESG investments in Emerging, European, and Global ESG stock markets during the COVID-19 pandemic and that the best choice for the highest diversification effect is the European ESG stock market.

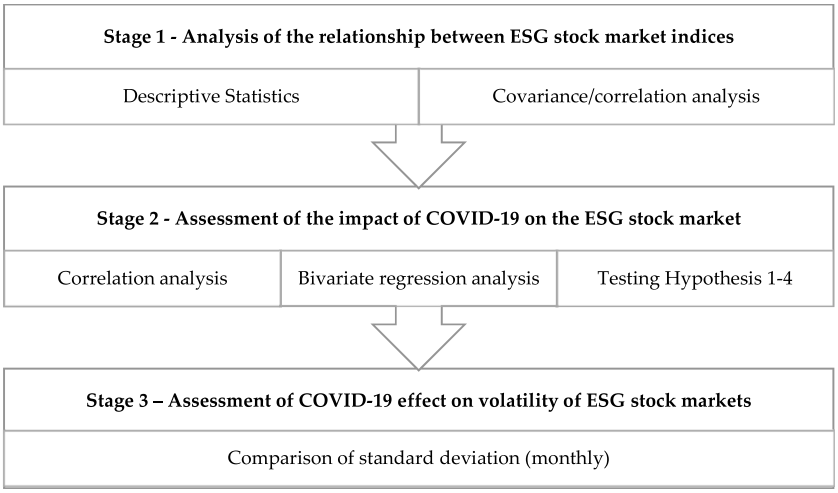

FIGURE 1 | Research design.

Hence, our research expanded the list of critical literature about sustainable and responsible investments valuing the impact of the COVID-19 pandemic and considering the factor of different regions.

This article consists of three parts. Firstly, we reviewed different scientific works to find what has been done till now. Secondly, we presented methodological issues. Our methodology calculates descriptive statistics parameters, applies covariance/correlation analysis, and uses bivariate regression analysis. Finally, we discussed our results using stock market indices in different regions. Our main results show that the European ESG stock market is a good tool for diversification and risk mitigation during critical moments. Our results can be used in practice for portfolio management purposes. Institutional and other investors can use these results for SRI portfolio management and risk mitigation.

RESEARCH FRAMEWORK

Main Variables and Development of Hypotheses

This research consists of three stages: 1) analysis of the relationship between selected ESG stock market indices, 2) analysis of the impact of COVID-19 on the ESG stock market, and 3) assessment of COVID-19 effect on the volatility of ESG stock markets, which will be discussed in detail. The research design is summarized in **Figure 1**.

For the empirical analysis, we used daily data of four stock market indices: S&P Emerging LargeMidCap E.S.G. Index, S&P Global 1200 ESG Index, S&P Europe 350 ESG Index, and S&P Global LargeMidCap E.S.G. Index. The choice of indices is because: 1) they are broad-based indices measuring the performance of securities from the underlying index that meet the sustainability criteria (S&P Dow Jones Indexes, 2020); 2) the choice of indices allows to analyze ESG investments in different regions, that is, Emerging, Europe, and Global markets. We used different periods to measure descriptive statistics parameters together with correlation and covariance between indices. We have chosen the other period to find the impact of COVID-19 on ESG stock market indices.

The sample covers the period from January 2020 to September 2020.

Data of stock market indices are retrieved from Reuters. In contrast, COVID-19-related data such as confirmed cases of infection, confirmed deaths, countries affected, case fatality rates, etc., are collected from World Health Organisation Coronavirus disease (COVID-19) situation reports (WHO, 2020) and the website of the European Centre for Disease Prevention and Control (ECDC, 2020).

To find the impact of COVID-19 on ESG stock market indices, four dependent and twenty independent (COVID-19 related) variables are collected (**Table 1**), the choice of which is based on the analysis of scientific literature and criteria of data availability.

In addition, for a more detailed assessment of ESG stock markets' reaction to the spread of COVID-19 infection, all the above variables (except the number of countries affected) are analyzed from four geographical perspectives: 1) China, 2) Europe, 3) the rest of the world excluding China, and 4) global perspective.

First, this research intends to investigate whether the geographical spread of COVID-19 infection affects ESG stock markets. As a significant number of researches showed negative (at least primary) response of the financial markets to the spread of the COVID-19 pandemic [e.g., Ashraf (2020); Al-Awadhi et al. (2020); Zhang et al. (2020); Czech et al. (2020); Albulescu (2020a); Zaremba et al. (2020) and others], our research intended to check in the direction of the reaction of ESG stock markets was the same (null and alternative hypotheses are described in **Supplementary Appendix SA3**). Based on the results of the literature analysis, the first hypothesis of this research is formulated as follows:

TABLE 1 | Variables of a regression model, abbreviations, and description.

Variable		Description
Abbreviation	**Full name**	
Dependent variables	—	—
SPELMUPt	S&P Emerging LargeMidCap ESG Index USD	SPELMUPt is a composite index of S&P Europe Emerging, Latin-America Emerging, Mid-East, and Africa Emerging, Asia Pacific Emerging LargeMidCap E.S.G. subindices for a period t
SPEESUPt	S&P Europe 350 ESG Index USD	SPEESUPt is an index consisting of 350 leading ESG companies from developed European markets for a period t
SPGESUPt	S&P Global 1200 ESG Index USD	SPGESUPt is an index consisting of 1222 ESG companies from 7 distinct regions and 30 countries for a period t
SPLESGUPt	S&P Global LargeMidCap ESG Index USD	SPLESGUPt is a composite index of S&P Europe Developed, Mid-East and Africa Developed, Asia Pacific Developed, Europe Emerging, Latin America Emerging, Mid-East, and Africa Emerging, Asia Pacific Emerging LargeMidCap E.S.G. subindices for a period t
Independent variables	—	—
CAt	Countries affected	CAt is measured by several countries that have confirmed coronavirus cases for a period t
NCwt	New cases world	NCwt is measured by the number of new cases of coronavirus reported in a world since the previous day for a period t (a number of cases per day)
TCwt	Total cases world	TCwt is measured by the number of total cases of coronavirus reported in a world for a period t (a cumulative number of cases)
NDwt	New deaths world	NDwt is measured by the number of new deaths caused by coronavirus reported in a world since the previous day for a period t (a number of deaths per day)
TDwt	Total deaths world	TDwt is measured by the number of total deaths caused by coronavirus reported in a world for a period t (a cumulative number of deaths)
FRwt	Case fatality rate world	FRwt is measured by a ratio between confirmed deaths and confirmed cases in a world for a period t (percent)
NCct	New cases China	NCct is measured by the number of new cases of coronavirus reported in China since the previous day for a period t (a number of cases per day)
TCct	Total cases China	TCct is measured by the number of total cases of coronavirus reported in China for a period t (a cumulative number of cases)
NDct	New deaths China	TDct is measured by the number of total deaths caused by coronavirus reported in China for a period t (a cumulative number of deaths)
TDct	Total deaths China	TDct is measured by the number of total deaths caused by coronavirus reported in China for a period t (a cumulative number of deaths)
FRct	Case fatality rate China	FRct is measured by a ratio between confirmed deaths and confirmed cases in China for a period t (percent)
NCect	New cases excl. China	NCect is measured by a number of new cases of coronavirus reported in a world excluding China since the previous day for a period t (a number of cases per day)
TCect	Total cases excl. China	TCect is measured by the number of total cases of coronavirus reported in a world excluding China for a period t (a cumulative number of cases)
NDect	New deaths excl. China	TDect is measured by the number of total deaths caused by coronavirus reported in a world excluding China for a period t (a cumulative number of deaths)
TDect	Total deaths excl. China	TDect is measured by the number of total deaths caused by coronavirus reported in a world excluding China for a period t (a cumulative number of deaths)
NCet	New cases Europe	NCet is measured by the number of new cases of coronavirus reported in Europe since the previous day for a period t (a number of cases per day)
TCet	Total cases Europe	TCet is measured by the number of total cases of coronavirus reported in Europe for a period t (a cumulative number of cases)
NDet	New deaths Europe	TDet is measured by the number of total deaths caused by coronavirus reported in Europe for a period t (a cumulative number of deaths)
TDet	Total deaths Europe	TDet is measured by the number of total deaths caused by coronavirus reported in Europe for a period t (a cumulative number of deaths)
FRet	Case fatality rate Europe	FRet is measured by a ratio between confirmed deaths and confirmed cases in Europe for a period t (percent)

Source: Compiled by the authors.

Hypothesis 1: The global prevalence of COVID-19 infection has a significant negative effect on the performance of the ESG stock market indices.

To assess the geographical spread of COVID-19 infection, some researchers (e.g., Albulescu, 2020a) use the number of countries affected by COVID-19, that is, the number of countries that have reported at least one case on a given day. Therefore, to evaluate the global prevalence of COVID-19 infection, the number of countries with confirmed infection cases (CAt) is used.

Secondly, in our research, we sought to determine whether and how the ESG stock markets are responding to the increase in the number of confirmed COVID-19 cases and deaths.

Thus, the second and third hypotheses are formulated as follows:

Hypothesis 2: The number of cases of COVID-19 confirmed has a significant adverse effect on the performance of the ESG stock market indices.

Hypothesis 3: The number of deaths caused by COVID-19 reported has a significant adverse effect on the performance of the ESG stock market indices.

It is important to note that researchers select different measures to estimate the growth of COVID-19 infections and deaths. For instance, Ashraf (2020), Al-Awadhi et al. (2020), Zhang et al. (2020), and Czech et al. (2020) have used the number of total cases and total deaths, while Albulescu (2020a) and Zaremba et al. (2020) have used the measure of new cases and new deaths reported. We are given in mind that the market can react differently to the change of daily numbers and cumulative numbers; in our research, we decided to use both approaches.

Therefore, in this research, the measures of the number of new cases of COVID-19 reported per day, and the total number of COVID-19 cases confirmed in China, Europe, the rest of the world excluding China, and globally (NCc_t, NCe_t, $NCec_t$, NCw_t; and TCc_t, TCe_t $TCec_t$, TCw_t, respectively); and the measures of the number of new deaths caused by COVID-19 reported per day, and the total number of deaths caused by COVID-19 reported in China, Europe, the rest of the world excluding China, and globally (NDc_t, NDe_t, $NDec_t$, NDw_t; and TDc_t, TDe_t $TDec_t$, TDw_t, respectively) are used.

Finally, it was essential to find whether the changes in COVID-19 mortality risk affect the performance of ESG stock markets, which is why the fourth hypothesis of our research is formulated as follows:

Hypothesis 4: Mortality risk of COVID-19 infection has a significant negative effect on the performance of the ESG stock market indices.

To estimate the actual mortality rate, we need to know the number of actual (not reported) closed cases and the number of related deaths. As these estimates are unknown due to the asymptomatic manifestation of COVID-19 and many unclosed cases, we decided to analyze the current data, that is, reported cases and deaths, as suggested by researchers (Albulescu, 2020a; Ritchie and Roser, 2020). Taking this into account, to evaluate the mortality risk, the measure of COVID-19 case fatality rate is used in this research and measured as a ratio between confirmed deaths and confirmed cases in China (FRc_t), in Europe (FRe_t), and globally (FRw_t).

These variables are further analyzed using the methods of descriptive statistics, correlation, and regression analysis. To support or reject research hypotheses, the method of bivariate regression analysis and the estimates of t statistics and p-values of the created models were used. For this purpose, the significance level (α) is set to 0.05 (5%).

Descriptive Statistics

In our research, we tried to find the volatility of different indices. For volatility calculation, we used standard deviation. The formula of standard deviation is shown below:

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(r_i - \bar{r})^2}, \tag{1}$$

In **Eq. (1)** r_i denotes returns in every period, and n denotes the total number of periods in a year.

Different scientific works confirm that fund returns, compared with the returns of other securities, do not have normal distributions. Jondeau, E. et al. stressed that “asset returns do not behave according to the bell-shaped curve, associated with the Gaussian or normal distribution.” This creates risks of “higher moments.”

Further in our research, we used skewness and kurtosis measures to find tail risk. As explained in the literature, skewness can be described as the degree of distortion from the symmetrical normal distribution, while kurtosis can be found as a tool for heavy-tailed or light-tailed distribution identification.

Skewness is defined as

$$S = \frac{1}{n}\frac{\sum_{i=1}^{n}(r_i - \bar{r})^3}{\sigma^3} \tag{2}$$

Kurtosis is defined as

$$E_k = \frac{1}{n}\frac{\sum_{i=1}^{n}(r_i - \bar{r})^4}{\sigma^4} - 3 \tag{3}$$

In **Eqs (2)**, **(3)**, r_i points the return in a period i, $\bar{r}$ denotes the mean, and n denotes the number of days in a year, while σ denotes the standard deviation of returns.

To show the main characteristics of descriptive statistics and to check data distribution, we use data from 2 September 2019, till 1 October 2020. The period was selected quite short just to look at broad tendencies as the main goal of this research was to concentrate on time related to the COVID-19 pandemic.

Looking at the correlation matrix (**Table 3**), we can see a strong positive correlation between ESG investments in Emerging markets and ESG investments in Global markets (indices: S&P Emerging LargeMidCap E.S.G. Index, S&P Global 1200 ESG Index, S&P Europe 350 ESG Index, S&P Global LargeMidCap E.S.G. Index). Nevertheless, the most interesting fact in the correlation matrix is that we have a negative correlation between the European ESG investments and Emerging markets ESG investments. Also, we would like to pay attention to the fact that the correlation between the European ESG market and Global markets is positive but exceptionally low. Therefore, we can conclude that the European ESG market might be suitable for SRI portfolio management diversification purposes.

Data in **Figure 2** show that the European ESG market is a bit different in the period we are analyzing as the index standing for this market does not have outliers, and we see that the median is equal to the mean of the distribution, which shows that the data have a normal distribution shape and skewness and confirm normal distribution as its level is incredibly low (see **Table 2**).

TABLE 2 | Descriptive statistics.

	S&P emerging large MidCap ESG index	S&P Europe 350 ESG index	S&P global 1200 ESG index	S&P global large MidCap ESG index
Mean	84.41735	737,501.0	182.9283	171.2355
Median	86.74550	737,501.0	186.0699	174.5551
Maximum	95.63470	737,698.0	205.9576	192.2467
Minimum	62.79030	737,303.0	133.7536	124.8159
Std. Dev	7.190898	115.6798	14.00505	13.30299
Skewness	–0.850651	–0.014086	–1.037183	–1.057011
Kurtosis	2.960240	1.785621	3.881289	3.831042
Jarque-Bera	33.66613	17.15280	59.05109	59.98172
Probability	0.000000	0.000189	0.000000	0.000000
Sum	23,552.44	2.06E+08	51,036.98	47,774.72
Sum Sq. Dev.	14,375.11	3,720,147	54,527.29	49,197.53
Observations	279	279	279	279

TABLE 3 | Covariance and correlation.

Covariance	S&P emerging large MidCap ESG index	S&P Europe 350 ESG index	S&P global 1200 ESG index	S&P global large MidCap ESG index
S&P emerging large MidCap ESG index	51.52368	—	—	—
S&P Europe 350 ESG index	−134.7783	13,333.86	—	—
S&P global 1200 ESG index	91.75227	195.2416	195.4383	—
S&P global large MidCap ESG index	90.11551	130.6399	182.0577	176.3352
Correlation	S&P emerging large MidCap ESG index	S&P Europe 350 ESG index	S&P Global 1200 ESG index	S&P global large MidCap ESG index
S&P emerging large MidCap ESG index	1.000000	—	—	—
S&P Europe 350 ESG index	–0.162607	1.000000	—	—
S&P global 1200 ESG Index	0.914342	0.120945	1.000000	—
S&P global large MidCap ESG Index	0.945424	0.085198	0.980696	1.000000

Regression Model Specification

The second step of analysis is to assess the impact of COVD-19 on ESG stock market indices. Firstly, correlation analysis is conducted. Secondly, bivariate linear regression models (least squares), examining the changes of dependent variables (ESG stock market indices) as the functions of each independent (COVID-19 related) variable, are constructed (**Eq. (4)**).

$$I_n = \alpha + \beta IndVar_k + \varepsilon \tag{4}$$

In this model, α corresponds to constant, n = 1 to 4 and corresponds to ESG market indices, k = 1 to 20 and corresponds to independent (COVID-19 related) variables (see **Table 1**), and ε corresponds to error. Thus, for each of the four selected ESG stock market indices, 20 bivariate linear regression models are constructed.

The descriptive statistics of dependent and independent variables are provided in **Table 4**. The dynamics of those variables are depicted in **Supplementary Appendix SA1**.

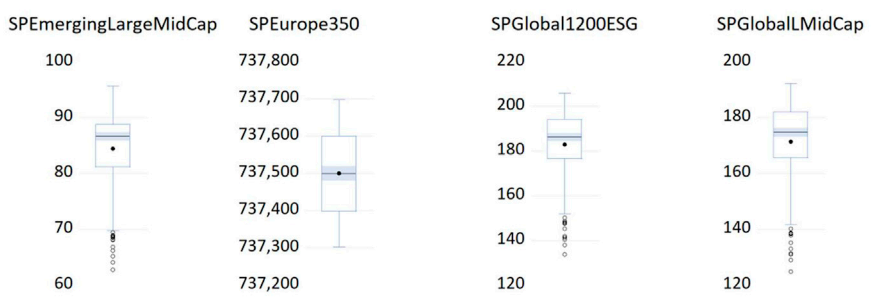

FIGURE 2 | Dynamics of ESG indices, data source Bloomberg.

TABLE 4 | Summary of descriptive statistics of model variables.

Variable	Observations	Minimum	Maximum	Mean	Median	Standard deviation
SPELMUPt	198	62.7903	95.6347	83.2953	86.1895	8.0426
SPEESUPt	195	85.2927	132.7510	115.4575	117.9002	11.8091
SPGESUPt	197	133.7536	205.9506	182.7190	187.5191	16.3329
SPLESGUPt	198	124.8159	192.2467	170.8402	175.3357	15.4752
CAt	198	1.0000	215.0000	160.6313	210.0000	82.1481
NCwt	198	0.0000	321,140.0	12,141.1	90,000.00	105,355.0
TCwt	198	27.0000	340,444,333	8,944,402	4,545,000	10,274,637
NDwt	198	0.0000	10,489.00	3679.833	4159.500	2665.414
TDwt	198	0.0000	1,015,224	354,499.8	308,248.0	335,196.1
FRwt	182	1.2500	7.300	4.4150	3.9700	1.5497
NCct	198	0.0000	15,141.00	347.5354	33.0000	1285.267
TCct	198	27.0000	90,528.000	72,332.46	84,041.50	28,807.95
NDct	198	0.0000	1290.0000	18.8333	0.0000	96.2430
TDct	198	0.0000	4739.000	3548.919	4637.500	1659.394
FRct	182	1.2800	5.5400	4.6846	5.3000	1.1179
NCect	198	0.0000	321,125.0	120,793.6	89,996.00	105,685.6
TCect	198	0.0000	33,953,905	8,872,070	4,460,959	10,260,909
NDect	198	0.0000	104,890.00	3661.000	4158.000	2670.543
TDect	198	0.0000	1,010,485	350,950.8	303,610.5	334,020.2
NCet	198	0.0000	75,797.00	18,730.80	16,284.00	16,094.05
TCet	198	0.0000	5,055,085	1,655,091	1,652,220	1,464,157
NDet	198	0.0000	5028.000	807.2525	377.5000	1101.183
TDet	198	0.0000	222,920.0	115,963.1	160,159.0	88,700.95
FRet	158	1.6700	10.3400	7.0153	7.2500	2.2269

*Note: SPELMUPt, S&P Emerging LargeMidCap ESG, Index USD; SPEESUPt, S&P Europe 350 ESG, Index USD; SPGESUPt, S&P Global 1200 ESG, Index USD; SPLESGUPt, S&P Global LargeMidCap ESG, Index USD; CAt, countries affected; NCwt, new cases world; TCwt, total cases world; NDwt, new deaths world; TDwt, total deaths world; FRwt, case fatality rate world; NCct, new cases China; TCct, total cases China; NDct, new deaths China; TDct, total deaths China; FRct, case fatality rate China; NCect, new cases excl. China; TCect, total cases excl. China; NDect, new deaths excl. China; TDect, total deaths excl. China; NCet, new cases Europe; TCet, total cases Europe; NDet, new deaths Europe; TDet, total deaths Europe; FRet, case fatality rate Europe (see **Table 1**).*

Analysis of the dynamics of COVID-19 related variables and ESG stock market indices reveals that the strongest adverse reaction of ESG stock market indices to COVID-19 is seen in March 2020–April 2020, while in the following periods investigated, such reaction is no longer clearly expressed (see **Supplementary Appendix SA1**). For this reason, a more detailed analysis is needed, the results of which are presented in the next section.

RESULTS AND DISCUSSION

Correlation Between COVID-19 and the Performance of ESG Stocks

To access the effect of COVID-19 on the performance of securities meeting ESG criteria (measured by four ESG stock market indices) during the selected timeframe (01/01/2020–30/09/2020); period t = 1 . . . 198), at the first step, the correlation analysis of selected variables is conducted (see **Table 5**).

Based on the results of **Table 5** (correlation coefficients and probabilities), it can be said that:

1) Only three COVID-19-related variables [number of countries affected (*CAt*), number of new deaths confirmed per day in China (*NDct*), and number of new cases confirmed per day in Europe (*NCet*)] are not statistically related to the performance of Emerging and European ESG stock markets (S&P Emerging LargeMidCap E.S.G. and S&P Europe 350 ESG indices) (proved to be insignificant), while even 17 variables are statistically significant (99% or 95% confidence level) related to the performance of Emerging and European ESG stock markets, 14 of them directly and only 3 (fatality rate in world (*FRwt*), number of new deaths confirmed per day in Europe (*NDet*) and fatality rate in Europe (*FRet*)) inversely;
2) Only two COVID-19-related variables (number of new deaths per day and total deaths in China (*NDct* and *NCct,* respectively) are not statistically related to the performance of global ESG stock markets (S&P Global 1200 ESG and S&P Global LargeMidCap E.S.G. indices), while 18 variables are statistically significant related to global indices, 15 of them directly, while only 3 (fatality rate in world (*FRwt*), number of new deaths confirmed per day in Europe (*NDet*) and fatality rate in Europe (*FRet*)) inversely.

As we can see, the results of correlation analysis revealed an inverse relationship between the performance of Emerging, Europe, and Global ESG stock markets and: 1) the number of deaths caused by COVID-19 infection in Europe, and 2) COVID-19 mortality risk in Europe and globally.

To get a clearer view of COVID-19 effect on the performance of Emerging, European, and Global ESG stock markets, the regression analysis is further performed. To assess the impact

TABLE 5 | Correlation of selected financial market indices and COVID-19 related variables.

Variable	Correlation	Probability	Correlation	Probability	Correlation	Probability	Correlation	Probability
–	SPELMUPt		SPEESUPt		SPGESUPt		SPLESGUPt	
CA_t	0.0136	0.8652[a]	0.0044	0.9561[a]	0.1811	0.0228[b]	0.1706	0.0321[b]
NCw_t	0.7139	0.0000[c]	0.6598	0.0000[c]	0.7737	0.0000[c]	0.7734	0.0000[c]
TCw_t	0.7287	0.0000[c]	0.6695	0.0000[c]	0.7879	0.0000[c]	0.7897	0.0000[c]
NDw_t	0.1745	0.0283[b]	0.1766	0.0265[b]	0.3064	0.0001[c]	0.2969	0.0002[c]
TDw_t	0.7445	0.0000[c]	0.6978	0.0000[c]	0.8255	0.0000[c]	0.8252	0.0000[c]
FRw_t	–0.6492	0.0000[c]	–0.5722	0.0000[c]	–0.5230	0.0000[c]	–0.5361	0.0000[c]
NCc_t	0.2151	0.0066[c]	0.2465	0.0018[c]	0.0949	0.2354[a]	0.1002	0.2105[a]
TCc_t	0.5865	0.0000[c]	0.5320	0.0000[c]	0.6959	0.0000[c]	0.6928	0.0000[c]
NDc_t	–0.0555	0.4885[a]	–0.0455	0.5715[a]	–0.0556	0.4875[a]	–0.0575	0.4733[a]
TDc_t	0.3945	0.0000[c]	0.3853	0.0000[c]	0.5462	0.0000[c]	0.5375	0.0000[c]
FRc_t	0.3006	0.0001[c]	0.3070	0.0001[c]	0.4518	0.0000[c]	0.4419	0.0000[c]
$NCec_t$	0.7136	0.0000[c]	0.6594	0.0000[c]	0.7734	0.0000[c]	0.7731	0.0000[c]
$TCec_t$	0.7288	0.0000[c]	0.6695	0.0000[c]	0.7879	0.0000[c]	0.7897	0.0000[c]
$NDec_t$	0.1774	0.0283[b]	0.1789	0.0245[b]	0.3095	0.0001[c]	0.3000	0.0001[c]
$TDec_t$	0.7449	0.0000[c]	0.6581	0.0000[c]	0.8257	0.0000[c]	0.8252	0.0000[c]
NCe_t	0.1249	0.1148[a]	0.0974	0.2233[a]	0.2380	0.0026[c]	0.2369	0.0027[c]
TCe_t	0.6867	0.0000[c]	0.6475	0.0000[c]	0.7849	0.0000[c]	0.7837	0.0000[c]
NDe_t	–0.6696	0.0000[c]	–0.6271	0.0000[c]	–0.5911	0.0000[c]	–0.5991	0.0000[c]
TDe_t	0.6026	0.0000[c]	0.5913	0.0000[c]	0.7342	0.0000[c]	0.7281	0.0000[c]
FRe_t	–0.3660	0.0000[c]	–0.3071	0.0001[c]	–0.2056	0.0095[c]	–0.2205	0.0054[c]

[a] *Insignificant.*
[b] *95% c.l.*
[c] *99% c.l.,*

*Note: SPELMUPt, S&P Emerging LargeMidCap ESG Index USD; SPEESUPt, S&P Europe 350 ESG Index USD; SPGESUPt, S&P Global 1200 ESG Index USD; SPLESGUPt, S&P Global LargeMidCap ESG Index USD; CAt, countries affected; NCwt, new cases world; TCwt, total cases world; NDwt, new deaths world; TDwt, total deaths world; FRwt, case fatality rate world; NCct, new cases China; TCct, total cases China; NDct, new deaths China; TDct, total deaths China; FRct, case fatality rate China; NCect, new cases excl. China; TCect, total cases excl. China; NDect, new deaths excl. China; TDect, total deaths excl. China; NCet, new cases Europe; TCet, total cases Europe; NDet, new deaths Europe; TDet, total deaths Europe; FRet, case fatality rate Europe (see **Table 1**). Model Const. = model constant; Coef. = coefficient; p-Stat = p-Statistics; Observ. = observations.*

TABLE 6 | Bivariate regression models for COVID-19 effect on S&P Emerging LargeMidCap E.S.G. Index.

Variable	Model Const.	Coef	t-stat	*p*-value	R	Observ.
CA_t	91.2446	–0.0495	–8.2016	0.0000[a]	0.2555	198
NCw_t	81.7591	1.27 e-05	2.3585	0.0193[b]	0.0276	198
TCw_t	81.2259	2.31 e-07	4.3316	0.0000[a]	0.0874	198
NDw_t	86.4701	–0.0009	–4.1773	0.0000[a]	0.0818	198
TDw_t	81.3799	5.40 e-06	3.2357	0.0014[a]	0.0507	198
FRw_t	98.5307	–3.6181	–14.3058	0.0000[a]	0.5320	182
NCc_t	82.7832	0.0015	3.3920	0.0008[a]	0.0554	198
TCc_t	93.2176	–0.0001	–7.8981	0.0000[a]	0.2414	198
NDc_t	83.2809	0.0008	0.1284	0.8980[b]	0.0001	198
TDc_t	90.3555	–0.0019	–6.3018	0.0000[a]	0.1685	198
FRc_t	90.1806	–1.6274	–3.2681	0.0013[a]	0.0560	182
$NCec_t$	81.7994	1.24 e-05	2.3092	0.0220[b]	0.0265	198
$TCec_t$	81.2276	2.33 e-07	4.3601	0.0000[a]	0.0884	198
$NDec_t$	86.4453	–0.0009	–4.1438	0.0000[a]	0.0816	198
$TDec_t$	81.3686	5.49 e-06	3.2786	0.0012[a]	0.0519	198
NCe_t	85.6060	–0.0001	–3.5665	0.0005[a]	0.0609	198
TCe_t	81.9187	8.23 e-07	2.1445	0.0332[b]	0.0229	198
NDe_t	87.5062	–0.0052	–14.2822	0.0000[a]	0.5099	198
TDe_t	83.1499	1.25 e-06	0.1936	0.8467[b]	0.0002	198
FRe_t	89.5366	–1.1946	-–4.9127	0.1339[b]	0.0000	158

[a] *99% c. l.,*
[b] *95% c. l.*
[c] *Insignificant.*

*Note: SPELMUPt, S&P Emerging LargeMidCap ESG, Index USD; CAt, countries affected; NCwt, new cases world; TCwt, total cases world; NDwt, new deaths world; TDwt, total deaths world; FRwt, case fatality rate world; NCct, new cases China; TCct, total cases China; NDct, new deaths China; TDct, total deaths China; FRct, case fatality rate China; NCect, new cases excl. China; TCect, total cases excl. China; NDect, new deaths excl. China; TDect, total deaths excl. China; NCet, new cases Europe; TCet, total cases Europe; NDet, new deaths Europe; TDet, total deaths Europe; FRet, case fatality rate Europe (see **Table 1**). Model Const., model constant; Coef., coefficient; t-Stat, t-Statistics; Observ. = observations.*

TABLE 7 | Bivariate regression models for COVID-19 effect on S&P Europe 350 ESG Index.

Variable	Model Const.	Coef.	t-stat	*p*-value	R	Observ.
CA_t	128.3832	−0.0803	−9.3058	0.0000[a]	0.3097	195
NCw_t	114.4615	8.07 e-06	1.0059	0.3157[c]	0.0052	195
TCw_t	113.4129	2.26 e-07	2.7892	0.0058[a]	0.0387	195
NDw_t	120.6616	−0.0014	−4.6748	0.0000[a]	0.1017	195
TDw_t	113.7956	4.63 e-06	1.8458	0.0665[c]	0.0173	195
FRw_t	136.7965	−5.0956	−12.9571	0.0000[a]	0.4826	182
NCc_t	114.5033	0.0027	4.3235	0.0000[a]	0.0883	195
TCc_t	131.5891	−0.0002	−8.8448	0.0000[a]	0.2884	195
NDc_t	115.3737	0.0044	0.5001	0.6176[c]	0.0013	195
TDc_t	127.5030	−0.0034	−7.4434	0.0000[a]	0.2229	195
FRc_t	129.3069	−3.2036	−4.4536	0.0000[a]	0.0993	182
$NCec_t$	114.5299	7.61 e-06	0.9519	0.3423[c]	0.0047	195
$TCec_t$	113.4085	2.28 e-07	2.8149	0.0054[a]	0.0294	195
$NDec_t$	120.6357	−0.0014	-4.6860	0.0000[a]	0.1022	195
$TDec_t$	113.7714	4.75 e-06	1.8857	0.0681[c]	0.0181	182
NCe_t	119.5136	−0.0002	−4.3005	0.0000[a]	0.0874	195
TCe_t	114.5786	5.26 e-07	0.9096	0.3642[c]	0.0043	195
NDe_t	121.3638	−0.0076	−12.8395	0.0000[a]	0.4607	195
TDe_t	116.2049	−7.24 e-06	-0.7586	0.4490[c]	0.0029	195
FRe_t	121.6335	−1.3963	−4.0304	0.0001[a]	0.0943	158

[a]*99% c. l.,*
[b]*95% c. l.*
[c]*Insignificant.*
Note: SPEESUPt, S&P Europe 350 ESG, Index USD; CAt, countries affected; NCwt, new cases world; TCwt, total cases world; NDwt, new deaths world; TDwt, total deaths world; FRwt, case fatality rate world; NCct, new cases China; TCct, total cases China; NDct, new deaths China; TDct, total deaths China; FRct, case fatality rate China; NCect, new cases excl. China; TCect, total cases excl. China; NDect, new deaths excl. China; TDect, total deaths excl. China; NCet, new cases Europe; TCet, total cases Europe; NDet, new deaths Europe; TDet, total deaths Europe; FRet, case fatality rate Europe (see ***Table 1****). Model Const. = model constant; Coef. = coefficient; t-Stat = t-Statistics; Observ., observations.*

TABLE 8 | Bivariate regression models for COVID-19 effect on S&P Global 1200 ESG Index.

Variable	Model Const	Coef.	t-stat	*p*-value	R	Observ
CA_t	192.1835	−0.0586	−4.2754	0.0000[a]	0.0857	197
NCw_t	176.0338	5.49 e-05	5.2835	0.0000[a]	0.1252	197
TCw_t	175.9874	7.49 e-07	7.4629	0.0000[a]	0.2222	197
NDw_t	184.5678	−0.0005	−1.1403	0.2556[c]	0.0066	197
TDw_t	175.2941	2.08 e-05	6.6043	0.0000[a]	0.1828	197
FRw_t	210.3695	−6.4263	−10.1788	0.0000[a]	0.3653	182
NCc_t	181.7608	0.0003	3.0951	0.0023[a]	0.0468	197
TCc_t	195.3807	−0.0002	−4.4396	0.0000[a]	0.0918	197
NDc_t	182.6925	0.0014	0.1154	0.9082[c]	0.0001	197
TDc_t	189.5525	−0.0019	−2.7445	0.0066[a]	0.0372	197
FRc_t	186.8723	−1.0406	−0.9495	0.3436[c]	0.0049	182
$NCec_t$	176.1447	5.42 e-05	5.2195	0.0000[a]	0.1226	197
$TCec_t$	176.0124	7.52 e-07	7.4927	0.0000[a]	0.2235	197
$NDec_t$	184.5578	−0.0005	−1.1422	0.2548[c]	0.0066	197
$TDec_t$	175.3008	2.10 e-05	6.6505	0.0000[a]	0.1849	197
NCe_t	183.9785	−6.69 e-05	-0.9217	0.3578[c]	0.0043	197
TCe_t	175.9469	4.07 e-06	5.4691	0.0000[a]	0.1329	197
NDe_t	190.5438	−0.0009	−11.9727	0.0000[a]	0.4237	197
TDe_t	177.3897	4.5 e-05	3.5727	0.0004[a]	0.0614	197
FRe_t	190.2500	−1.5148	−2.6242	0.0095[a]	0.0423	158

[a]*99% c. l.,*
[b]*95% c. l.*
[c]*Insignificant.*
Note: SPGESUPt, S&P Global 1200 ESG, Index USD; CAt, countries affected; NCwt, new cases world; TCwt, total cases world; NDwt, new deaths world; TDwt, total deaths world; FRwt, case fatality rate world; NCct, new cases China; TCct, total cases China; NDct, new deaths China; TDct, total deaths China; FRct, case fatality rate China; NCect, new cases excl. China; TCect, total cases excl. China; NDect, new deaths excl. China; TDect, total deaths excl. China; NCet, new cases Europe; TCet, total cases Europe; NDet, new deaths Europe; TDet, total deaths Europe; FRet, case fatality rate Europe (see ***Table 1****). Model Const., model constant; Coef., coefficient; t-Stat, t-Statistics; Observ., observations.*

TABLE 9 | Bivariate regression models for COVID-19 effect on S&P Global LargeMidCap ESG Index.

Variable	Model Const.	Coef.	t-stat	*p*-value	R	Observ
Ca*t*	180.2380	−0.05851	−4.5741	0.0000[a]	0.0965	198
NCw*t*	164.7979	4.99 e-05	5.0543	0.0000[a]	0.1153	198
TCw*t*	164.6310	6.94 e-07	7.2712	0.0000[a]	0.2124	198
NDw*t*	172.9748	−0.0006	−1.4058	0.1614[c]	0.0099	198
TDw*t*	164.0736	1.91 e-05	6.3570	0.0000[a]	0.1709	198
FRw*t*	197.3981	−6.1948	−10.4967	0.0000[a]	0.3797	182
NCc*t*	169.9427	0.0026	3.0745	0.0024	0.0460	198
TCc*t*	183.2605	−0.0002	−4.7229	0.0000[a]	0.1022	198
NDc*t*	170.8242	0.0009	0.0743	0.9408[c]	0.0000	198
TDc*t*	177.8576	−0.0019	−3.0375	0.0027[a]	0.0449	198
FRc*t*	175.2463	−1.1096	−1.0716	0.2853[c]	0.0006	182
NCec*t*	164.8990	4.92 e-05	4.9927	0.0000[a]	0.1128	198
TCec*t*	164.6527	6.97 e-07	7.3016	0.0000[a]	0.2138	198
NDec*t*	172.9598	−0.0006	−1.4058	0.1614[c]	0.0099	198
TDec*t*	164.0770	1.93 e-05	6.4036	0.0000[a]	0.1730	198
NCe*t*	172.2279	−7.41 e-05	−1.0818	0.2806[c]	0.0059	198
TCe*t*	164.7207	3.70 e-06	5.2279	0.0000[a]	0.1224	198
NDe*t*	178.3244	−0.0093	−12.2871	0.0000[a]	0.4251	198
TDe*t*	166.2013	3.99 e-05	3.2912	0.0012[a]	0.0534	198
Fre*t*	178.5350	−1.5336	−1.8240	0.0054[a]	0.04864	158

[a]*99% c. l.*
[b]*95% c. l.*
[c]*Insignificant.*
*Note: SPLESGUPt, S&P Global LargeMidCap ESG, Index USD; CAt, countries affected; NCwt, new cases world; TCwt, total cases world; NDwt, new deaths world; TDwt, total deaths world; FRwt, case fatality rate world; NCct, new cases China; TCct, total cases China; NDct, new deaths China; TDct, total deaths China; FRct, case fatality rate China; NCect, new cases excl. China; TCect, total cases excl. China; NDect, new deaths excl. China; TDect, total deaths excl. China; NCet, new cases Europe; TCet, total cases Europe; NDet, new deaths Europe; TDet, total deaths Europe; FRet, case fatality rate Europe (see **Table 1**). Model Const., model constant; Coef., coefficient; t-Stat, t-Statistics; Observ., observations.*

of COVID-19 on ESG stock markets, the bivariate regression models (least squares) are constructed (**Tables 6**, **7**, **8**, **9**).

Effect of COVID-19 on the Performance of Emerging ESG Markets

The results of the assessment of COVID-19 impact on the performance of Emerging ESG markets are provided in **Table 6**.

Based on the results of **Table 6** (t value and *p* statistics), it can be noticed that:

1) Three variables [number of new deaths reported per day in China (*NDct*), number of total deaths in Europe (*TDet*), and case fatality rate in Europe (*FRet*)] proved to have no statistically significant effect on the performance of Emerging ESG stock markets;
2) Eight variables (NCw_t, TCw_t, TDw_t, NCc_t, $NCec_t$, *TCec*, $TDec_t$, and TCe_t) appear to affect the performance of the Emerging ESG stock market positively, while nine variables (CA_t, NDw_t, FRw_t, TCc_t, TDc_t, FRc_t, $NDec_t$, NCe_t, and NDe_t) negatively.
3) The number of countries that reported cases of COVID-19 has s significant negative impact on the performance of emerging ESG stock markets.
4) Global and China case fatality rates had the most significant negative impact on the performance of the emerging ESG stock market.
5) The number of new deaths caused by COVID-19 appeared to have a significant negative impact on the performance of Emerging ESG stock markets in three of four geographical perspectives (Europe, rest of the world excluding China, and global).
6) An interesting result is that the market reaction to an increasing number of daily COVID-19 cases confirmed differs depending on the geographical perspective: The reaction to the increase in China, the rest of the world excluding China, and global daily cases is positive, while the reaction to increase of daily cases in Europe is significantly negative.

To conclude, it can be said that in the case of Emerging ESG stock markets, the results support Hypothesis 1 and Hypothesis 4. In contrast, in the case of the remaining hypotheses, the results are ambiguous.

Effect of COVID-19 on the Performance of European ESG Markets

The results of the assessment of COVID-19 impact on the performance of European ESG markets are provided in **Table 7**.

Based on the results of **Table 7** (t value and *p* statistics), it can be said that:

1) Seven variables (NCw_t, TDw_t, NDc_t, $NCec_t$, $TDec_t$, TCe_t, and TDe_t) proved to have no statistically significant effect on the performance of the European ESG stock market (S&P Europe 350 ESG Index).

2) 10 variables (CA_t, NDw_t, FRw_t, TCc_t, TDc_t, FRc_t, $NDec_t$, NCe_t, NDe_t, and FRe_t) appear to affect the stock market negatively, while only 3 (TCw_t, NCc_t, TCect) positively.
3) The number of countries that reported cases of COVID-19 has s significant negative impact on the performance of the European ESG stock markets.
4) Global case fatality rate as well as case fatality rates in Europe and China seemed to show the most significant adverse effect on the performance of the European ESG stock market.
5) The number of new deaths per day caused by COVID-19 appeared to have a significant negative impact on the performance of the European ESG stock markets in three of four geographical perspectives (Europe, rest of the world excluding China, and global), while the number of new deaths in China has no significant impact.
6) An interesting result is that the number of total deaths in China has a significant negative impact on the European market. In contrast, the number of deaths in other regions seemed to have no statistically significant impact.

To conclude, it can be said that, in the case of the European ESG stock markets, the results support Hypothesis 1, Hypothesis 3, and Hypothesis 4. In contrast, in the case of Hypothesis 2, the results are ambiguous.

Effect of COVID-19 on the Performance of Global ESG Markets

The results of the assessment of COVID-19 impact on the performance of Global ESG markets (measured by S&P Global 1200 ESG Index and S&P Global LargeMidCap E.S.G. Index) are provided in **Tables 8** and **9**.

It is important to notice that: 1) the results in **Table 8** and **Table 9** are remarkably similar, which suggests that the impact of COVID-19 does not depend on the capitalization size and 2) the results in **Tables 8** and **9** differ from the results in **Tables 6** and 7, thus showing that the effect of COVID-19 on Global ESG stock markets is slightly different from that on Emerging and European ESG stock markets. The main similarities and differences are worth further discussion.

Based on the results of **Tables 8** and **9** (t value and p statistics), it can be said that:

1) Five variables (number of new deaths reported per day in China, Europe, and in the rest of the world excluding China (NDw_t, NDc_t, $NDec_t$), the number of daily new cases reported in Europe (NCe_t), and case fatality rate in Europe (FRe_t)), proved to have no statistically significant effect on the Global ESG stock market.
2) Nine variables affect the performance of the Global ESG stock market positively (NCw_t, TCw_t, TDw_t, NCc_t, $NCec_t$, $TCec$, $TDec_t$, TCe_t, and TDe_t), while six negatively (CA_t, FRw_t, TCc_t, TDc_t, FRc_t, and NDe_t).

To conclude, it can be said that in the case of the Global ESG stock markets, the results support Hypothesis 1 and Hypothesis 4. In contrast, in the case of the remaining hypotheses, the results are ambiguous.

Comparison of COVID-19 Effect on Emerging, European, and Global ESG Markets

The comparison of findings allows us to say that:

1) As with Emerging and European markets, the number of countries that reported cases of COVID-19 has s significant negative impact on the performance of the Global ESG stock market.
2) As well as in the case of Emerging and European ESG stock markets, the global case fatality rate proved the most significant adverse effect.
3) It is interesting that unlike cases of Emerging and European markets, the Global ESG stock markets do not prove a significant reaction to the increase of daily COVID-19 cases in Europe, while the reaction to the increase in China, the rest of the world excluding China, and global daily cases is the same, that is, positive.
4) It is also worth mentioning that the number of new deaths per day caused by COVID-19 appeared to have a significant negative impact on the performance of the Global ESG stock markets only in one of four geographical perspectives (Europe) (in comparison with three of four perspectives in earlier cases).
5) Unlike the case of European ESG stock markets, the number of total deaths caused by COVID-19 in Europe, the rest of the world, excluding China, and globally has proven to have a significant positive impact on the performance of the Global ESG stock markets. In contrast, the reaction to increasing number of total deaths in China appeared to be negative.

COVID-19 Effect on the Volatility of ESG Stock Markets

In addition to the results discussed, it is worth mentioning that a substantial number of authors (e.g., Albulescu, 2020b; Zaremba et. Al., 2020; Bakas and Triantafyllou, 2020; and others) expressed the impact of COVID-19 on financial volatility rather than on market returns. Therefore, to assess the short-term effect, ESG stock market volatility expressed monthly standard deviations of the values of indices are analyzed in relation to the average number of new COVID-19 cases and deaths per month (both Global and European) (**Table 10**).

The data in **Table 10** show that the most pronounced adverse reaction (estimated by the highest volatility) of all analyzed indices was seen in March, when the number of confirmed new COVID-19 cases and deaths increased rapidly. In later periods, a decrease in volatility is seen even with the increasing incidence of COVID-19 infections.

According to the summary of research results (provided in **Supplementary Appendix SA2**), it can be concluded that the findings of this research support the following hypotheses: H1 and H4. In contrast, hypotheses H2 and H3 cannot be supported,

TABLE 10 | Monthly analysis of selected financial market indexes and COVID-19-related variables.

Variable	Month (2020)								
	M1	M2	M3	M4	M5	M6	M7	M8	M9
SPELMUPt (St.dev.)	1.8096	2.2787	7.6607	2.0497	0.9954	1.2124	1.7193	1.0663	1.5499
SPEESUPt (St.dev.)	1.3035	4.4076	11.7308	2.8958	2.7518	2.2378	2.2221	1.2829	2.5993
SPGESUPt (St.dev.)	1.6641	7.1323	15.4339	6.1979	3.6261	3.0711	2.6646	3.111	3.9835
SPLESGUPt (St.dev.)	1.6501	6.4888	14.6074	5.6299	3.3337	2.7687	2.5001	2.989	3.5887
NCwt (monthly Aver.)	370	2799	22,216	75,761	90,550	135,097	227,797	251,079	275,856
NDwt (monthly Aver.)	8	96	1115	6215	4626	4590	5330	5719	5381
NCet (monthly Aver.)	1	36	12,463	27,886	19,677	14,792	15,205	26,993	48,910
NDet (monthly Aver.)	0	1	874	3399	1280	575	329	322	509

*Note: SPELMUPt, S&P Emerging LargeMidCap ESG, Index USD; SPEESUPt, S&P Europe 350 ESG, Index USD; SPGESUPt, S&P Global 1200 ESG, Index USD; SPLESGUPt, S&P Global LargeMidCap ESG, Index USD; NCwt, new cases world; NDwt, new deaths world; NCet, new cases Europe; NDet, new deaths Europe; (see **Table 1**). St.dev., standard deviation; Aver., average; M1, January; M2 = February; M3, March; M4 = April; M5 = May; M6 = June; M7 = July; M8, August; M9, September.*

TABLE 11 | Results of the assessment of COVID-19 effect on ESG stock market indices.

Index	Hypothesis	Finding
SPELMUPt	Hypothesis 1	Supported
—	Hypothesis 2	Not supported
—	Hypothesis 3	Not supported
—	Hypothesis 4	Supported
SPEESUPt	Hypothesis 1	Supported
—	Hypothesis 2	Not supported
—	Hypothesis 3	Supported
—	Hypothesis 4	Supported
SPGESUPt	Hypothesis 1	Supported
—	Hypothesis 2	Not supported
—	Hypothesis 3	Not supported
—	Hypothesis 4	Supported
SPELMUPt	Hypothesis 1	Supported
—	Hypothesis 2	Not supported
—	Hypothesis 3	Not supported
—	Hypothesis 4	Supported

*Note: SPELMUPt, S&P Emerging LargeMidCap ESG, Index USD; SPEESUPt, S&P Europe 350 ESG, Index USD; SPGESUPt, S&P Global 1200 ESG, Index USD; SPLESGUPt, S&P Global LargeMidCap ESG, Index USD (see **Table 1**).*

while the results obtained are ambiguous and require further analysis (**Table 11**).

This research shows that the global prevalence of COVID-19 infection, expressed as the number of countries that have confirmed COVID-19 cases, has a significant negative effect on the performance of Emerging, European, and Global ESG stock markets. This research has also revealed that the mortality risk of COVID-19 infection, measured as a case fatality rate, has a significant negative effect on ESG stock markets. The effect of COVID-19 cases reported and deaths caused by COVID-19 infection appeared to be mixed.

The results of this research also revealed that: 1) all analyzed ESG stock markets (Emerging, European, and Global) are more sensitive to the growth of COVID-19 deaths in Europe than in China; and 2) China's COVID-19 case fatality rate has no statistically significant impact on the performance of Global ESG markets, while it negatively affects Emerging and European ESG stock markets. This suggests that markets tend to respond differently to the mortality of COVID-19 seen in different regions.

CONCLUSION AND FUTURE RESEARCH

Conclusion

After researching different regions and stock markets, we noticed some differences in performance and reaction to COVID 19 pandemic. The analysis of the relationship between sustainable investments in different markets revealed that ESG investments in Emerging and Global stock markets are strongly positively correlated. But the relationship between European ESG investments and Emerging markets ESG investments is inverse, so because of these results, we can say that the European ESG market can be used as a diversification measure in low carbon portfolio management.

The comparison of the regression analysis results showed specific differences between ESG investments in Emerging, European, and Global ESG stock markets. Unlike in the cases of Emerging and European ESG markets, the Global ESG stock markets do not prove a significant reaction to the increase of daily COVID-19 cases in Europe, while the reaction to the increase in China, the rest of the world, excluding China, and global daily cases is positive in all markets investigated. The other conclusions can be made that the number of new deaths per day caused by COVID-19 appeared to have a significant negative impact on the performance of the Global ESG stock markets only in one of four geographical perspectives (Europe) (in comparison with three of four perspectives in cases of Emerging and European ESG markets).

The other aspect we would like to stress from our research is that unlike in the case of the European ESG stock markets, the number of total deaths caused by COVID-19 in Europe, the rest of the world, excluding China, and globally has proven to have a significant positive impact on the performance of the Global ESG stock markets. In contrast, the reaction to the increasing number of total deaths in China appeared to be negative.

The differences in Emerging, European, and Global ESG market reactions to the COVID-19 pandemic reveal investment diversification opportunities. Private and institutional investors can achieve better portfolio market risk management results, including sustainable and responsible investments from regions with very low positive or better negative correlations. The other point that practitioners can stress is that investing in ESG investments and other values than profitability should be considered.

The summarized regression analysis results showed that an increasing number of countries that have reported COVID-19 cases have a significant adverse effect on the performance of Emerging, European, and Global ESG stock markets.

The results have also revealed that the case fatality rate of COVID-19 infection has appeared to have a significant adverse effect on ESG stock markets. In contrast, the effect of COVID-19 cases reported (new and cumulative) and deaths (new and cumulative) caused by COVID-19 infection appeared mixed.

The research also revealed that the strongest adverse reaction and volatility of ESG stock market indices to COVID-19 were seen from March 2020 to April 2020; in the later periods, such reaction is no longer dominant. Moreover, a decrease in volatility is seen even with the increasing incidence of COVID-19 infections.

Limitations and Future Research

It is particularly important to note that this research is based on limited data series. The assessment of the COVID-19 effect on ESG stock market performance (indices) using longer-term data series and assessment and comparison of the COVID-19 effect over different timeframes is a further direction for future research.

Some future research can be conducted to extend the results of our research. The longer-term data series could be used to see a more detailed picture of the analyzed issue, and the COVID-19 effect over different timeframes could be assessed and compared. It would be interesting to compare the impact of the COVID-19 pandemic on the stock market of different sectors and bond markets in future research.

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

Conceptualization, RK, DT, GK-S, JK, and DB; methodology, DT and GS-S; software, DT and GS-S; formal analysis, DT and GS-S; investigation, DT, GS; data curation, DT, GS-S, and DB; writing-original draft preparation, DT, JK and GS-S; writing-review and editing, GS-S, DT, DB, RK, JG, GG, and XY; visualization, DT, JK, and DB; supervision, RK. All authors have read and agreed to the published version of the manuscript.

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The current paradigm of the EU energy system and its impact on the sustainability of member states' economies by 2050

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In a context of multi-crises, as well as the challenges of both the medium and long term, associated with elements highlighted by the transformation of the EU energy system, we appreciate that not only is it a very difficult time to overcome efficiently and balanced EU Member States, but above all it is a time to activate research systems on identifying key solutions, as well as firm decisions at the level of decision-making institutions at the level of the European Institutions. Moreover, based on the latest European studies, systematic testing of ongoing initiatives can strategically prepare for an increase in the resilience of Member States' economies to crisis shocks, as well as "the key to success Europe's ecological transformation and climate neutrality of the EU economy in a broader sense." The paper aims to highlight how to act at European level in the context of the latest energy decisions (regulations, strategies, pro-grams and directives) and how to stimulate "the EU economy with about 3.3% of EU GDP or EUR 464 billion in 2030 and up to EUR 5.6% or more than EUR 1 trillion in 2050." At the same time, we appreciate that as a result of green energy, digitalization and technology, the environmental objective on the EU and UN net emissions in 2050 can be achieved, especially as a result of a fair and equitable transformation for the economic environment and for citizens, being an objective that directly contributes to achieving a sustainable, collaborative and prosperous society with an open and modern society, but more chosen efficiently in terms of resource optimization and a sustainable and competitive economy.

KEYWORDS

climate neutrality, energy system, competitiveness, sustainability, collaborative economy

Introduction

Following Member States' decisions on the production of renewable energy from hydro, wind, hydrogen and solar by installing new renewable energy production capacity is a priority for each nation's economy. This goal is also given by the alignment of state economies with the internal GHG the permanent target is to raise the level of reduction by at least 40% in 2030 compared to 1990 levels, in line with the principles and targets set out in European and global strategies and agreements.

It should be noted that in order to achieve these objectives, Member States receive significant financial support and support for investments in electricity production based on renewable resources from wind and solar energy, with or without integrated storage facilities, helping to achieve the objectives undertaken by member states in their National Recovery and Resilience Plans, which provide for specific investment measures.

Climate change, environmentally friendly technologies, innovations in the clean energy industry, make interventions aimed at promoting direct investments in the clean energy sector and energy efficiency to ensure the contribution to the objectives set by the European Green Agreement, make the targets set in the National Integrated Plan for Energy and Climate Change 2021–2030 (PNIESC) oriented on the production of energy based on renewable resources, as well as those established in the PNRR, by increasing the share of its production of wind and solar energy, to be targets that can be achieved by state decision makers.

Investments supported by these sources of funding at EU level from which an impact with direct effect is expected, respectively:

1) the first and most important is given by the reduction of carbon emissions into the atmosphere generated by the energy sector by replacing a part of the amount of fossil fuels consumed each year—coal, natural gas;
2) the second impact is that there is an increase in primary resources compared to the increase in renewable energy production resources, as a result of the investments to increase the installed power to produce electricity from renewable sources of wind and solar energy;
3) the third we consider is supported increase production based on renewable resources in total energy production and which make an important contribution to achieving the objectives in the European Green Pact as a strategy for sustainable growth in Europe and combating climate change in line with the Union's commitments to put implementing the UN Sustainable Development Goals set out in the 2030 Agenda;
4) the fourth concerns the fact that a competitive, efficient and environmentally friendly system in the sustainability of the economy in terms of the use of sources leads to sustainable development; and
5) the fifth is given by the objectives regarding the use of renewable resources in energy production according to European regulations and directives (Directive (EU) 2018/2001).

In our paper we aim, on the one hand, to present a factual situation that exists at European level and national level, and, on the other hand, to highlight the renewable resources that can actively contribute to the implementation of energy strategies and policies in the actual context.

The paper addresses a current issue at European and global level, namely the EU energy system and its impact on the sustainability of Member States' economies by 2050 from several perspectives, namely:

1. From the perspective of the decisions taken by the European Commission on energy sources and how this energy transition impacts the economies of the Member States.
2. From the perspective of the structures of domestic and industrial consumers, given that the energy resource is one of the vital resources of the consumer whether domestic or industrial, and the transition to renewable sources directly influences family budgets and the budgets of companies involved in various industrial processes, energy and vital part of these processes;

3. From the perspective of the solutions offered by decision-makers through the regulations providing for this green transition, the strategies that support this transition from conventional to renewable sources of electricity production, and the funding programs and European directives that support resources and financial instruments investments in electricity generation capacities based on renewable resources, but especially industrial consumers and household consumers in endowment with investments in energy production equipment through renewable resources (wind, solar, hydrogen, biofuels, water, etc.) and which resources were also mentioned in our paper.

Literature review

Both financial performance and profitability are key indicators for the business environment to be as stable as possible and for companies to be sustainable in their sector of activity (Morina et al., 2021). Overall, it is important to understand the bottom-up approach to sustainable economic development. Starting from the micro-level, firms have to be encouraged to invest in technologies offering good standards for renewable energy. This has to be regulated by the governmental bodies and has to be endorsed by the companies that agree upon the beneficial

TABLE 1 Evolution of the share of energy costs over time in the main sectors of activity analyzed at European level.

	2008 (%)	2009 (%)	2010 (%)	2011 (%)	2012 (%)	2013 (%)	2014 (%)	2015	Changes 2008–2015	Changes 2008–2011	Changes 2011–2015	Level 2015 (%)	Average	Max. Level
C103—Fruit and vegetables	3.6	3.5	2.8	2.8	3.0	2.8	2.9	2.5%	−1.1%	−0.8%	−0.3%	2.5	3.0%	3.6%
C106—Grain products	3.8	3.8	3.3	3.1	3.3	3.1	3.3	3.0%	−0.8%	−0.6%	−0.1%	3.0	3.3%	3.8%
C132—Textiles	4.3	6.4	3.6	2.5	2.7	2.4	2.3	2.1%	−2.2%	−1.8%	−0.4%	2.1	3.3%	6.4%
C161—Sawmills	3.7	4.1	3.6	4.1	3.7	3.6	3.4	3.1%	−0.6%	0.4%	−1.0%	3.1	3.7%	4.1%
C171—Pulp and paper	12.2	13.0	11.1	11.2	10.7	9.9	9.1	8.4%	−3.9%	−1.1%	−2.8%	8.4	10.7%	13.0%
C172—Articles of paper	3.6	3.7	3.1	2.8	3.0	3.0	2.7	2.5%	−1.0%	−0.8%	−0.3%	2.5	3.0%	3.7%
C192—Refineries	3.2	2.4	2.5	2.0	2.8	3.1	3.1	3.7%	0.6%	−1.2%	1.7%	3.7	2.8%	3.7%
C201—Basic chemicals	7.1	7.7	6.8	7.0	6.7	6.7	6.1	5.7%	−1.4%	−0.1%	−1.3%	5.7	6.7%	7.7%
C206—Man-made fibres	8.6	12.4	7.8	7.1	6.7	8.5	6.5	6.2%	−2.4%	−1.6%	−0.9%	6.2	8.0%	12.4%
C222—Plastics products	3.5	3.5	2.9	2.9	2.8	2.9	2.7	2.6%	−0.9%	−0.6%	−0.3%	2.6	3.0%	3.5%
C231—Glass	9.8	10.1	8.9	9.1	10.3	10.1	9.3	8.2%	−1.7%	−0.7%	−0.9%	8.2	9.5%	10.3%
C232—Refractory products	6.9	6.5	6.2	5.9	6.5	6.6	5.8	6.1%	−0.8%	−1.0%	0.1%	6.1	6.3%	6.9%
C233—Clay building materials	15.4	14.1	11.8	11.0	12.4	12.4	11.3	11.1%	−4.3%	−4.4%	0.1%	11.1	12.4%	15.4%
C234—Porcelain and ceramics	6.0	5.7	4.8	5.0	5.3	5.4	5.0	4.3%	−1.7%	−1.0%	−0.8%	4.3	5.2%	6.0%
C235—Cement, lime and plaster	22.1	22.9	22.1	23.5	21.4	21.8	20.9	16.3%	−5.8%	1.5%	−7.3%	16.3	21.4%	23.5%
C237—Stone	4.8	4.4	3.3	3.4	2.6	4.3	3.1	3.2%	−1.5%	−1.4%	−0.1%	3.2	3.6%	4.8%
C239—Abrasive products	5.8	5.3	4.9	4.9	5.0	5.2	4.8	5.1%	−0.7%	−0.9%	0.1%	5.1	5.1%	5.8%
C241—Iron and steel	9.2	11.9	9.5	7.7	8.5	8.5	7.3	7.5%	−1.7%	−1.4%	−0.3%	7.5	8.8%	11.9%
C244—Non-ferrous metals	4.6	6.0	4.2	4.0	3.9	4.0	3.6	3.5%	−1.1%	−0.5%	−0.6%	3.5	4.2%	6.0%
C245—Casting of metal	6.4	7.1	6.0	5.2	5.4	5.5	5.3	4.9%	−1.4%	−1.1%	−0.3%	4.9	5.7%	7.1%
C11—Beverages	2.6	2.6	2.6	2.7	2.6	2.6	2.5	2.4	−0.2%	0.1%	−0.2%	2.4	2.6	2.7
C21—Pharmaceutical products	2.8	1.7	1.2	1.2	1.3	1.3	1.2	1.1	−1.7%	−1.6%	−0.1%	1.1	1.5	2.8
C25—Fabricated metal products	2.2	2.4	2.3	1.9	2.0	2.1	2.1	1.9	−0.2%	−0.3%	0.0%	1.9	2.1	2.4
C26—Computer and electronics	0.9	0.9	0.7	0.8	0.8	0.8	0.8	0.8	−0.2%	−0.2%	0.0%	0.8	0.8	0.9
C27—Electrical equipment	1.1	1.3	1.0	1.0	1.0	1.0	1.1	0.9	−0.3%	−0.2%	−0.1%	0.9	1.0	1.3
C28—Machinery and equipment	1.1	1.2	1.0	0.9	0.9	1.0	0.9	0.8	−0.3%	−0.2%	−0.1%	0.8	1.0	1.2
C29—Motor vehicles	1.0	1.0	0.8	0.8	0.8	0.8	0.7	0.7	−0.3%	−0.2%	−0.1%	0.7	0.8	1.0
C30—Other transport equipment	1.1	1.0	0.9	0.8	0.8	0.9	0.7	0.8	−0.3%	−0.3%	−0.1%	0.8	0.9	1.1
C32—Other manufacturing	1.3	1.4	1.3	1.1	1.1	1.1	1.1	1.0	−0.3%	−0.2%	−0.1%	1.0	1.2	1.4
C33—Repair of machinery	1.3	1.2	1.1	1.1	1.1	1.2	1.1	0.9	−0.4%	−0.2%	−0.2%	0.9	1.1	1.3
Other sections														
B—Mining and quarrying	3.4	2.9	2.9	2.7	2.8	2.8	2.7	3.1	−0.3%	−0.8%	0.5%	3.1	2.9	3.4
B06—Oil and gas	1.6	0.6	0.6	0.5	0.6	0.7	0.7	0.7	−0.9%	−1.1%	0.2%	0.7	0.7	1.6
B07—Mining of metal ores	15.8	16.6	19.7	20.8	19.6	19.4	17.7	18.4	2.6%	5.0%	−2.4%	18.4	18.5	20.8
B08—Other mining	10.3	9.8	10.4	10.4	10.9	10.2	9.6	9.4	−0.9%	0.1%	−1.0%	9.4	10.1	10.9
D35—Electricity, gas and steam	17.0	16.8	16.9	16.4	14.3	12.3	11.4	11.5	−5.5%	−0.6%	−4.9%	11.5	14.6	17.0
E38—Waste management	4.0	3.0	3.1	3.5	4.2	4.3	4.8	4.3	0.3%	−0.5%	0.8%	4.3	3.9	4.8
F—Construction	1.5	1.5	1.5	1.7	1.7	1.7	1.6	1.4	0.0%	0.2%	−0.3%	1.4	1.6	1.7
G—Wholesale and retail trade	0.7	0.8	0.7	0.6	0.7	0.6	0.6	0.6	−0.1%	0.0%	0.0%	0.6	0.7	0.8
H49—Land transport	36.3	31.0	33.2	40.6	37.0	34.4	32.1	27.0	−9.3%	4.3%	−13.6%	27.0	33.9	40.6
H51—Air transport	19.5	16.7	21.6	20.1	23.3	20.0	24.4	20.2	0.7%	0.6%	0.1%	20.2	20.7	24.4
I—Accommodation and restaurants	3.9	4.2	4.7	4.2	4.5	4.3	3.7	3.9	0.0%	0.3%	−0.3%	3.9	4.2	4.7

Source: data processing based the (Rademaekers et al., 2018), Final Report, Trinomics.

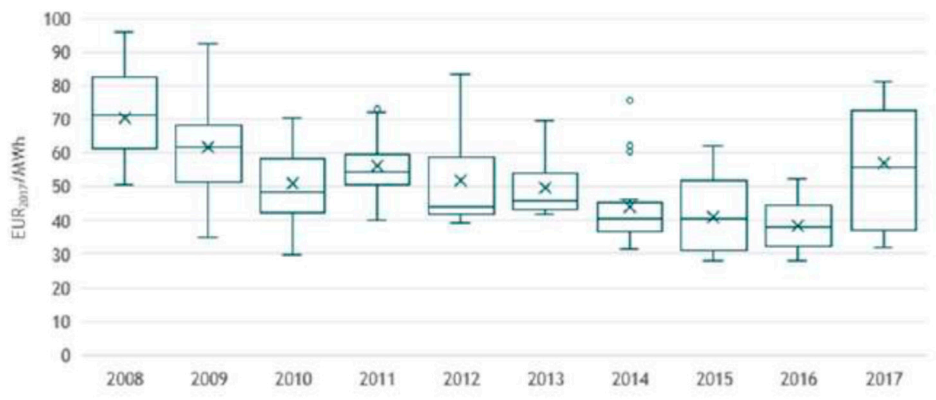

CHART 1
"Box plot" of EU wholesale electricity prices (28) in the period 2008–2017. Source: data processing based the (Rademaekers et al., 2018).

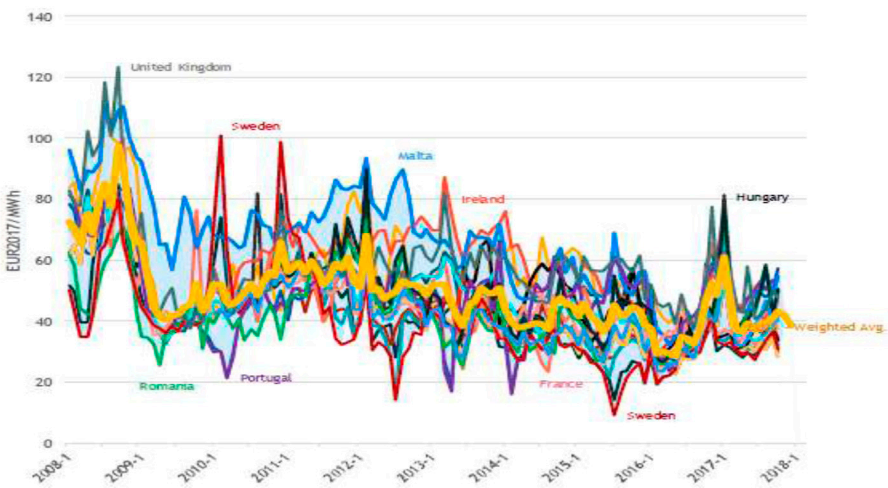

CHART 2
Wholesale electricity prices in the EU (28) 2008–2017. Source: data processing based the (Rademaekers et al., 2018).

aspects of investing in renewable and green energies. As the aggregate of all companies investing in renewable energies, and innovation related to, the impact targets the macro-level, addressing one sole country, or a group of countries.

According to the general literature, we identify two main views with regard to profit-ability and its determinants, opposing each other. From one side, structural conduct performance, and market concentration are found as the key indicator in the analysis of the company's profitability [2]. On the other hand, there are various other studies that show that different factors decisively influence the performance of activities (Barney, 1991; Morina et al., 2021; Spanos et al., 2004). Additional to the theoretical studies, some empirical studies examined the environmental and the financial results of the companies involved in the production of energy based on renewable resources (Wang et al., 2014) and (Ruggiero and Lehkonen, 2017). Furthermore, the literature showed that investing in renewable energy would cause financial difficulties for companies (Paun, 2017). Additionally, it is important that such firms be supported by governments (Marian and Panait, 2019). Emphasized the importance of the role of governments in supporting local development, environmental implications and limiting shocks in open energy markets, as such endorsing sustainable development. This is also supported by the study of Abbasi et al. (2020), which states that companies endorsing renewable resources actively contribute to the sustainable

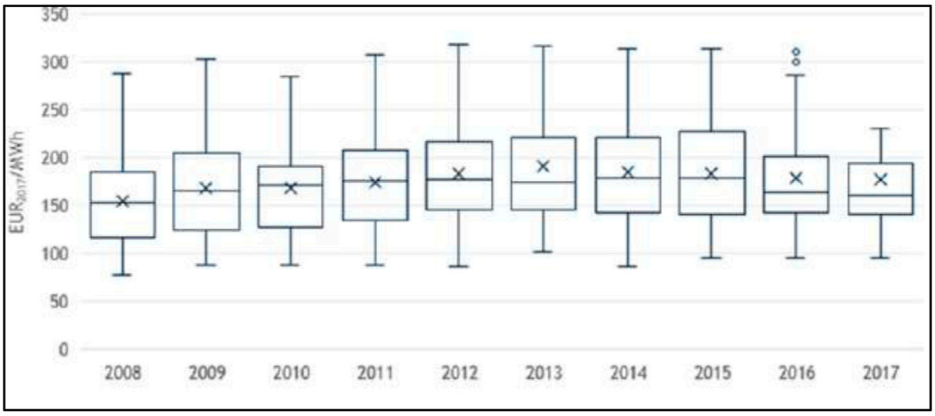

CHART 3
"Box plot" of retail electricity prices for EU households (28) 2008–2017. Source: data processing based the (Rademaekers et al., 2018).

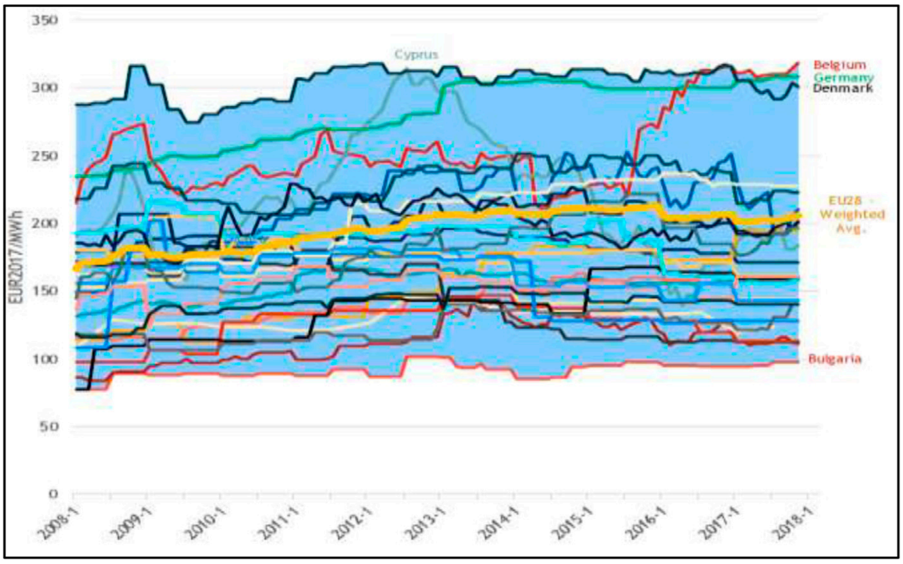

CHART 4
Electricity prices for EU households (28) in the period 2008–2017. Source: data processing based the (Rademaekers et al., 2018).

development of the economy, implicitly of their growth and also keep the environment clean.

Moreover, starting from the early 1990s, there were some pioneering studies trying to identify in there exists a correlation between sustainable economic development and environmental indicators. The study by Kuznets (1955) points out the existence of the inverted U-shaped curve, nowadays known as the Kuznet curve. Afterward, Grossman and Krueger (1995) investigated the relationship between sustainable economic development and specific environmental indicators. They confirmed the Kuznet curve and defined this curve as the Environmental Kuznets Curve (EKC) (Kuznets, 1955).

It should be noted that at the beginning of sustainable economic development (including growth), the firms and/or countries do not harm the environment because of their low industrialization level. As the firms and/or countries go through the growth process, along with the economic growth it can be seen an increase in environmental destruction. In the meantime, while firms and/or countries put themselves in a better position with regard to development and growth, they are finding ways to

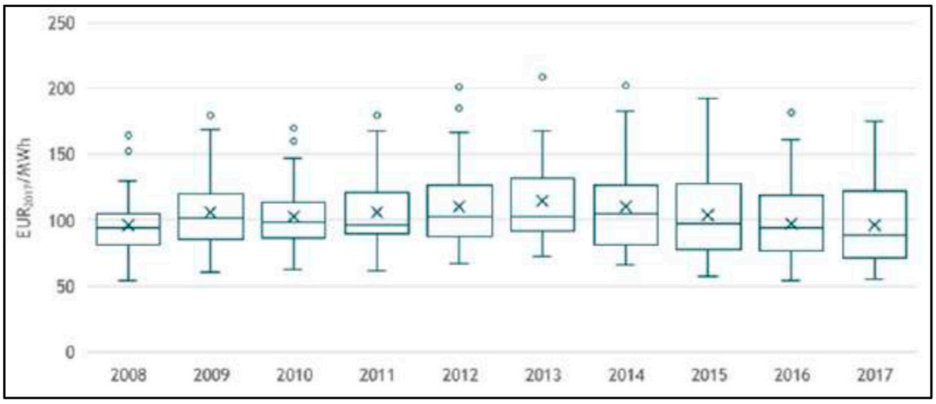

CHART 5
"Box plot" of wholesale EU gas prices (28) in the period 2008–2017. Source: data processing based the (Rademaekers et al., 2018).

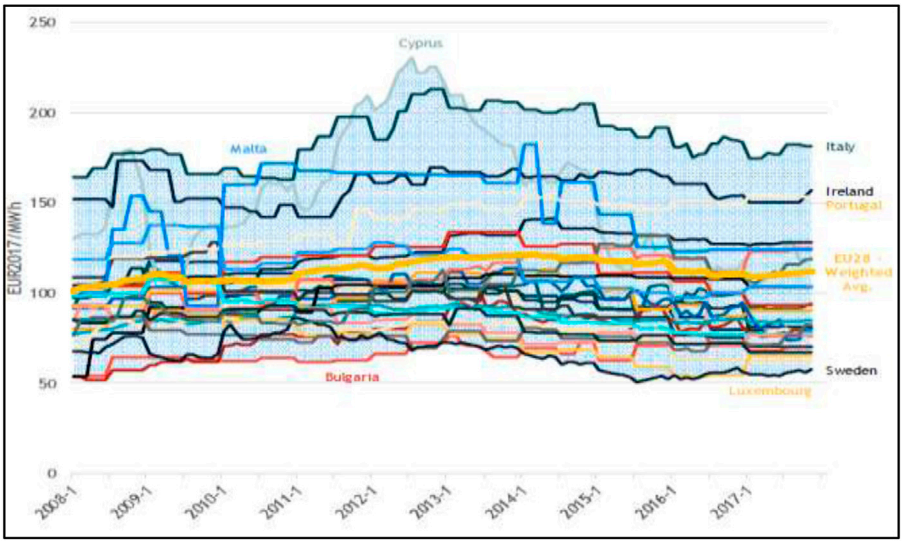

CHART 6
EU natural gas wholesale prices for 2008–2017. Source: data processing based the (Rademaekers et al., 2018).

improve the environment. As such, with the development, governments try to keep with proper laws and rules for a better environment, targeting sustainable development. The EKC hypothesis has been a question of research from many researchers that used empirical analysis to confirm it. The inverted U-shaper curve was confirmed by other studies (Grossman and Krueger, 1995), (List and Gallet, 1999), (Andrei et al., 2014), and (Shukla and Parikh, 1992). Different from what was found before (Shafik and Bandyopadhyay, 1992), found that it might exist an N-shaped relation among the above-mentioned variables. Some other studies failed to confirm EKC hypothesis (Bo, 2011). Additional studies (Iddagoda et al., 2021) were developed for different groups of countries in order to demonstrate the relationship be-tween economic development and environmental pollution (Panait et al., 2019), (Leitão et al., 2021), (Simionescu, 2021), (Badulescu et al., 2020), (Khan et al., 2016), (Sharif et al., 2020), (Armeanu et al., 2018), and (Armeanu et al., 2021).

Obviously, the main concern is given by how we can maintain a balance between social and corporate, all the more so as the gap between the social economy and the corporate economy is growing. The study of (Nurunnabi et al., 2020)

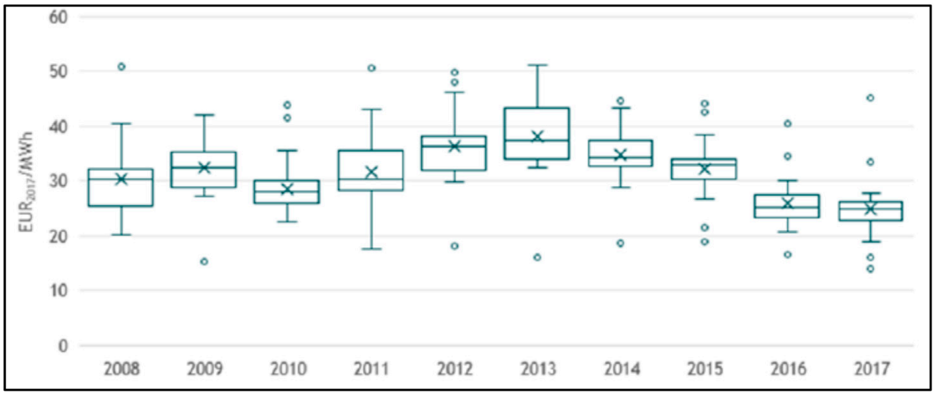

CHART 7
"Box plot" of industrial retail prices in the EU28 for natural gas in the period 2008–2017. Source: data processing based the (Rademaekers et al., 2018).

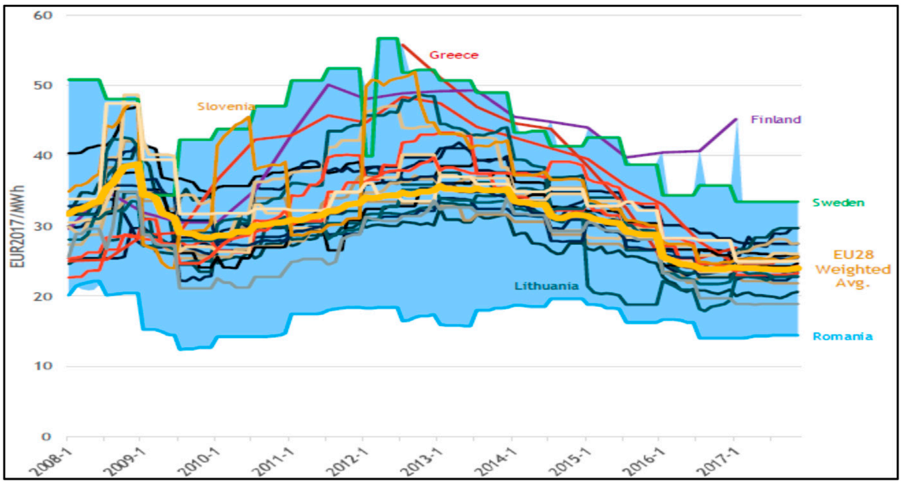

CHART 8
EU28 industrial retail prices for natural gas for the period 2008–2017. Source: data processing based the (Rademaekers et al., 2018).

answered this question by confirming the positive effect that these energy initiatives, especially energy efficiency, we believe should be in line with social issues and the objectives of the 2030 Agenda, while supporting cost reduction and the sustainable development of economies. Another question might be related to the factors motivating the responsibility in the energy sector? According to (Agudelo et al., 2020) these drivers can be internal and external. Business strategy, corporate environment, cost reduction and sustainable development of economies, sustainable environmental policies and the prevention and limitation of climate change, risk management are listed as internal drivers, being at the same time in line with the sustainable development aspect (economic-environmental-social). Elements related to competitiveness, environmental regulations and legislation, the social framework and societal impact and engagements, stockholder compliance with regulations and the impact of satisfaction are found as external drivers (Agudelo et al., 2020), (Neacsa et al., 2020), (Panait et al., 2022), (Vollero et al., 2011), (Piciocchi et al., 2009), and (Janjua, 2021).

Global energy decisions impact decisions at the state level, for example at the November 2021 COP 26 (United Nations, 2022) Conference (26th Conference) on climate change, following the debates. To a decision in the form of a joint agreement on

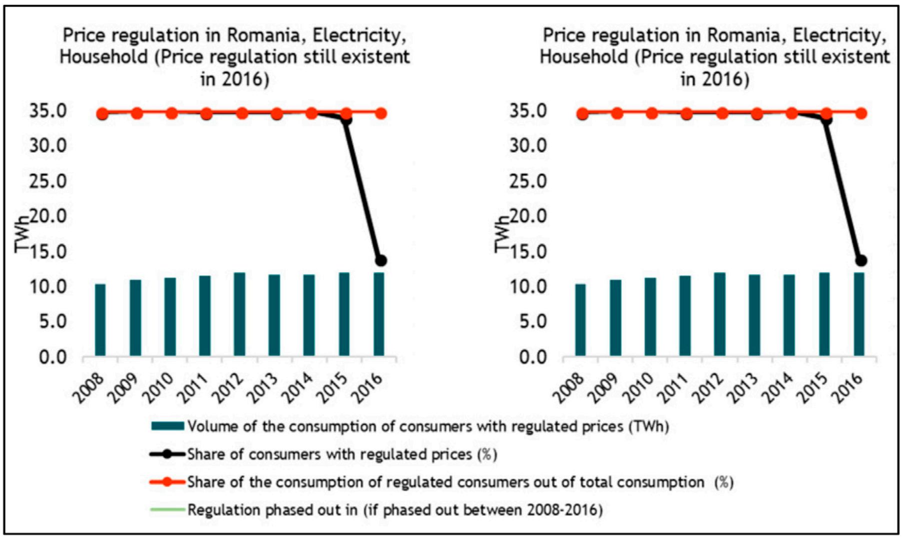

CHART 9
Regulation of household prices in Romania from 2008 to 2016. Source: data processing based the CEER, 2018.

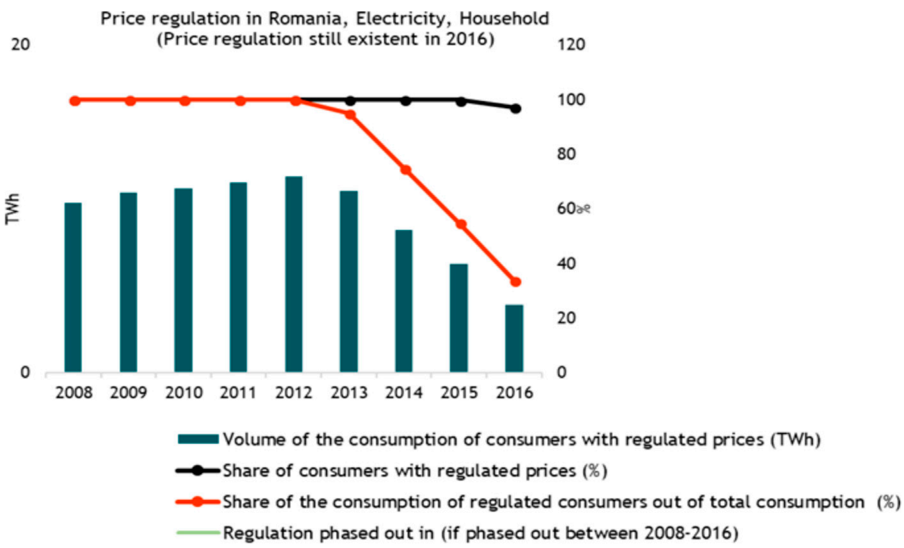

CHART 10
Regulated quotas of households. Source: data processing based the CEER, 2018.

eradicating emissions by 2050 (Shahbaz et al., 2022). As we mentioned earlier in our paper, in parallel with the transition to renewable energy production, it is a major priority to limit these emissions so that we do not exceed 1.5°C globally for the levels allowed in upstream of industries. It is noteworthy that globally up to 2022, societal activities continued to directly affect this growth, thus reaching a global temperature exceedance of 1.1°C (United Nations, 2022). Moreover, another priority is given by the way of forest management and the limitation of deforestation, or rather of their reversal until 2030 (World leaders, 2022). The 2030 Agenda is the one that has guided our strategies, activities, funding programs and others over the last years, so that through them we can actively contribute to achieving the objectives mentioned in it. Among these objectives is the 15th of the

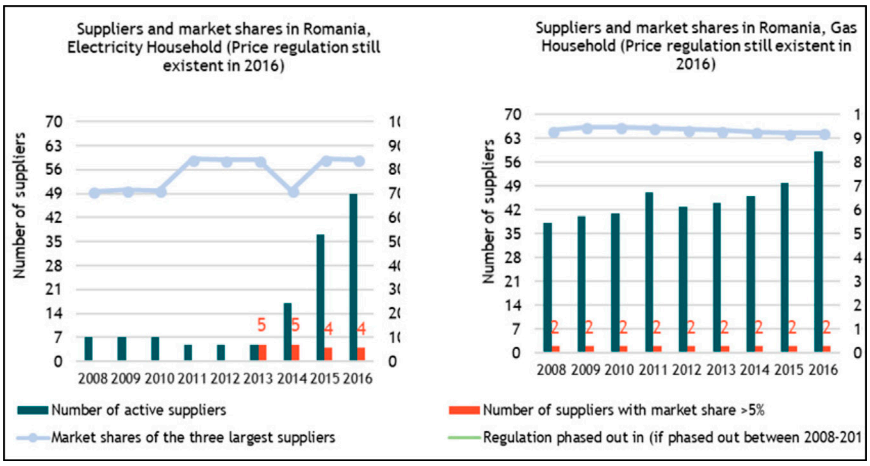

CHART 11
Presentation of the situation of suppliers and their market share. Source: data processing based the CEER, 2018.

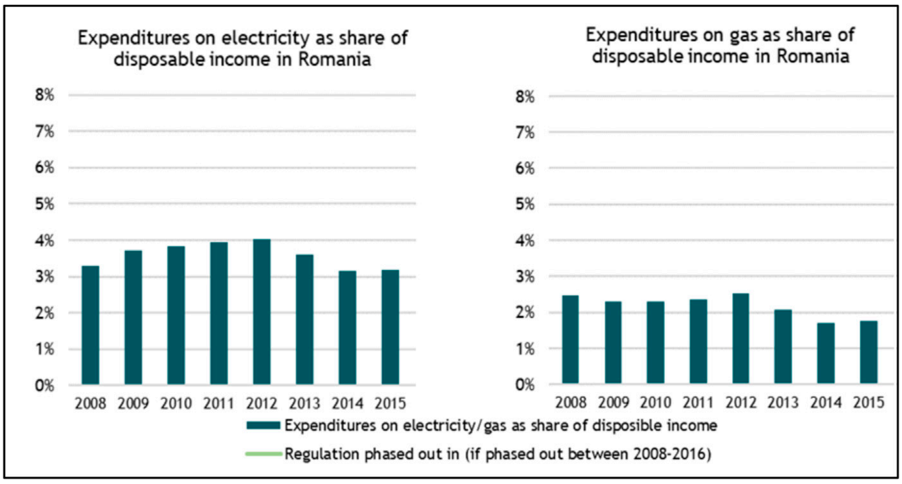

CHART 12
Share of energy expenditure (electricity and gas) in disposable household income (based on prices). Source: data processing based the (Rademaekers et al., 2018).

"Land Life" objectives, which leads us to major decisions on biodiversity, how humans act in contact with nature, as well as how to protect resources and the ecosystem, but especially the management of natural disasters generated by deforestation activities and the creation of natural imbalance (Forests, 2019). Biomass-based renewable energy resources are directly linked to this major problem of deforestation at European and global level. Which means that only through regulation and support programs can this problem be limited and geared to these sustainable resources and contribute to reducing these increases in global greenhouse gas emissions, all the more so as through the forest resource, terrestrial carbon could reach significant levels by limiting these emissions (Oldekop et al., 2019) and (Lawrence and Vandecar, 2015).

It is noteworthy that the energy resource influences social life both at European and global level, which makes the integration of renewable resources, whether it is Sun, wind, hydrogen, biomass, water and others, to be done accordingly. The socio-economic specificities of the area in which investment projects on renewable energy production are in balance with the local ecosystem, especially in areas where the absolute and relative poverty rate is high, which makes that these communities find it

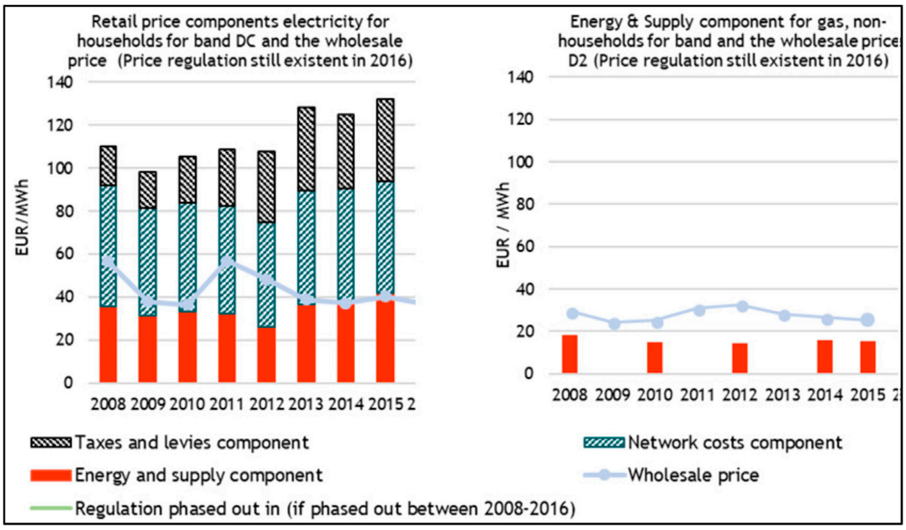

CHART 13
Presentation of the evolution of the price situation at the household level. Source: data processing based the Eurostat, 2018.

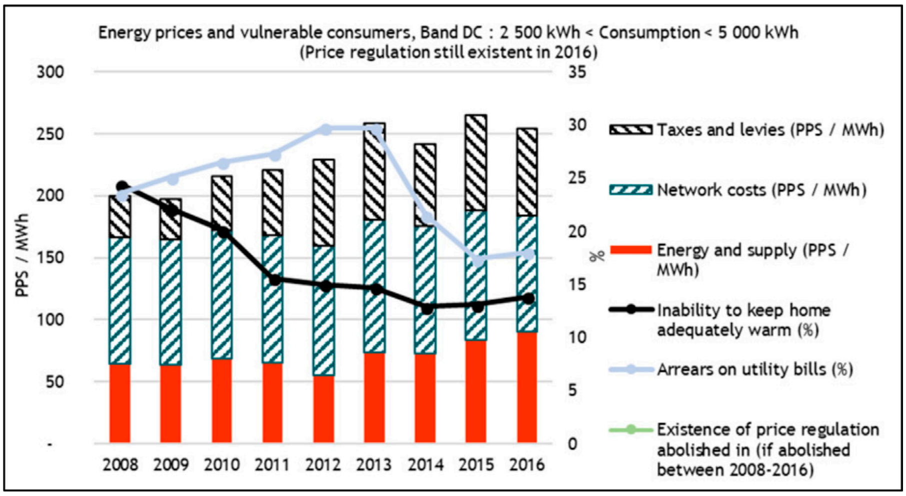

CHART 14
The components of the electricity price for the DC band, the inability to maintain the adequate quality of services and the arrears on utility bills in Romania. Source: data processing based Eurostat, 2018.

very difficult to bear this transition due to lack of material resources, and in this sense government decisions and support programs are the solution for the green transition in these communities, being known interdependence between nature and man (social), it is valid both for poor communities and for developed areas (Klooster and Masera, 2000), (Samii et al., 2014), and (Zulu, 2010).

Finally, it is important to agree that environmental issues may be costly to a certain extent for companies, but at the same time investing in the environment brings social benefits. If the companies involve innovative tools that contribute to both, environ-mental enhancement and cost reduction, then this would be beneficial for both, private and social contexts. However, what is crucial, is a good collaboration among

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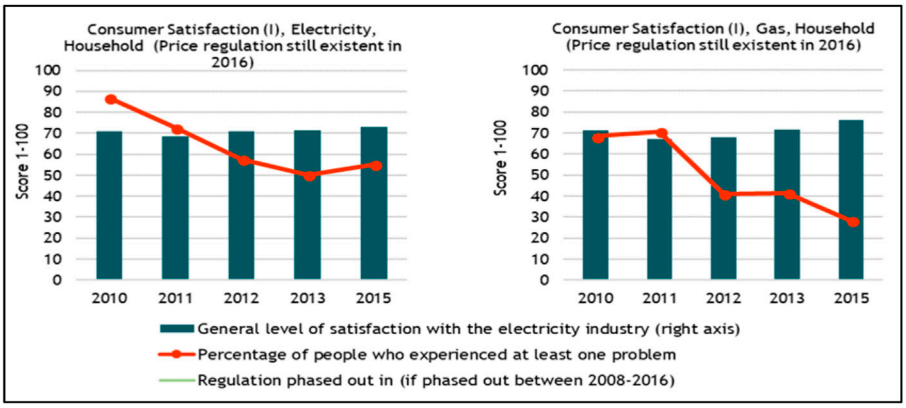

CHART 15
Presentation of the level of satisfaction indicator for the energy market services in Romania. Source: data processing based DG Justice, 2018.

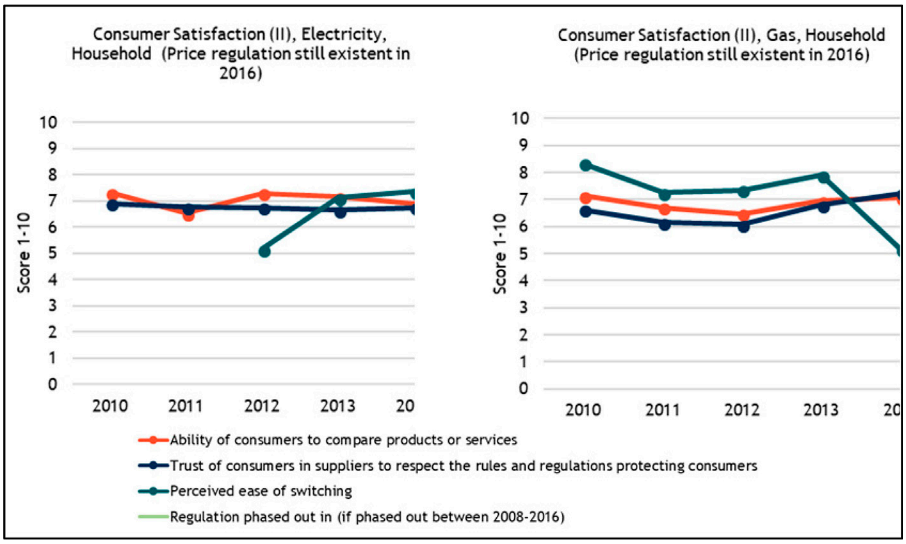

CHART 16
Consumer adaptation to change and the confidence indicator. Source: data processing based DG Justice, 2018.

governmental bodies, academia, businesses, and civil society is key to innovation for sustainability (Hysa et al., 2020), which can further target to achieve sustainable development principles.

Research methodology

To support research methodology, namely: "competence, objectivity, truth, method-ology, aspects related to the demonstration and the final results of the research and psychomotor" (Schuwirth and Van der Vleuten, 2018). Our empirical research is based on documentation of existing European strategies and regulations on Member States' national recovery and resilience plans, as well as the objectives and targets set out in the European Green Agreement and the 2030 UN Energy Agenda.

At the same time, for the sizing of energy investment projects, several benchmarks have been established at European level, including:

Indicator 1 "Newly installed capacity for renewable energy production" (Song et al., 2021) = newly installed capacity (Song et al., 2021) for renewable energy production (Song et al., 2021) (solar/wind) put into operation and connected to the grid, built by project.

Calculation formula: Newly installed capacity to produce energy from renewable sources, expressed in MW.

Indicator 2 "Reduction of greenhouse gases" = total estimate of the annual decrease in the amount as a result of the process of

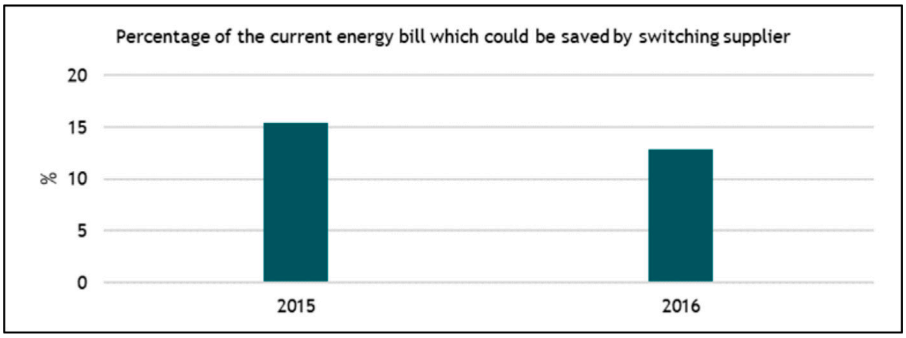

CHART 17
The consumer saving option generated by the change of supplier. Source: processing company data VaasaETT, 2017.

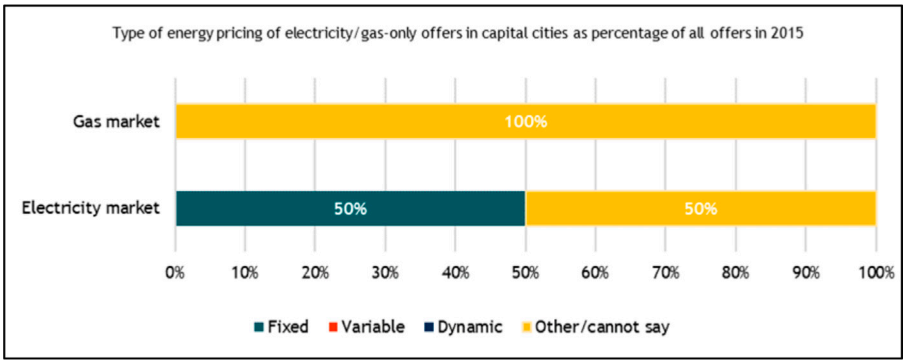

CHART 18
Exemplification of offers for household consumers in Romania. Source: data processing based ACER/CEER, 2015.

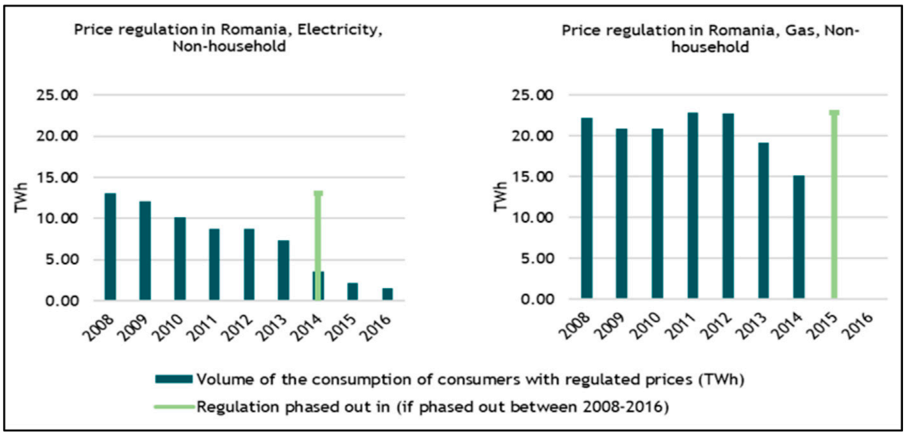

CHART 19
Presentation of price regulation for industrial consumers during 2008 and until 2016. Source: data processing based CEER, 2018.

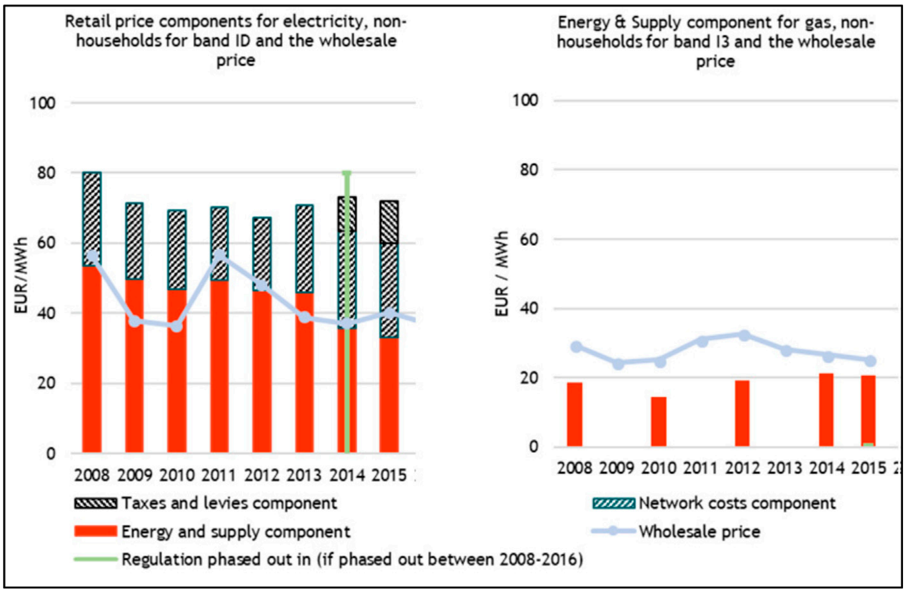

CHART 20
Components of industry retail prices and those wholesale in the Romanian energy market. Source: data processing based Eurostat, 2018.

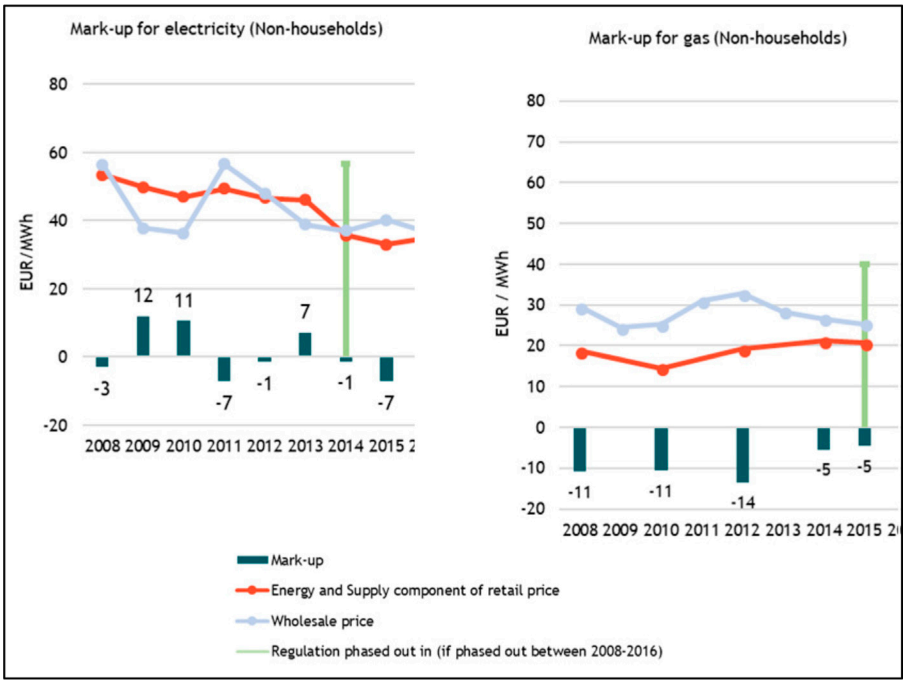

CHART 21
Evolutions of the growth in consumption of the Romanian energy market. Source: data processing based Eurostat, 2018.

replacing conventional energy production with energy based on renewable resources, respectively the reduction of greenhouse gas emissions.

Calculation formula: reduction of the amount of greenhouse gas emissions, as a result of the production of energy from renewable resources, respectively of its neutralization, in tons of CO2 equivalent.

It is calculated by following the steps below:

1. **Calculate the annual electricity production** = capacity to be installed from renewables * annual use period (not less than 1138 h/year for solar energy and 2100 h/year for wind energy)
2. **Calculate the reduced amount of emissions**: the annual electricity production is multiplied by the emission factor, of the national weighted average CO2 for fossil sources based on the data of National Energy Regulatory Agency (ANRE, 2020) report for 2020.

The national weighted average CO2 emission factor according to the ANRE report for each MWh of fossil sources is 0.6177 tons of CO2/MWh.

Indicator 3 "Gross production of energy from renewable resources" = Gross production of energy from renewable resources (wind and solar).

Calculation methodology: Renewable energy production (wind and solar) according to the installed capacity, monitored by the annual reports of registered operators and official statistics.

Indicator 4 "Total electricity production from renewable sources" = Total electricity production from renewable sources (wind and solar).

Calculation formula: Annual electricity production * analysis period (20 years).

As working hypotheses we have structured three possible innovative projects in the field of renewable energy of 50 MW, 100 MW and 150 MW capacity.

At the same time, we start from the working hypothesis that the four key indicators help us to demonstrate the efficiency and effectiveness of investment projects, as well as their sizing at the territorial level in terms of financial resources allocated to each project.

Along with the structure of investment projects, it is necessary on the basis of empirical documentation to identify all support financing programs, as well as regulations on public procurement, "green energy" policy and the instrument of financing investments through public programs, as well as globally—considered representative for the understanding of the studied phenomena.

Results and discussions

In order to respond to the sizing of projects according to the working methodology, it is particularly important to know the financial support at national, European and global governmental level, as well as the financing conditions for each type of eligible project.

A first financial support (EUR 1134.6 billion) is the Multiannual Financial Framework 2021–2027, and which budget has been built in line with European policies at the level of each Member State. The current budget at European level includes grant-type financial instruments and credit-type financial instruments, which is why the funding mix must be carefully analyzed at each level so that the effectiveness of each project is achieved. Moreover, for the first time, a share of 25% of the eligible budget of each project needs to be directed towards environmentally friendly investments, and which have a positive impact on climate change at national and European level.

The European funding programs that support the above-mentioned objectives are the Horizon Europe program (EUR 97.6 billion), being a program that supports innovations in the field and applied research at European level, as well as the Life with a Budget program a total of EUR 5.4 billion, a support program for all actions aimed at the environment and climate change, as well as supporting jobs and supporting a healthy economic environment. Moreover, these support programs, which also directly support European policies, respect "the transition to a low-carbon economy, environmental protection and climate action" (Simionescu, 2021).

Researchers, experts and specialists in the field of renewable resources support through their results both efficient models of use of renewable resources, but especially the efficient use and with appropriate reductions based on technologies at the level of industries and the population. Moreover, close monitoring at European and global level of the use of these resources can be a solution developed in parallel with the identification of efficient renewable resources that can lead to a balanced solution in the context of current energy challenges.

In addition to knowing the energy consumption data of both the population and the economic agents in this study, we appreciate that we should first know the Earth's ability to give the renewable resources so necessary to us all.

Therefore, at the planetary level according to studies falls on Earth each year an estimated power between 85 and 290 W/m2 and appreciating a different gap from one to three in some regions. Quoting Carlo Rubia (Nobel Prize in Physics), Jean-Maria Chevalier recalls that in the Sahara it "rains" every year the equivalent of a barrel of oil per square meter, in solar form[1]. Or, keep in mind that the Earth receives 10,000 times the consumption of primary energy from the Sun annually.[2]

1 to be seen Jean–Maria Chevalier, op.cit.pp 45–46.

2 to be seen Christian Ngõ, op.cit. pp 97.

Therefore, the solar resource is a renewable resource available to everyone, but it also depends a lot on the regions and the number of sunny days.

Among the major producers of solar energy, we can mention Germany and Japan with a percentage of each of these states of 38%, followed by the United States with a percentage of 13% according to existing global studies. Al Gore mentioned in his works that "what comes from the Sun in an hour is theoretically equal to the world's energy consumption in a year".

Another important resource is hydropower using tidal energy (ocean energy) we can consider that water can be appreciated as a renewable resource that can be used continuously. Among the hydropower producing countries we can mention in the top 10 after Christian Ngõ: China, Canada, Brazil, United States, Russia, Norway, India, Japan, Venezuela and Sweden.

Geothermal energy is the next renewable resource that uses the heat of the crust (Earth's temperature), the Italians being among the first to build a plant in 1904 at Larderello. From existing studies and research we find information that a majority of the Earth has a very high temperature, respectively over 10000C. However, current science and technological research have highlighted heat pumps, which are often based on an extremely efficient and reversible principle, namely producing heat in winter and coolness in summer. Sweden is currently the largest producer of geoenergy (over 270,000 production units), and Europe is the continent that uses this renewable resource the most.

Another resource that joins the above is the wind, the global wind potential according to studies is 50,000 TWh. In Europe we have the leaders of this category of renewable resource, namely Denmark and Germany. Followed by these two countries in the ranking of the United States, China and India.

Last but not least in the category of renewable resources based on biomass and biofuels resulting from agricultural products (sunflower, corn, rapeseed, wheat, soybeans, etc.) and wood pulp. However, in the context of the food crisis, there are differing views on the use of agricultural products for electricity production to the detriment of agri-food products and animal feed. Among the leading producing countries of this category we mention the United States and France.

Moving on from the main categories of renewable resources, we appreciate that it is important from existing studies at European level to highlight on the one hand the situation of domestic energy consumers as well as industrial consumers, especially before highlighting the decision to liberalize the market in 2018 with applicability until December 2021.

At European and global level in the context of the European and Global Green Agreement, strategic priorities have been set, and which are currently being transposed into decision-making at state level through decision-making programs.

Developments in international energy prices–price dynamics in the EU

In order to reflect these developments as suggestively as possible, we have used the Rademaekers et al., 2018, from which we have taken all the specific relevant elements both at European level, but especially at national level.

Notes on Charts 1–8: Average and median values differ from EU averages because the values are unweighted and in Table 1 you can see the evolution of the share of energy costs over time in the main activity sectors analyzed at the European level, a situation presented in the same final report (Rademaekers et al., 2018).

Regarding the evolution of prices, costs and energy subsidies for Romania, we also identified in the above-mentioned study, the following considerations relevant to our analysis, respectively: the fact sheet presented in the study was examined by a representative of ANR and the data were adjusted accordingly.

Regulation of household prices in Romania before December 2021

By December 2021, Romania had a regulated energy market (gas and electricity) and gradually began in 2007 (Romania's accession to the EU) and continued through government policies since 2012 price liberalization, while keeping the market regulated through the government apparatus until at the level of 2021. Being a member of the European Union, the liberalization of prices was based on a memorandum with the Commission signed in 2012, and through which Romania liberalized energy prices for both domestic and industrial consumers. The strategic plan is given by the gradual transition to the use of renewable resources and the transition to a sustained policy of green energy production.

The regulated market supported a policy of government intervention on prices and tariff systems established by the regulator. In order to highlight as clearly as possible the situation of price regulation in Romania for households, we present you in the figure below. It is noteworthy that by 2017 the price regulation policies and the transition to the free market had to be eliminated, however according to the agreements with the European Commission, this price regulation was possible until 2021 (Charts 9, 10) when it went directly to the free energy market with all its consequences.

Social support policy for energy prices

The policy of social support of groups vulnerable to tariffs on the market was applied only for electricity and not for gas. The evolutions of social tariffs at the level of 2008 being of 16%, and at the level of 2016 announcing at 10% (CEER, 2018).

As we mentioned for the gas market there is no social policy support in terms of regulation. At the market level, it is worth mentioning the fact that the first three suppliers in the natural gas and energy market had a percentage of 70%, and in recent years about 90%. In the context of market liberalization, we would appreciate not the monopoly but the competitiveness through the emergence of new players that can create the free market in the true sense of the concept of free market.

Evolution of consumer price trends

The evolution of electricity tariffs, knowing slight evolutions, respectively (Chart 11) increased by 0.7% in 2016 compared to 2014, and a trend being in the period 2010 and until 2018 increasing slightly (CEER, 2018).

It is certain that the period in which tariffs were regulated, the impact was minor at the beginning and very difficult to bear at present when the market was liberalized. In the period 2010–2018, the share of disposable income as an indicator spent on energy was very close to the European average (Chart 12). The decrease in energy expenditure was due to a sharp increase in disposable income.

Raising the level of competitiveness of the energy market

Efficiency and competitiveness are directly linked to final consumer tariffs, which is why depending on the source of the resource (especially gas) the price differs from 20 €/MWh (domestic) compared to the import tariff which is significantly higher. For the electricity component, the wholesale price was close to the retail price, justified also by the fact that the electricity production is mostly local, which allows the efficiency and competitiveness policy to be under the influence of internal factors and more limited under the influence of external factors (Chart 13).

It is noteworthy that according to the graphs below the price developments were negative until 2013, and the price experienced an upward trend reaching in 2016 to increase to 7 EUR/MWh. Compared to other European countries, Romania has evolved for many years with an upward but negative trend.

The effects of energy on vulnerable groups in poverty

In the chart below (Chart 14) and based on the policy of regulation and support we can see a downward evolution of the indicators presented in the chart since 2008. However in the context of liberalization at present (2022) these groups have become very vulnerable and government policies must specifically aimed at supporting them, based on both the past and the present, in order to be able to project a more predictable future.

Quality of services with utilities (electricity and gas)

The evolution of the quality of services provided to consumers is directly related to the satisfaction of the final consumer and the quality of the services offered to consumers.

Consumer satisfaction

In recent years, the consumer satisfaction indicator for the services provided by energy markets has experienced an increased positive evolution over time, based on the decade of the market in 2010 and 2011, respectively energy remained at a relatively low level of stagnation (Chart 15).

The graphs below (Chart 16) show that for both electricity and gas, consumers' ability to compare products or services has been stable over time (with a score of about seven on a scale of 1–10). For electricity, the perceived ease of switching increased from 2011 to 2015 (after a sharp decrease in 2011 compared to 2010). For gas, the perceived ease of switching decreased between 2013 and 2015.

The consumer's options

At present we cannot discuss a standardization of options but only a direct influence of it by direct factors related to the purchasing power of the final consumer. As can be seen from the graph below, the consumer's choice can be induced by a reduction of up to 15% of the total value of the bill in which the energy services are mentioned, and implicitly depending on this aspect the consumer can opt for one supplier or another, which is also a limitation of this study (Chart 17).

The graphs below (Charts 18, 19) show different offers on the market for both the gas component and electricity.

Regulation of non-household prices in Romania

Romania has gradually eliminated the regulation of energy prices for both domestic and industrial consumers starting with 2014 for electricity consumption and continuing with 2015 for gas consumption. A small part of the final consumers still benefited from regulated prices. For industrial consumers, price regulation ended in 2014 (ANRE, 2014), however, there were occasional interventions during 2014 and until 2016 in a limited share for these consumers. This share reached 4.2% in 2016. From 2015 until now, the regulation of gas prices for non-household consumers has been abolished (Romanian Energy Regulatory Authority, 2017; ANRE, 2020).

Competitiveness issues in the context of regulations

The evolution of energy prices for both industries and household consumers has created a "proxy" in the efficiency of competitive players in the market. Moreover, competition was assessed in terms of both retail and wholesale price developments, as can be seen in the graph below (Chart 20), and regulation or deregulation was the decisive influencing factor in the national market.

The evolution of competition in terms of competitiveness and efficiency is evolving as shown above, but the profit indicator at the level of energy suppliers is the one that is also correlated with the increases practiced by them. Moreover, at the level of markets, increases in retail prices are determined as the difference between the wholesale price and the retail energy price.

In the projection below (Chart 21), the figures show that price increases are directly proportional to increases in the price of wholesale energy, as well as increases in energy in 2009, 2010, and 2013. In the energy component gas can be seen from the graph increases, but negative (2014, respectively 2015), as can be seen directly in the graph.

Between 2008 and 2016, the Romanian energy market experienced a clear tariff deficit. Moreover, negative growth influences as we have shown on the energy market were registered during this period and due to the fact that for certain periods of time the energy market regulations were present, but the income deficiencies were mainly generated by the price policy, and these were often not optimal in terms of expenditure (European Commission, 2014) At the same time, starting with 2014, the intervention of the European Commission both in the area of tariff deficiencies, but especially in the area of performance and competitiveness of regulated companies in the energy field (European Commission, 2014), highlighting on the one hand that regulated prices were not properly assessed, respectively they were small compared to the European average. Starting with 2021, respectively with the liberalization of the Romanian energy market, the evolutions of the tariff deficits were adequate and did not represent a problem compared to the European average. However, the lack of regulation cannot be said to be directly proportional to the tariff deficit, which is why at government level the proposed strategies and action plans seek to identify optimal solutions and on the one hand to meet consumer needs and on the other hand to align with policies and regulations at European level, especially in the context of military conflict with a direct impact on the energy market at national and European level. So, the energy transition poses many challenges for both public authorities and companies and consumers, which is why the concerns of European officials have been focused on achieving a fairer process for the parties involved. Liberalization of the energy market but also the political tensions generated by energy dependence will have negative effects on consumers who will face the intensification of the phenomenon of energy poverty (Dobrowolski, 2021), (Dobrowolski and Drozdowski, 2022), (Neacsa et al., 2020), (Druică et al., 2019), and (Apergis et al., 2022).

Through the presented results we wanted to highlight through the analyzed indicators the state of the domestic and industrial consumer at the level of a member state of the European Union (Romania), so that the solutions offered by decision makers both locally and at European level through the legislature and the regulations providing for this green transition, be carefully structured on the basis of strategies that support this transition from conventional to renewable sources of electricity production, and through funding programs and European directives that support through resources and financial instruments investments in electricity generation capacity based on renewable resources, to come as support to sustainably succeed this move to the green transition. Moreover, the efforts of both the population and the industries must be sustained so that they can reasonably pay for their energy consumption on the one hand, and on the other hand succeed in making financial investments in order to produce green energy for own consumption (for the domestic consumer) and for own consumption and for the energy system (for the industrial consumer). Through future discussions, we aim not only to assess the impact of decisions at national and European level in 2018–2022, but especially to analyze the profile of domestic and industrial renewable energy consumers, as well as to highlight solutions for energy policy, but especially for green investments, all the more so as the whole process of sustainable societal transformation has as its clear target the year 2050.

Conclusion

Referring to history, 1933 was the year that President Roosevelt F.D. to get the US out of the disastrous situation of the financial and economic crisis initiated and launched the economic program "New Deal," and today with the specific elements of the present we are in a period of multi-crisis, which leads us to consider that this program of The European Commission "The New Green Deal" comes as a solution to economic recovery in the context of the current situation. Green energy is an integral part of the strategic directions until 2050. It should be noted that from the point of view of the regulatory framework at European level, the energy market has a stable framework since 2011, when the action plan on the European energy market until 2050 was also designed.

In our paper, in addition to the clear identification of renewable resources and the clear projection of the real situation in energy and gas consumption in Romania, we appreciate that only through a uniform support related to renewable resources and consumption can we move to the transition to green energy. Moreover, the emission reduction limitations of up to 60% in 2030 and 80% in 2040, respectively, compared to the level of 1990, determine us to continue our research, so that starting with the following years in addition to the indicators reflected in this study to analyze the types of energy used by both domestic and industrial consumers, as well as the level of emission reduction through their use. However, from our point of view, the sudden transition to green energy cannot be borne by citizens, which is why stages such as 2030, stage 2040 and stage 2,950 can be achievable and sustainable stages. Due to the lack of data, some of the indicators could not be presented until 2018, and this is a limitation of our study, but a determination to continue our future research.

The proposal through policies and regulations at the level of the European Commission for the EU to become neutral by 2050 in the current climate context, respectively the support through financing programs of member states' economies and the establishment of these neutral and zero greenhouse effect economies, determines us not only to state that we will continue our research, but we will also try to outline applied economic models in different fields of activity and especially in the development of financial instruments to support these decisions and activities. Predictability also comes in the context of the objectives mentioned in the European Green Agreement, as well as in the context of existing global commitments and negotiations to support the Paris Agreement and against climate change, being a global action, and our research in this field we can say that it will create a multiplying effect, being a global problem. In addition, we will continue to engage in our future research both in the evolution of this topic and in the adoption of the European energy market, including market liberalization and the removal of regulated prices.

Moreover, this transition can also open new horizons of opportunity through our innovative capacity to actively participate in a sustainable and better future in the context of these climate constraints and through the active involvement of research, government and business environments and not least of the citizens, given the fact that "energy" is a necessary resource for the well-being of each of us. Therefore, the continuation of our research in this field is not only a desire, but rather an obligation, being part of this just societal ecosystem.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

Conceptualization, LZ, OM, and IM; methodology, OM and IM; validation, OM, IM, and OF; formal analysis, OM, IM, and OF; investigation, OM, IM, and OF; resources, LZ, OM, IM, and OF data curation, OM, IM, and OF; writing—original draft preparation, LZ and OM; writing—review and editing, LZ, OM, IM, and OF; supervision, OM; project administration, OM; funding acquisition LZ. All authors have read and agreed to the published version of the manuscript.

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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A Study on Public Perceptions of Carbon Neutrality in China: has the Idea of ESG Been Encompassed?

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China has pledged to become carbon neutral by 2060 and has employed a variety of strategies to minimize carbon emissions. As people's support to achieve the carbon neutrality goal affects its success, this study reviewed the public's perception of carbon neutrality via cluster analysis on microposts. The co-occurrence matrix showed 258 nodes and 3,212 ties in the carbon neutrality social network. The top five most prominent nodes were neutralized, energy, China, blue-green, and economy. The keyword like blue-green (means water and plant) illustrated the popular terminology used by mainland Weibo users and its essential role in carbon neutrality. The multidimensional scaling analysis found that there were 11 clusters in carbon neutrality. The results revealed that people's concerns about carbon neutrality were mainly related to the environment (e.g. low carbon, sustainable, and wind power), social (e.g. country and poverty), and governance (responsibility, government report). Weibo users believed that achieving carbon-neutrality allows us to pursue a better life. Among the data collected, positive sentiment microposts (83.9%) were approximately eight times more than the negative ones (9.9%), and only 6.3% were neutral. The results indicated that most Weibo users were opitimistic on carbon neutrality.

Keywords: carbon neutrality, China, cluster analysis, Weibo, sentiment analysis, ESG

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1 INTRODUCTION

One of the most serious environmental problems and difficulties people confront in the 21st century is global climate change (Wei et al., Forthcoming 2022). Thus, the idea of environmental, social, and governance (ESG) is suggested. Listed companies have to submit ESG reports as required by some stock markets. Similarly, carbon neutrality has become an essential agenda in global climate governance. As of 22 April 2022, 83 countries worldwide have set their goals to reduce global carbon emissions by 74% (Climate Watch 2022).

Parties are urged by the Paris Agreement to submit their most recent nationally determined contributions and long-term low-temperature greenhouse gas emission development policies by 2100. The proposal was made during the Paris Climate Peace Conference in 2020 to attain carbon neutrality targets between 2050 and 2060. China, a growing nation, has pledged to the international community that it will become carbon neutral by 2060. (Zhao, 2022). In September 2020, the Chinese government set a goal to achieve carbon neutrality by 2060 (Huang et al., 2022).

TABLE 1 | Carbon neutrality strategic plans in China from 2003 to 2021.

Time	Plan
14 January 2003	Circular of the State Council on Printing and Distributing China's Action Plan for Sustainable Development in the Early 21st Century
28 March 2008	Several Opinions of the State Council on Promoting the Sustainable Development of Resource-Based Cities
20 August 2013	Notice of the Ministry of Transport on Printing and Distributing the Guiding Opinions on Accelerating the Development of Green Circular and Low-Carbon Transportation
2 December 2013	Notice of the State Council on Printing and Distributing the National Sustainable Development Plan for Resource-Based Cities (2013–2020)
30 April 2014	Notice of the National Development and Reform Commission on printing and distributing the Interim Measures for the Promotion and Administration of Energy-Saving and Low-Carbon Technologies
20 February 2015	Interim Measures for the Administration of Carbon Emissions Trading
20 December 2015	Measures for the Administration of Certification of Energy-Saving and Low-Carbon Products
13 December 2016	Notice on the Construction Plan of China's Innovation Demonstration Zone for the Implementation of the 2030 Agenda for Sustainable Development
20 September 2019	Guidelines for the Implementation of Carbon Neutrality in Large-Scale Activities (Trial Implementation)
26 October 2020	The 14th Five-Year Plan for National Economic and Social Development and the Long-Term Goals for the Year 2035
22 February 2021	Guiding Opinions on Accelerating the Establishment and Improvement of a Green and Low-Carbon Circular Development Economic System
10 March 2021	Administrative Measures for Carbon Emissions Trading (Trial Implementation)
11 March 2021	Outline of the 14th Five-Year Plan for National Economic and Social Development of the People's Republic of China and The Long-term Goals for 2035.
26 April 2021	Opinions on Establishing and Improving the Value Realisation Mechanism for Ecological Products
12 September 2021	Opinions on Deepening the Reform of the Compensation System for Ecological Protection
22 September 2021	Opinions on the Complete, Accurate, and Comprehensive Implementation of the New Development Concept to do an Excellent Job in Carbon Peak Carbon Neutrality
10 October 2021	National Standardization Development Program.
21 October 2021	Opinions on Promoting the Green Development of Urban and Rural Construction
24 October 2021	Opinions of the CPC Central Committee and the State Council on The Complete, Accurate, and Comprehensive Implementation of the New Development Concept to Do a Good Job in Carbon Peaking and Carbon Neutrality
26 October 2021	Notice of the State Council on Printing and Distributing the Action Plan for Carbon Peaking by 2030
27 October 2021	China's Policies and Actions to Address Climate Change

https://www.ndrc.gov.cn/?code=&state=123

The idea of sustainable development, green mountains, and clear water existed long ago on China's agenda. Similar to this is the notion of "carbon neutrality". China explores the means to reduce carbon emissions under the premise of industrial transformation and maintain rapid economic development simultaneously. However, cooperation between businesses and individuals to realise national policies is crucial for reaching carbon neutrality. As a result, its success depends on how much a nation's citizens care about, are aware of, and support achieving carbon neutrality (Shi 2006).

This article reviews people's concerns on Weibo because of the abovementioned lines of thoughts. Weibo is one of the most well-known social media platforms in mainland China (Zeng and Li, 2022) that enables people to publish their opinions online. Analyzing the published posts reflects people's sentiments and perceptions on social issues. It can overcome traditional questionnaire problems, such as inadequate response (Li et al., 2022). Moreover, collecting people's perception allows us to obtain the real-time data (Lee et al., 2022, forthcoming). All these drive us to use a relatively new approach to collect data from Weibo, rather than collecting data *via* survey.

In the following sections, **Section 2** examines China's strategic approach to reducing carbon emissions. The literature review in **Section 3** introduces Weibo and the databases we explored for information on carbon neutrality in China. It also exemplifies earlier studies on emotion analysis and carbon neutrality. **Section 4** provides examples of the research approach and findings. **Section 5** wraps up the article.

2 CHINA'S STRATEGIC PLAN FOR CARBON NEUTRALITY

China has set a target of reaching a peak in carbon dioxide emissions by 2030 and working toward carbon neutrality by 2060. China's achievements have suggested that economic growth does not necessarily have to slow down to attain the goal (State Council of the PRC, 2021a). Since the Communist Party's 18th National Congress, China has completed 960 million mu (about 64 million hectares) afforestation. The forest cover increases by 2.68%–23.04%.

China's strategic plan at the national level regarding carbon reduction can be summarized as commitments, systematic planning, and implementation. **Table 1** shows China's important national documents on carbon reduction since 2003.

The State Council of the PRC's circular on Printing and Distributing China's Action Plan for Sustainable Development in the early 21st century (State Council of the PRC, 2003) highlighted the philosophy behind China's sustainable development strategy focuses on people-oriented, harmony between human and nature as the primary concern, economic development as the core target, improving people's quality of lives as the starting point. Scientific, technological, and institutional innovation, constantly promotes the coordination between resources, and improves China's national strength and competitiveness, and lays a solid foundation to realizing the third-stage strategic goal.

Notice of the State Council on Printing and Distributing China's Implementation of the 2030 Agenda for Sustainable Development Innovation Demonstration Zone Construction Plan (State Council of the PRC 2016) centered on the implementation of the 2030 Agenda for Sustainable Development and aimed at reaching future development goals in poverty reduction, health, education, and environmental protection. While innovation is the driving force, China will promote economic and social development. The target year of the agenda for reaching the goal of sustainable development is the same as reaching a carbon peak in 2030.

In 2021, the State Council initially released their opinions on carbon neutrality and carbon peak (State Council of the PRC, 2021b). The proposal highlights the attainment of carbon peak and carbon neutrality as a the direction. Building a community with a common destiny for all of humanity is a solemn obligation.

The Action Plan for Carbon Peak before 2030 (State Council of the PRC, 2021c), published by the State Council on October 26, 2021, outlined China's development strategy and ideology for reaching a carbon peak.

3 LITERATURE REVIEW

3.1 Carbon Peak and Neutrality

According to the Intergovernmental Panel on Climate Change (IPCC, 2022), "carbon neutrality" refers to the anthropogenic emissions of carbon dioxide that are balanced by anthropogenic removals over a particular period. A "carbon peak" has been proposed in line with the carbon neutrality concept. It is defined as where carbon dioxide emissions reach the peak, stop increasing, and then fall. Prior to achieving carbon neutrality, the carbon peak must be reached.

Using industrial data from China, Zhang et al. (2021) evaluated how the carbon trading industry will affect economic production and carbon emissions. China may be able to meet the 2060 carbon neutrality goal, according to research by Yang et al. (2021). Due to the widespread use of coal-fired power, Wyrwa et al. (2022) investigated how to achieve carbon neutrality and suggested solutions. From the construction industry standpoint, Sun et al. (2022) carried out the research and review on achieving carbon neutrality in the construction industry. Some studies have investigated the relationship between renewable energy and carbon emission reductions (Gullberg et al., 2014).

3.2 Weibo

In China, the general public's favorite social media is Weibo. It allows users to share information in words, images, and videos (Zeng and Li, 2022). In the 2017 Research Report on the Development of Internet Governance in China (Zhang and Lu, 2018), websites and social media were the main news sources, followed by WeChat and Weibo. WeChat (27%) and Weibo (38%) were the top three media information dissemination channels. Despite WeChat is also a social media platform, it serves a fundamentally different purpose than Weibo. Weibo is frequently referred to be Chinese Twitter, although WeChat is comparable to "WhatsApp." Weibo had 249 million average daily active users and 573 million monthly active users by the end of 2021, according to the company's 2021 fourth quarter and full-year financial report (Weibo 2022). In 2020, people who learned about COVID-19 through Weibo made up 57.74% throughout the pandemic preventive and control phases (Zhu and Pan, 2021).

Weibo users can look for microposts that contain specific themes by keyword search on Weibo users can create tags that resemble Twitter's tags. However, the syntax is #tag#. A tag is typically used for a more specific event, making it easy for others to search for and discuss. Instead of focusing on tags, this study examines the entire contents of Weibo micro posts. This is because the search results encompass all those with tags. A micropost would not appear in search results if it was published without a "#tag#."

For instance, Tommy wrote on a micropost that carbon neutral is incredible! "#Carbon neutral is impossible#" said Janet in a blog post. As there is no "#tag# in Tommy's micropost, nobody could see his by searching for the tag. Yet, Janet"s posts could be seen.

3.3 Sentiment Analysis

Sentiment is an essential part of human beings. People express their sentiments and opinions about a topic through their posts on social media. Sentiment analysis uses computer algorithms and a word dictionary to automatically extract users' emotional states. Public opinion analysis, information prediction, information screening, personalized recommendations, and many other industries have benefited greatly from this kind of analysis (Poria et al., 2017). Song et al. (2022) studied linguacultural differences by analyzing Twitter sentiment *via* machine learning. It found that more positive English tweets were more likely to be retweeted. Nevertheless, more negative French tweets were more likely the tweets to be retweeted. Yao et al. (2021) found that there was a positive correlation between retweets and favorites in construction safety knowledge sharing.

On the Internet, bad news has constantly been circulated. In the Chinese proverb "seven emotions and six desires," four express negative emotions. Weibo's share of the first adverse event reports is as high as 75.6%, according to studies by Yin et al. (2011) and Tang et al. (2021). People are inherently more sensitive to unpleasant feelings.

4 RESEARCH METHOD AND RESULTS

This study obtained the real-time Weibo data, it involved three main processes: data crawling, clustering and sentiment analyses (**Figure 1**). It investigated 11 sets of keywords in Chinese: 1. carbon peak, carbon-neutral, industry, and adjustments; 2. Carbon neutral and achieve target; 3. Carbon neutral and regulations; 4. Carbon-neutral, economy, and industry; 5.

FIGURE 1 | Research flow chart.

TABLE 2 | Total amount of the Weibo data.

Keywords	Number of massages	Keywords in Chinese
Carbon peak, carbon-neutral, Industry, and Adjustment	1,416	碳达峰 碳中和 产业 调整
Carbon-neutral; Achieve target	1,180	碳中和 达到目标
Carbon-neutral; Regulations	394	碳中和 规定
Carbon-neutral, Economy, and Industry	951	碳中和 经济 产业
Carbon neutrality, Achieve, and Target	66	碳中和 目标 达标
Carbon-neutral; Photovoltaic	978	碳中和 光伏
Carbon peak, carbon-neutral, and Sustainable development	991	碳达峰 碳中和 可持续发展
Carbon-neutral, Two Sessions, and Proposal	60	碳中和 两会 提案
Carbon-neutral, Practices, and Regulations	12	碳中和 实践 规定
Carbon-neutral; Life change	719	碳中和 生活 改变
Carbon-neutral, Two Sessions, and Economy	271	碳中和 两会 经济
Total	7,038	

Carbon neutrality, achieve, and target; 6. Carbon-neutral and photovoltaic; 7. Carbon peak, carbon-neutral, and sustainable development; 8. Carbon-neutral, two sessions and proposal; 9. Carbon-neutral, practice, and regulations; 10. Carbon-neutral and life change; and 11. Carbon-neutral, two sessions (**Table 2**).

4.1 Keyword Search Results

There are 7,038 relevant microposts from Weibo. After deleting the same microposts from the same users and irrelevant content, there are 3,851 carbon neutrality microposts. The co-occurrence matrix is analyzed from UCINET 6. Degree Centrality is the most direct measure of node centrality in network analysis. The larger the node the higher is the degree of centrality, and the more influential the node is in the network. From **Figure 2**, 58 nodes and 3,212 ties are observed. The top five most prominent nodes are neutralized, energy, China, blue-green (in mainland China, blue green refers to the water and plant), and economy, which are vital keywords in carbon neutrality. Keyword like blue-green reflects Chinese slang used by Weibo users.

The cluster analysis method uses the statistical method of clustering, takes the frequency of co-word occurrence as the research object, simplifies the co-occurrence network into the relationship between several groups, and visually illustrates the results by clustering. Multidimensional scaling analysis finds the topic structure by measuring the distance between topic words and can intuitively judge the position of a research field within the discipline. The KHCoder is used to perform the clustering of research samples from Weibo. In **Figure 3**, there are 11 clusters. The most crucial cluster includes carbon, neutrality, goal, industry, development, new, green, adjustment, structure, consumption, low-carbon, transformation, sustainable, economic, and social. The second-largest cluster includes country, emission, reduction, major, and responsibility. The third-largest cluster includes capacity, power, and generation. It also reveals various people's concerns on carbon neutrality link to the environment (e.g. low carbon, sustainable, and wind power), social (e.g. country and poverty), and governance (responsibility and government report).

4.2 Keyword Search Results

4.2.1 Carbon Neutral, Economy, and Industry

High-frequency words included the following among the 951 microposts found using the keyword search "carbon neutral, economy, and industry", high-frequency words included the following: Development and Reform Commission, slip,

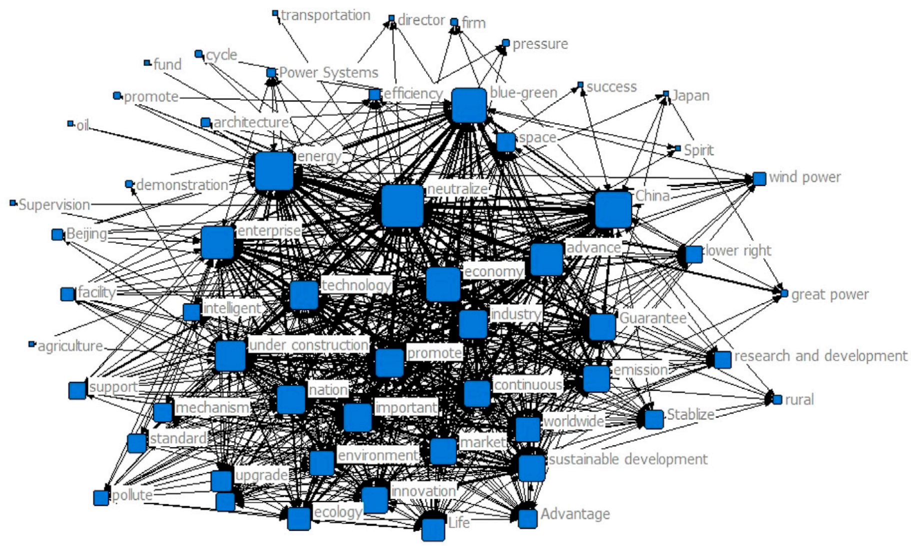

FIGURE 2 | Co-occurrence matrix analysis.

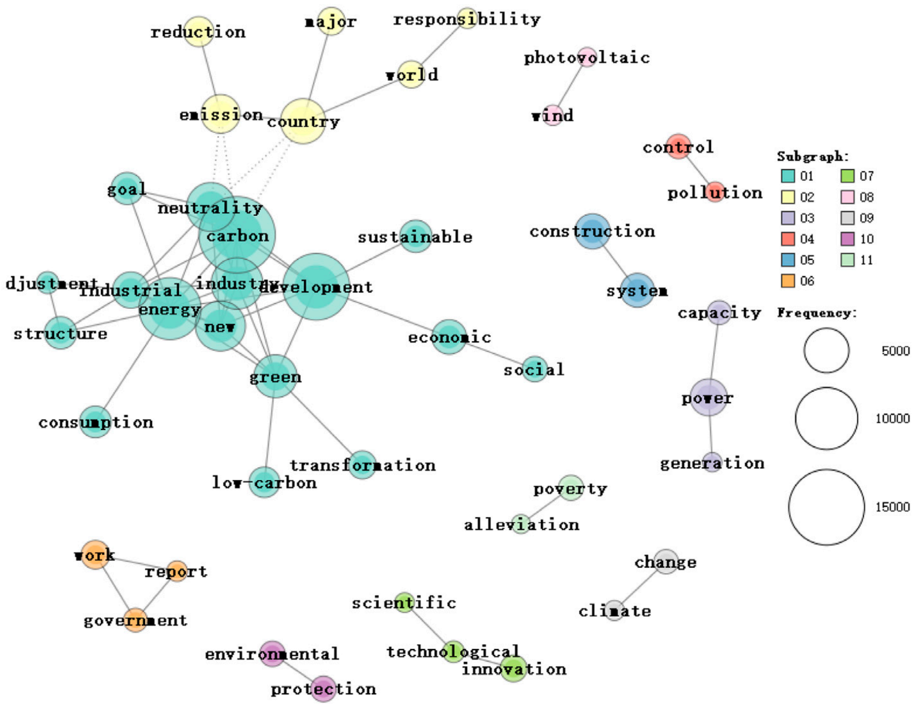

FIGURE 3 | Co-occurrence network analysis.

COVID-19, unfavorable, new energy, digitizing, optimization, low carbon, transformation, the 14th Five-Year Plan, green finance, strive, environmentally friendly, digital economy, and persist in **Figure 4**.

Low-carbon (333), new energy (239), and transformation (292), appeared to be the most often stated keywords (one to five words) connected with "carbon neutral, economy, industry" in the findings of tokenisation. It is consistent with the national goal of industrial transformation to drive low-carbon economic development and new energy development.

Positive high-frequency keywords are associated with new policies (National Development and Reform Commission,

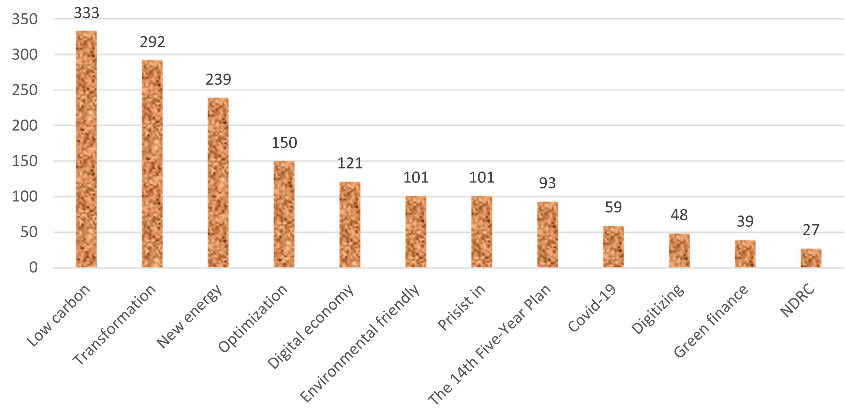

FIGURE 4 | Most mentioned keywords for "Carbon-neutral, Economy, and Industry" in Weibo microposts.

Transformation, and 14th Five-Year Plan), digitization (digital economy and green finance), and new energy (low carbon and environmentally friendly). The words "persist in" and "strive" convey the nation's and its citizens' confidence in driving economic growth through industrial transformation.

4.2.2 Carbon Peak, Carbon-Neutral, Industry, and Adjustment

There were numerous duplicates among the 1,416 microposts for the keywords "Carbon peak, Carbon-neutral, Industry, and Adjustment." Forty media sites, for instance, published the same micropost regarding the "China Carbon Peak Carbon Neutrality Progress Report in 2021" 623 unique microposts left after removing duplicates. The following words frequently appeared in the high-frequency keywords list: energy, develop, carbon peak, carbon-neutral, new, green, accomplish, enterprise, China, promote, industry, advance, work, industrial structure, and target (**Figure 5**).

The keywords "carbon peak, carbon-neutral, industry, and adjustment" were mentioned in 177 microposts, which made up 28.41% of all posts. This demonstrates that Weibo users consider industrial change is important to reach carbon neutrality. Among them, 52 microposts has unique authors who commented on "Guiding Opinions on Promoting the High-quality Development of Central Enterprises and Doing a Good Job of Carbon Peak carbon neutrality." These comments centre on the government's declarations: "by 2025, the adjustment and optimisation of the industrial and energy structures of central enterprises will make significant progress; the energy utilisation efficiency of key industries will be greatly improved; the construction of new power systems will be accelerated; the research, development, and promotion and application of green and low-carbon technologies will make positive progress; total energy consumption of the output value of central enterprises will be reduced by 15% as compared with 2020; the output value of 10,000 yuan will be reduced by 18% compared with 2020; and the proportion of renewable energy power generation capacity will reach more than 50%. The proportion of revenue of strategic emerging industries is not less than 30%, laying a solid foundation for achieving the carbon peak."

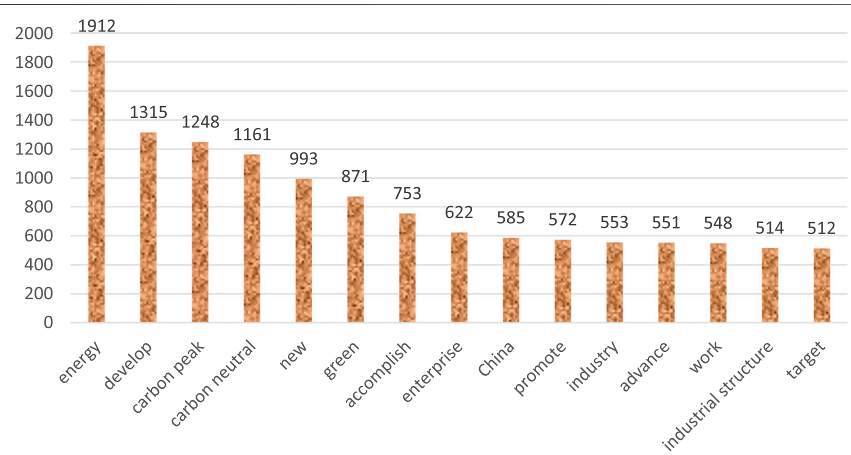

FIGURE 5 | Most mentioned keywords for "Carbon peak, Carbon-neutral, Industry, and Adjustment" in Weibo microposts.

4.2.3 Carbon Neutrality in the Photovoltaic Sector

The microposts on carbon neutrality have frequently brought up the photovoltaic business. This article gathered data using the keywords "photovoltaic and carbon neutral." As the growth of the new energy sector inextricably links to the achievement of carbon neutrality (Liu and Lu, 2022), China places much significance on the photovoltaic industry as one of the new energy sectors. The photovoltaic industry in China is currently heavily dependent on government subsidies despite being a crucial new energy source and component of the optimisation of energy transformation. The power generation cost is high, continued technology advancement and extensive grid connections are required.

The user's investment history in the photovoltaic business and the private investment proposal for the sector made up around half of the data. Many Weibo users expressed their worries about the situation in Europe, they asked, "Will Western European countries leave carbon neutrality, abandon the photovoltaic industry, and turn to cheaper thermal electricity in the context of the Russian-Ukrainian conflict?" Is it necessary to halt investments? Because the consumers lost money when they invested in the photovoltaic sector, some micropost entries denigrated the photovoltaic industry and carbon neutrality.

Users' perspectives on the growth of the photovoltaic industry in China were more favorable. Microposts from various regional and solar enterprises make up about one-third of the data. After all the photovoltaic power is used, diesel will be reduced by over 1,000 tons annually, and carbon dioxide emissions will be lowered by more than 3,000 tons. The shelter forest covers 3,128 hectares, can absorb approximately 20,000 tons of carbon dioxide annually, neutralies cars' carbon emissions. Users' support for carbon-neutral legislation and satisfaction with national accomplishments can be seen in microposts. Thirteen distinct microposts evidenced photovoltaic energy's role in Beijing's commitment to the Winter Olympics' carbon neutrality, reaffirming the viability of photovoltaic energy generation.

Regarding the set of keywords energy, develop, power generation, industry, electricity, construction, market, and green. Micropost users most commonly used "energy" in this keyword group. It appeared 1,515 times, more than twice as frequently as the runner-up "development" (710). Industry only appeared 415 times, or approximately 25% as often as energy (**Figure 6**).

All in all, the development of the photovoltaic industry is viewed as being crucial throughout the nation, and Weibo users are optimistic about the industry's future in China.

4.2.4 Carbon Neutrality and Change in Life

The keyword "carbon-neutrality, change in life" was chosen to determine users' views about how carbon neutrality affected life. With this particular collection of keywords, 719 results were obtained. 388 remained after deleting duplicates. 237 of the 388 were deleted as all these related to "CBN carbon-neutral communities." These posts began with "#CBN Carbon Neutral Community#". Although all the words seem to be different, they shared the same contents: "Come and buy the concept of CBN." Moreover, all the writers' ID format was "CBN" and "Chinese character" and "number" or "Chinese character and number." These micropost were marketing and advertising.

After deleting the micropost related to "CBN," 151 remained. **Table 3** shows some CBN microposts. These data differ from others as the microposts about foreign countries are collected. People frequently brought up energy (561) and the economy (432) when discussing how their lives have changed, and 15 (10%) microposts mentioned "Japan." A phrase that featured four times was "the Japanese government called the people to adjust their eating habits, eat more vegetarian cuisine, and contribute to reaching carbon neutrality." "Develop" was the word that appeared the most frequently (773) (**Figure 7**).

4.2.5 Carbon Neutrality, Targets, and Achieve

Five of the 66 microposts on "carbon neutrality, targets, and standards" cited electricity limits as a way to reach carbon neutrality objectives in some locations. The standard power-using activity should not jeopardize carbon neutrality, according to all five microposts. A micropost read, "China has stated it will accomplish

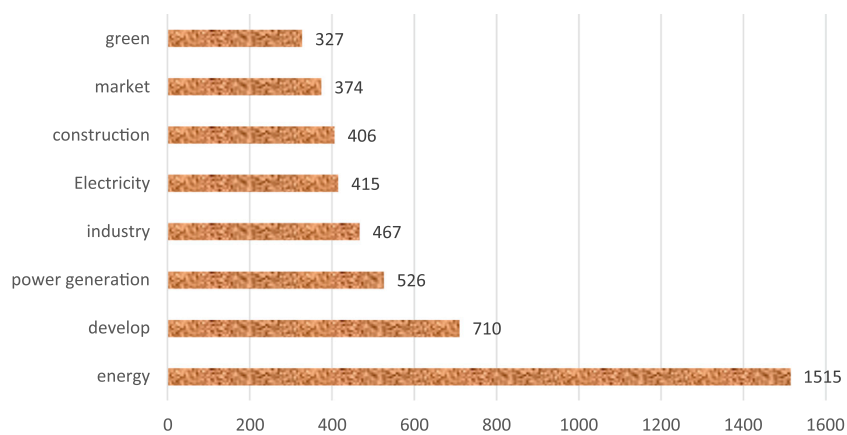

FIGURE 6 | Most mentioned keywords for "photovoltaic and carbon-neutral" in Weibo microposts.

TABLE 3 | Some of the "CBN" blogs.

A	Blogs
FENG***	#CBN Carbon Neutral Community#Do not leave life with regrets and regret. We should seize every opportunity to change our lives as much as possible. Now, the carbon-neutral CBN green financial chain is coming. Do you want to grab it to change your life?
QI***	#CBN Carbon Neutral Community#Do not leave life with regrets and regret. We should seize every opportunity to change our lives as much as possible. Now, the carbon-neutral CBN green financial chain is coming. Do you want to seize it to change your life?
QING***	#CBN Carbon Neutral Community# In order not to leave life with regrets and regrets, we should seize every opportunity to change our lives as much as possible. CBN 15% handling fee is strongly destroyed + automatic dividends for holding coins + underpinning makes the price of the currency fall and does not rise. The only contract address for pancake trading on Binance Chain: 0x3008ebba0131a6085fcc230ef947ed8f8f12346f
C***	#CBN Carbon Neutral Community# CBN Carbon Neutral Community Do not leave life with regrets and regret. We should seize every opportunity to change our lives as much as possible. Now, the carbon neutral CBN green financial chain is coming, do you want to seize it to change your life?
ZHI***	#CBN Carbon Neutral Community#Some people complain that life is unfair, but they do not want to change themselves. Some people work hard for a long time but always stop halfway at the critical moment. No one is born a king. On the way to growth, do not always think about where there is light, just run forward. Dreams are not empty words but the fruit of hard work in the lonely struggle! CBN family, happy Laba Festival! ! !
T***	#CBN Carbon Neutral Community#Some people complain that life is unfair, but they do not want to change themselves. Some people work hard for a long time but always stop halfway at the critical moment. No one is born a king. On the way to growth, do not always think about where there is light; just run forward. Dreams are not empty words but the fruit of hard work in the lonely struggle!
Q***	#CBN Carbon Neutral Community#CBN Carbon Neutral Community CBN If you did not get on, hurry up and get on! Do not miss this opportunity. Conditions Online and offline community. The strongest Weibo, super talk, finance, and economics section of the entire network is the first hot search...What you missed is the opportunity of turning 100 yuan to 2 million yuan‼

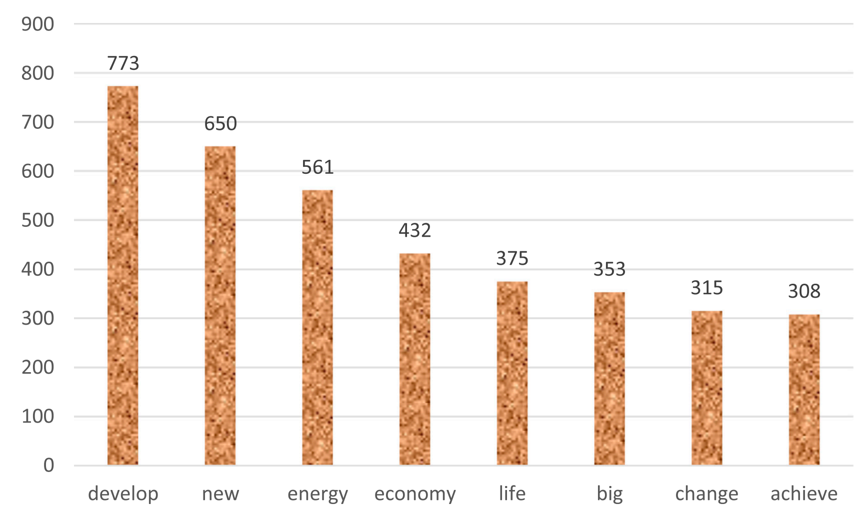

FIGURE 7 | Most mentioned keywords for "carbon neutral and life change" in Weibo microposts.

the carbon neutrality goal between 2030 and 2060. The global ecology demands a great deal of sacrifice and work. Naturally, the nation will restrict the production of coal-fired power! The central government has already proposed environmental protection indicators. There will be many "sudden shutdowns" if the local government continues to operate the same way as before.

Another lengthy micropost detailed locals' worries about power outages in Liaoning Province. Residents in Liaoning experienced "failure" of road traffic signals and had to purchase candles for unexpected power outages. They were concerned about how the power outages would affect the winter heating. Rising thermal power costs severely negatively impact Liaoning Province's economy (Liaoning Province Development and Reform Commission 2021). The Liaoning provincial government stated that it would not falsify the data to achieve carbon neutrality and pay close attention to people's livelihood (Liaoning Province Development and Reform Commission 2022). The micropost mentioned: "Can the power grid handle harsh temperatures with the new energy it relies on so heavily? This must be taken into consideration as renewable energy is developed."

"The Corolla icon that has been with me for 16 years will finally be changed," a user wrote in a post. "I have used this car for more than ten years without any issues. Only the emission standard symbol or national III needs to be replaced to reach the carbon neutrality goal. Although there is little data, users are aware of the aim of carbon neutrality and are prepared to put effort into achieving it. However, when achieving carbon neutrality conflicts with daily lives, everyday life needs should come before achieving carbon neutrality. Under this set of keywords, the word that appears the most frequently is "develop" (154), followed by "construction" (132). The additional two words that are more frequent are "project" (116) and "new" (106) (**Figure 8**).

4.2.6 Carbon Neutrality and Two Sessions

The Chinese People's Political Consultative Conference and the National People's Congress of the People's Republic of China are referred to as the "two sessions" collectively. This is mainly because of their timing and importance. The People's Republic of China's National People's Congress is the highest-ranking body in state power. The Standing Committee of the National People's Congress is its permanent organization. The state's legislative authority is exercised by the National People's Congress and its Standing Committee. Representatives chosen by provinces, autonomous regions, municipalities directly under the Central Government, special administrative regions, and the military make up the National People's Congress (National People's Congress. 1982). The Chinese People's Political Consultative Conference is a crucial

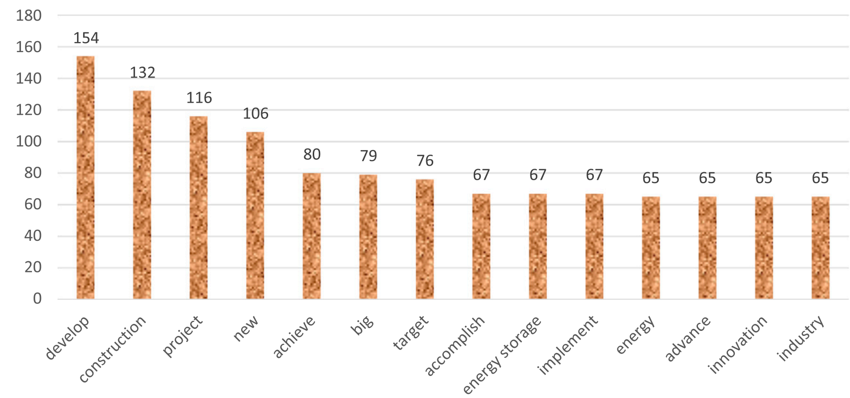

FIGURE 8 | Most mentioned words for "Carbon neutrality, Targets, and Achieve" in Weibo microposts.

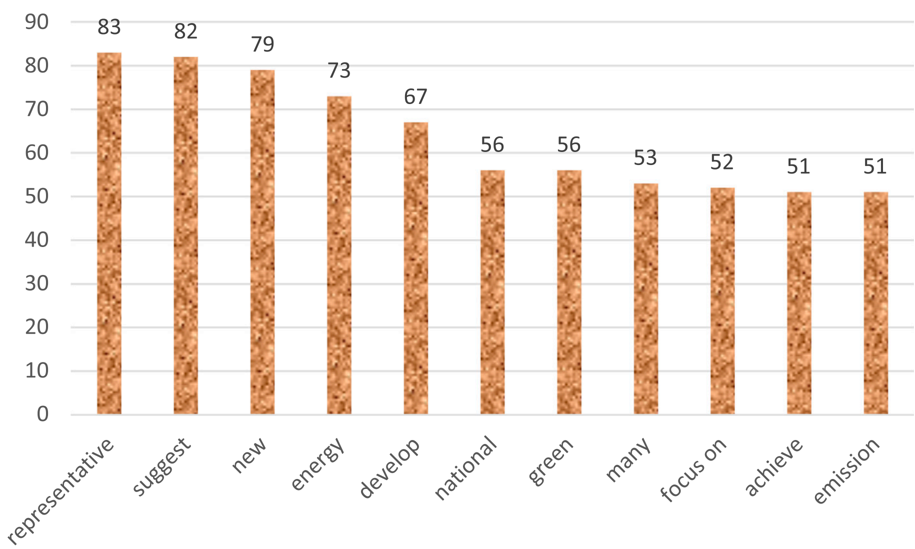

FIGURE 9 | Most mentioned words for "carbon neutrality, two sessions and proposals" in Weibo microposts.

TABLE 4 | Source data analysis.

	Positive score	Negative score	Neutral	No sent	No data	Overall
Total items processed	2996	353	224	278	0	3851
Total items processed	78%	9%	6%	7%	0	100%
Average number of words per item	294	260	218	70	0	270
No. containing a URL or email address	50	2	4	2	0	58
Percentage	2%	1%	2%	1%	0	2%

component of the national government system and a Chinese-specific institutional system (General Office of the Central Committee of the Communist Party of China, 2015). The "two sessions" per Chinese Constitution, are responsible for gathering and organizing public information, requesting its representatives, and relaying it to the Party Central Committee (National People's Representative Meeting, 1982). To some extent, the ideas made by the delegates of the two sessions can reflect public opinion. The people's attitudes about carbon-neutrality might reflect in the microposts with "carbon neutrality" and "two sessions."

The results of the "carbon neutrality, two sessions were relatively few (60) as compared to "two sessions, sustainable development" (1549). This is foreseeable since sustainable development is more comprehensive than carbon neutrality. While carbon neutrality is only one facet of the environmental problem, sustainable development addresses the economic, social, and environmental issues. Most frequent mentioned keywords are shown in **Figure 9**.

4.3 Sentiment Analysis

The research samples are also analyzed *via* AI Sentiment. The source data analysis is shown in **Table 4**. The most popular words (or tags) like 'Achieve,' 'high quality,' 'improve,' 'support,' and 'good' express a positive sentiment (**Figure 10**). From **Figure 11**, the words (or tags) with positive sentiment included 'achieve,' 'high quality,' 'improve,' 'support,' 'good,' 'comprehensive,' 'relevant,' and 'cooperation.' The negative sentiment include 'pollution,' 'epidemic,' 'waste,' 'problems,' 'however,' and 'issue' (**Figure 12**). From **Figure 13**, the proportion of positive sentiment accounts for 83.9%, while the negative sentiment only accounts for 9.9%. **Figure 13** shows the distribution of positive, negative and neutral microposts percentage and **Figure 14** illustrates the results of another algorithm that identified text emotions ranging from −18 to 40. The highest score (288) described Nanyang City's economic activities and provided detailed guidance on achieving the goals while controlling pollution. The lowest one scored −18. It criticied extravagant moon cake packaging that caused a lot of waste and excessive emissions, detrimental to the carbon-neutral goal.

FIGURE 10 | Word clouds of most frequent mentioned words' sentiment in carbon neutrality

FIGURE 11 | Word cloud for positive words in carbon neutrality microposts (Note: dark and light green are used to see all positive words or phrases in a clearer way).

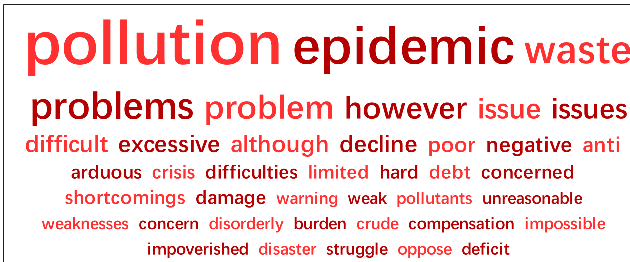

FIGURE 12 | Negative sentiment (Note: dark red and light red are used in the chart to identify every negative word or phrase).

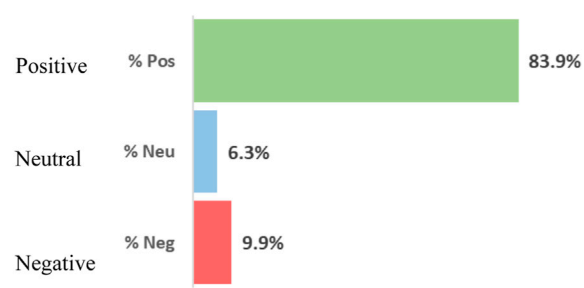

FIGURE 13 | Net sentiment.

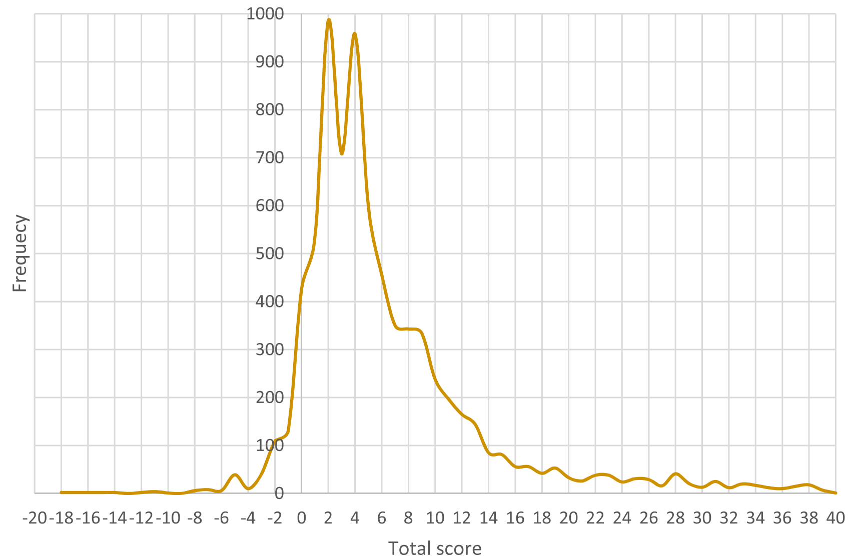

FIGURE 14 | Sentiment score distribution of all words in carbon neutrality microposts.

4.4 Parts of Speech

Figures 15 and **16** show the most frequent verbs and adjectives. Verbs such as "develop," "contribute," "promote," and "continue" are related to goals and development and the future.

Regarding the adjectives of more than 1,000 times, all except "low" was positive. However, "low" was usually combined with words like "low carbon," "low emission," and collocations "New" were usually mentioned. Common collocations included "new energy," "new chapter," "new opportunity". Although sustainable development is an old terminology, carbon-neutral is a "new concept", and carbon-neutral policies are also new. **Figure 15** shows the results of visualization.

4.5 Mega-Events and Carbon Neutrality

This study reflects carbon neutral events in China. As the first carbon neutral winter Olympics, "the Beijing Winter Olympics" appeared many times in Weibo. The Hangzhou Asian Games also appeared in the March microposts. These expressed user's appreciation for the Beijing Winter Olympics and expectations for the Asian Games, the first Asian Games which achieve carbon neutrality.

4.6 Is Carbon Neutrality a Friend of Economic Development?

By examining the microposts, it was discovered that the Weibo users supported carbon neutrality and believed it would enable them to live better. Similar ideas like "sustainable development" and "green mountains and clear water are mountains of gold and silver" were popular in China before the Western world developed the concept of "carbon neutrality." The idea of "carbon neutrality" is in line with Chinese policy, cultural norms, and ideals.

Beyond the bright side, several Weibo users questioned whether carbon neutrality was a trap set by the West to slow global development. We are all aware that industrial development must go through a process that results in substantial carbon emissions. Developing industries is essential for a developing nation. How can emerging nations conform to the industrial chain promise of carbon neutrality while assuring their development?

Many comments under this post advocated that the carbon neutrality commitments are all national aims. Nevertheless, the high carbon emissions in other countries frequently come at the expense of one country's attempt to become carbon neutral. For instance, as low-end sectors shifted to Southeast Asia, local carbon emissions in China decreased but increased in Southeast Asian nations.

Another post mentioned that, "carbon emission rights were an idea that the West utilied to stifle the development of later developing countries, according to another piece. China agreed to it because it represents the pinnacle of morality on the global stage." This statement highlights the importance of governance to meet the social and environmental needs when we wish to realise the goal of carbon neutrality.

Other users have expressed criticisms and dialectical analyses of the microposts: "China's carbon-neutral emission aim is not merely a moral dilemma in the highlands or a climate change problem. The most crucial aspect is that we employ it to improve our economic growth. As a result, the foundation for the sustainable development of the Chinese country was solidly constructed. Thus, the public favors low-carbon emission reduction, but they do not permit sacrificing national development and the quality of life for the people to reach the goal.

The promotion of high-quality development is vital for achieving carbon peak and neutrality, which must be done unwaveringly, according to the 2021 Central Economic Work Conference. It is

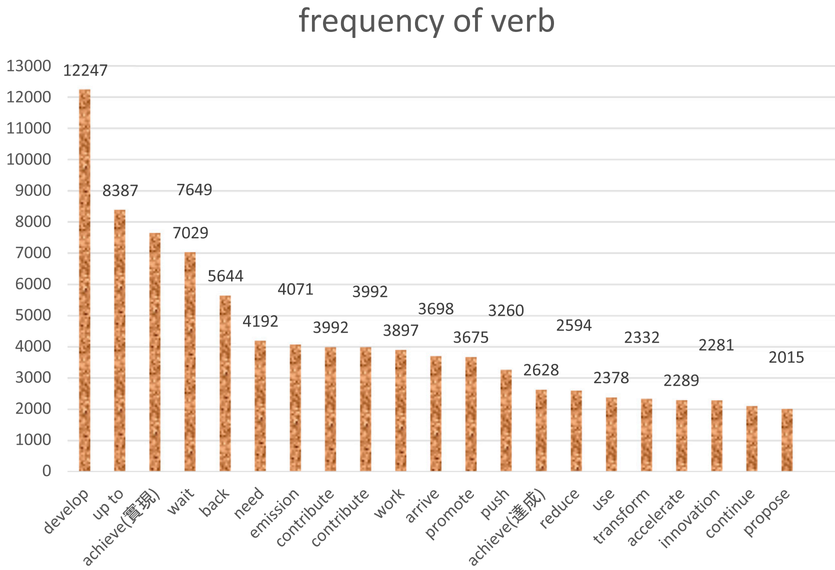

FIGURE 15 | Frequency of most mentioned verbs in carbon neutrality.

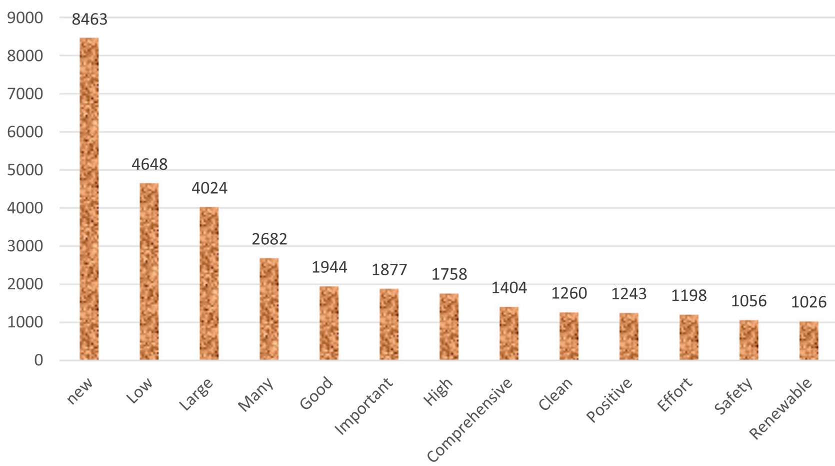

FIGURE 16 | Frequency of most mentioned adjectives in carbon neutrality.

nonetheless impossible to achieve all the goals at once. Since reaching the carbon peak and being carbon neutral would need significant economic and social transformation, it will not be simple. We must be steadfast for a long time if we want to promote carbon neutrality in an organized and methodical way. To solidly and successfully promote various works, we have to be patience.

5 CONCLUSION

One of China's primary objectives is carbon neutrality; writers on Weibo indicated an interest in it. Through data collection and sentiment analysis on Weibo, this study made a novel contribution by demonstrating how different people's concerns about carbon neutrality are related to the environment, social and governance (ESG). Weibo users expressed concern about new energy's role in achieving carbon neutrality and commented on environmental issues, such as low carbon and sustainability. Their posts highlighted that new energy-related businesses in China worked hard to develop cutting-edge technologies.

The notion that achieving carbon neutrality will enable us to live better lives was widely held in the social aspect. People mentioned governance (responsibility and government reports) in their posts. Therefore, the ESG idea existed even though this word was seldom mentioned in microposts. Besides, Weibo users are optimistic that China will accomplish its carbon neutrality targets and support national policies, despite their concerns about the potential adverse impacts.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

RL: Conceptualization, Validation, Writing-original and revised, Data analysis, Writing—review and editing, and Project administration, QW: Writing—original draft preparation, Investigation, Methodology, and Formal analysis LZ: Writing—original draft preparation, Software, Methodology, and Visualization HC: Resources and Conceptualization All authors have read and agreed to the submitted version of the manuscript.

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