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Government environmental information disclosure and corporate carbon performance

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Environmental problem is the key to the healthy development of China's eco-economy, and the environmental responsibility of micro-enterprises under the vision of "Dual Carbon" has attracted more attention. Under the effect of formal environmental regulation, firms will improve their environmental performance by improving technology and resource utilization. As an informal environmental system, can government environmental information disclosure (GEID) guide firms to actively carry out green innovation, ultimately improve the carbon emission problem of firms, have a positive impact on the carbon performance of enterprises, and provide strong support to protect ecological environment? To address this question, this study used the Pollution Information Transparency Index (PITI) to measure GEID, and empirically tested the impact of GEID on corporate carbon performance using a sample of listed companies involved in China's mining and manufacturing industries from 2013 to 2018. The study found that the higher the degree of GEID, the better was the corporate carbon performance. However, the improved public participation weakened the effect of GEID on corporate carbon performance. GEID reduced the carbon emission intensity of firms and improved their carbon performance via green innovation. Further research indicated that the enhanced GEID in state-owned enterprises significantly improved carbon performance of firms. This study provides empirical evidence for GEID to improve corporate carbon performance, and also proposes a policy strategy for the government to guide firms to undertake green innovation and promote firms to improve efficient carbon use.

KEYWORDS

environmental information disclosure, carbon performance, green innovation, informal environmental regulation, public participation

1 Introduction

Climate change is a serious challenge facing the whole world. All countries have taken positive actions to achieve the temperature control goal in the Paris Agreement. According to the *BP World Energy Statistical Yearbook of 2022*, China's total primary energy consumption increased from 16.65 EJ to 157.65 EJ, representing an increase from 6.11% to 26.5% of the world's total primary energy consumption between 1978 and 2021. Meanwhile, Energy carbon emissions of China increased from 1.419 billion tons to 10.523 billion tons, and the share of global carbon emissions increased from less than one-tenth to nearly one-third. As a major energy consumer and carbon emitter, China has set the goal of achieving the emission peak by 2030 and carbon neutrality by 2060. In order to achieve the dual carbon target, the Chinese State Council issued the *Comprehensive Work Plan for Energy Conservation and Emission Reduction for "14th Five Year Plan"* in January 2022. The Plan emphasized

improvement in policy mechanism for energy conservation and emission reduction, and promotion of green transformation of economic and social development. Further, China clearly formulated and revised the emission standards of air pollutants for key industries.

Over the years, under the economic model of government-led and vigorous development of heavy industry in China, enterprises have achieved rapid development, but at the same time, they have brought serious ecological and environmental problems (Yang et al., 2023). In 1973, China implemented the earliest environmental regulation: the "three simultaneities" system, but practice proved that it lacked sufficient resources to implement effective supervision and severe punishment mechanism (Fang and Guo, 2018). In 1982, China promulgated the Interim Measures for the Collection of Sewage Charges, which made an important contribution to energy conservation and emission reduction. However, due to its lack of compulsion, execution and supervision, there were some problems in its implementation, such as underreporting and incomplete government collection (Maung et al., 2016). The implementation of China's environmental policies is constrained by "active government, passive firms and inactive public" (Tu and Shen, 2015) due to the high cost and low efficiency of implementation of formal environmental regulations, and the rent-seeking behavior leading to "regulation capturing." In addition, factors such as the scale economy led to some firms paying pollution taxes or trade permits to pollute rather than change the production patterns of high pollution (Chen and Zhen, 2022).

The government and firms can only attach importance to environmental governance via "bottom-up" informal environmental regulations when the effects of "top-down" formal environmental regulations have no obvious effects. With the enhancement of public awareness to environmental protection, informal environmental regulation with the public as the main body has gradually developed and grow (Liu et al., 2021). Environmental problems are closely related to residents' daily lives. With the popularization of environmental protection concepts and the wide application of the Internet, increasing micro-subjects join the ranks of ecological protection (Michael et al., 2023). This kind of environmental regulation force with the public as the main body is called informal environmental regulation. Different from government regulation, this kind of public-led, relatively informal regulation often has no policy effect, and its mode of action is more random and flexible (Shen et al., 2023), mainly by guiding public opinion to form a soft constraint on enterprises and guiding enterprises to consciously move towards the road of green environmental protection.

Evidence suggests that informal environmental regulation is conducive to reducing the level of environmental pollution (Li, 2018). However, in academic circles, no consensus has been reached on the impact of informal environmental regulations on corporate carbon emissions (Cole et al., 2005; Kathuria, 2007; Lu, 2021). As one of the informal environmental regulations, government environmental information disclosure (GEID) may play an important role in guiding firms to improve pollution discharge and carbon performance.

In the existing literature, studies investigating the factors affecting carbon emissions mainly focus on the national and provincial levels. At the national level, the influencing factors mainly include the actual urbanization rate, *per capita* GDP, the proportion of tertiary and secondary industries, fixed asset investment, and the proportion of renewable energy (Shuai et al., 2018; Chen and Zhen, 2022). The influencing factors at the provincial level involve economic activities, energy structure, energy-saving technology and energy-use efficiency (Liu and Xu, 2023). Firms at the micro level, as a major participant in China's carbon emission reduction, have an important effect on the development of China's eco-friendly economy.

Hence, this study used the Pollution Information Transparency Index (PITI) to measure GEID, and evaluated the impact of GEID on corporate carbon performance and its mechanism based on a sample of China's A-share manufacturing and mining listed companies from 2013 to 2018. The results showed that GEID significantly improved corporate carbon performance, and green innovation was the primary mechanism of GEID affecting corporate carbon performance. Further, public participation could substitute GEID, which inhibited the positive impact between GEID and corporate carbon performance. The analysis of heterogeneity revealed that the impact of GEID on corporate carbon performance occurred mainly in state-owned enterprises with a close relationship with the government.

Compared with the existing studies, the marginal contribution of the study is as follows. First, this study enriches the research on factors influencing carbon emission reduction by firms at the micro level from the perspective of informal environmental regulation. Most of the existing studies focus on the impact of formal environmental regulation on environmental performance, and there are few studies on the role of environmental regulation and micro-enterprises. This study focuses on the influence of GEID, an informal environmental regulation, on corporate carbon performance, which supplements the perspective of existing literature.

Second, the research effectively tests the mechanism of GEID promoting corporate carbon performance, and provides a path for the government to guide firms to strengthen green innovation. Based on Porter's theory, this study demonstrates that GEID drives green innovation by firms, guides firms to improve environmental governance and thus improves corporate carbon performance.

Third, the study effectively reveals the factors influencing corporate carbon performance based on the degree of environmental information disclosure, which provides decision-making basis for the government to improve the "bottom-up" environmental governance system. The higher the level of GEID, the better the carbon performance of firms. However, currently, the Pollution Information Transparency Index (PITI) only measures and scores 120 cities in China. Therefore, it is necessary for the government to improve the degree of environmental information disclosure, increase the number of cities participating in PITI, and improve the degree of public participation in environmental governance.

The second part of this article is a literature review and hypothesis development. The third segment presents the research design. The fourth section provides empirical results. The fifth section discusses analysis of mechanism. The sixth section provides further analysis; The seventh section deals with study conclusion and discussion.

2 Institutional background, literature review and hypothesis development

2.1 Institutional background

Compared with developed countries and other developing countries, China's effort on environmental information disclosure is relatively late. The *Environmental Protection Law of the People's Republic of China* promulgated in 1989 formally established the environmental information disclosure system, requiring the central and provincial environmental protection departments to regularly issue environmental status bulletins.

For a long time, there has been a heavy ecological cost behind China's rapid economic growth. Frequent environmental pollution incidents not only damaged people's health, but also ran counter to the trend of the "double carbon." In order to promote energy conservation and emission reduction of enterprises, China has successively launched command based and market incentive based environmental regulation policies, but local governments often refuse to disclose environmental information for various reasons, resulting in that whether the environmental regulation system only involving the government and enterprises can promote sustainable economic development is still questionable (Tu and Shen, 2015).

In order to build an environmental governance system with multiple participation of the government, firms and the public, the former National Environmental Protection Administration issued the *Environmental Information Disclosure Measures* (*for Trial Implementation*) in 2007, requiring local governments to disclose environmental information such as enterprises with excessive emissions and the objects of pollution charges in a timely manner, opening the first year of environmental information disclosure. After the implementation of the *Environmental Information Disclosure Measures* (*for Trial Implementation*), the Institute of Public and Environmental Affairs (IPE) and the Natural Resources Defense Council (NRDC) jointly developed the Pollution Information Transparency Index (PITI), which has been evaluating the GEID of Chinese cities year by year since 2008.

2.2 Literature review

Environmental regulation can be divided into three types: 1) mandated regulation led by government, 2) formal regulation based on market incentives, and 3) informal regulation led by non-governmental organization (Ren et al., 2018). The mandated environmental regulation led by government, under the principle of unified planning, monitoring and supervision, can lead to enhanced cooperation and coordination among regions to effectively ameliorate environmental pollution (Yu and Yin, 2022). However, collaborative governance is a challenge, and there may be rent-seeking or other inefficiencies during the implementation (He and Wang, 2016). Studies show that the effect of compound emission reduction via mandated regulation and market-incentive regulation is often better than that of the single policy. Market-incentive environmental regulations, such as carbon emission trading policy (Dong and Wang, 2021; Tang and Xu, 2023) and ecological transfer payment policy (Pan, 2021), can effectively improve the progress of green

technology, reduce carbon dioxide emissions, and better protect the ecological environment. Informal environmental regulation, however, often exerts a binding force on irregular behaviors outside the scope of formal environmental regulation via public criticism, resistance to polluting firms' products and pressure exerted by media and environmental non-governmental organizations in the face of weak or absent formal environmental regulation (S. Pargal and D. Wheeler, 1996). Informal environmental regulations combined with laws and formal regulations, such as environmental taxes and emission trading permits, can prevent local firms from committing environmental violations (Han et al., 2016) and drive the government and firms to implement eco-friendly decisions to solve environmental challenges (M. Brigglio, 2017).

The academic community has yet to reach an agreement on whether GEID, one of the informal environmental regulations, is effective in improving corporate environmental performance. Many scholars believe that environmental information disclosure can contribute to the routine supervision of the entire society, resulting in environmental supervision with the participation of the government, firms, social organizations and the public (Du, 2022). It can guide strongly polluting firms to improve their environmental performance by increasing R&D investment, green innovation and other activities (Feng and He, 2020; Zhang and Feng, 2020; Wang et al., 2023). Other experts believe that due to the lack of public accountability and the characteristics of long cycle and large demand for funds to improve environmental performance, firms are likely to pursue short-term interests without focusing on environmental issues, suggesting that environmental information disclosure is not effective in improving environmental performance (Tu et al., 2019). The different perspectives of the existing studies question whether the GEID can be an effective tool in promoting environmental governance.

Obviously, the aforementioned research findings provide a solid theoretical basis for this study. However, the existing literature mainly considers environmental information disclosure as a quasi-natural experiment to test the impact of informal environmental regulation. The mechanism of the impact is not clear. It is also not clear whether the impact of PITI on corporate carbon performance is sustainable after 14 years of environmental information disclosure. Therefore, we conducted a supplementary study to analyze the impact mechanism of GEID indicators on corporate carbon performance.

2.3 Hypothesis development

In the context of market-oriented economy, the Chinese government not only intervenes in economic and social activities through laws and taxes, but also regulates corporate environmental behavior via licensing, environmental information disclosure and other channels (Shen and Jin, 2018). No government rules and regulations are available to mitigate the intensity of corporate carbon emissions despite the assessment of regional carbon emissions as one of the indicators of performance evaluation of local officials. Therefore, local governments restrict corporate carbon emissions from the purview of informal environmental regulations.

GEID belongs to the category of informal environmental regulation. It is a specific form of public participation in

FIGURE 1
Research hypothesis.
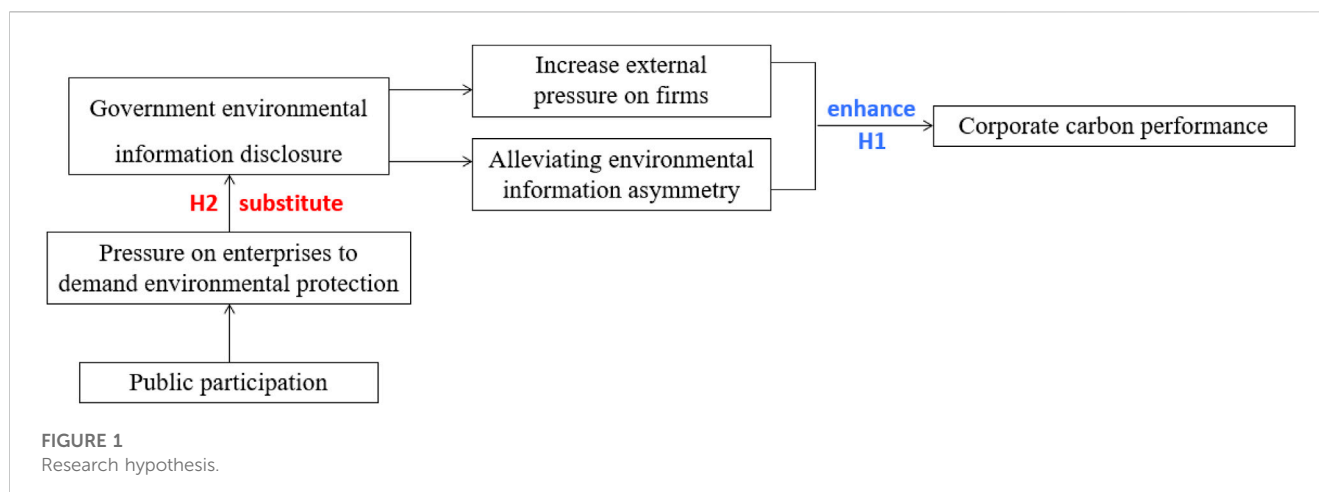
environmental governance (Zhang et al., 2021) and plays an important role in environmental governance of green development. First, GEID has increased public access to adverse information such as environmental laws and regulations, penalties and environmental litigation and alleviated the asymmetric environmental information between firms and external stakeholders. Second, GEID facilitated public participation in the supervision of corporate environmental issues substantially. Firms focus increasingly on environmental issues based on external pressure. Therefore, GEID can improve the efficiency of environmental supervision of firms.

GEID plays an important role in carbon emission reduction of local firms, when carbon emission reduction is supported by the central government. Therefore, as an informal environmental regulation policy, GEID affects the carbon emission performance of firms. This study proposes the following hypothesis:

Hypothesis 1(H1). GEID can reduce the carbon emission intensity of firms and improves their carbon performance.

The public can participate in the supervision system via GEID, thus alleviating the problem of information asymmetry. The disclosure of environmental information has increased the exposure rate of illegal activities by firms. Equipped with information regarding firms' environmental violations, the public can influence corporate decisions through complaints, protests, and refusal to purchase products or services (Lu, 2021). To prevent loss of reputation, image and other factors, and to avoid the risk of environmental violations disclosure, firms will choose to reduce emissions during the production process (Zhao and Zhang, 2020). Therefore, when the public has access to corporate environmental information, firms will improve environmental performance to address the environmental needs of the public (Yan et al., 2023).

Under a high degree of public participation regionally, the monitoring of environmental information of firms and government not only involves active disclosure of environmental information by the government, but also act under the pressure to address the need for public environmental protection. Firms will improve their carbon performance to meet public needs (Yang et al.,

2020). Therefore, public participation may substitute the role of GEID. This study proposes the following hypothesis:

Hypothesis 2(H2). Public participation has a moderating effect on GEID to promote corporate carbon performance.

Figure 1 illustrates the research hypotheses of this study.

3 Research design

3.1 Sample selection and data source

The carbon performance measured in this study is a manual collection of data from *China Energy Statistical Yearbook* and *China Industrial Economic Statistical Yearbook*. This data only contains detailed data of secondary classification of mining and manufacturing firms. In addition, the number of cities measured by the PITI index has increased year by year since its launch, and has stabilized at 120 since 2013. Therefore, considering the accuracy of data processing, this paper selected the listing of China's A-share mining and manufacturing industries from 2013 to 2018 as samples, and processed the data as follows: 1) exclusion of samples with abnormal trading status (ST, * ST) during the observation period; 2) elimination of samples with missing financial data; 3) removal of the samples not belonging to cities with open environmental information; 4) shrinking the main continuous variables by 1% in order to avoid the impact of extreme values. Finally, 7,705 observations of 1,576 listed companies were obtained. The financial data of this study were derived from the China Stock Market and Accounting Research Database (CSMAR), and the carbon emission intensity data were obtained from the *China Energy Statistical Yearbook* and the *China Industrial Economic Statistical Yearbook*.

3.2 Variable definition

3.2.1 Dependent variable

Corporate carbon performance (CEPI) was used as the dependent variable in this study. Considering the availability

TABLE 1 Energy standard coal conversion coefficient and carbon emission coefficient.

Energy varieties	Coal	Coke	Crude oil	Gasoline	Diesel oil	Fuel oil	Natural gas
Conversion coefficient of standard coal	0.7143	0.9714	1.4286	1.4714	1.4571	1.4286	1.3300
Carbon emission coefficient	0.7559	0.8550	0.5857	0.5538	0.5921	0.6185	0.4483

TABLE 2 Evaluation index of PITI.

Items	Regulatory information		Self-monitoring		Interactive response		Emission data	Environmental evaluation (%)
	Daily record of exceeding the standard (%)	Firm environmental behavior evaluation (%)	National automatic monitoring (%)	Key pollutant discharge units (%)	Environmental protection inspector and complaints (%)	Disclosure upon application (%)	Firm emission data (%)	Environmental evaluation (%)
Weight	25	5	20	6	7	8	14	15

of micro-level data, this study selected enterprise carbon emission intensity (CEP) to measure carbon performance, that is, carbon emissions per unit income (Clarkson et al., 2011). The greater the CEP, the lower the CEPI. According to (Yan et al., 2019), the carbon emissions of firms were estimated based on industrial carbon emissions, which were calculated by referring to the industrial energy consumption published in the China Energy Statistical Yearbook and the reference coefficient of energy carbon emissions listed in the carbon emissions trading network (Table 1); Industry operating costs are collected from *China Industrial Economic Statistical Yearbook*. According to the industry operating cost indicators in the statistics of main economic indicators of industrial enterprises above designated size, the legal entities above designated size with annual main business income of 20 million yuan or more are included in the industry. The CEP of firms and industry carbon emissions were calculated using the following formula:

$$CEP = \frac{Firm\ operating\ costs \times \frac{Industry\ carbon\ emissions}{Industry\ operating\ costs}}{Firm\ income} \quad (1)$$

$$Industry\ carbon\ emissions = \sum Energy\ consumption \times Carbon\ emission\ coefficient \quad (2)$$

3.2.2 Explanatory variables

The core explanatory variable in this study was GEID. The *Measures for the Disclosure of Environmental Information (for Trial Implementation)* came into effect in 2008, and the Institute of Public and Environmental Affairs (IPE) and the Natural Resources Defense Council (NRDC) jointly released the pollution source regulatory information disclosure index (PITI). The PITI index scores the open index of government environmental pollution supervision in 113 cities in China, and the number of evaluated cities has increased to 120 by 2013. The index includes eight secondary evaluation items, and the weight of each item is shown in Table 2.

PITI index is a systematic evaluation of local government's environmental information disclosure level by third-party non-government organizations, which can objectively and fairly reflect the implementation of relevant laws and regulations on environmental information disclosure by local government departments (Guo et al., 2014). Therefore, this study measures GEID with PITI index. The higher the PITI score, the higher the degree of GEID of the local government (Feng et al., 2021).

The geographical distribution of 120 cities scored by PITI of China is mainly concentrated in the eastern coastal areas and around the capital Beijing as shown in Figure 2.

3.2.3 Moderate variable

The moderating variable in this study was the degree of public participation (PUB). Based on the practice of Yan et al. (2022), and according to the *Statistical Yearbook of Chinese Cities*, the public participation in the city is measured as 100 times the ratio of the number of Internet connections in the city to the permanent population of the city (*i.e.*, the number of Internet connections per 100 people). Generally speaking, the higher the proportion of urban residents accessing the Internet, the higher the Internet penetration rate. Government information is mainly spread through the Internet medium. This study selected the Internet penetration rate to measure the degree of public participation in the city.

3.2.4 Control variables

To control any factors that may explain the change in carbon emission performance, this study selected the following intermediary variables that may affect the carbon performance of firms, including regional level and enterprise level (Meng et al., 2022; Yu et al., 2022). They include GDP growth rate (GDPG) and *per capita* GDP (AGDP) were selected at the regional level. Company size (SIZE), asset liability ratio (LEV), total asset net interest rate (ROA), total asset turnover (ATO), operating income growth rate (GROWTH), age of listing (AGE), Tobin Q value (TQ), management shareholding ratio (MS), equity balance (BAL), and

FIGURE 2
Geographical distribution of PITI cities of China.

management fee rate (MFEE) at the firm level. In addition, this study also controlled the annual dummy variable (YEAR), the company dummy variable (FIRM), and the city dummy variable (CITY). The specific definitions are presented in Table 3.

3.3 Model construction

To test the relationship between GEID and corporate carbon performance, this study constructed the following multiple regression model (Sun and Wei, 2022):

$$CEP_{i,t} = \beta_0 + \beta_1 PITI_{i,t} + \sum Controls_{i,t} + YEAR + FIRM + CITY + \varepsilon \quad (3)$$

To verify the moderating effect of public participation on the relationship between GEID and corporate carbon performance, the following model was set (Tian and Zhang, 2020; Zheng et al., 2021), in which the explanatory variable is the cross term of the degree of GEID and public participation:

$$CEP_{i,t} = \alpha_0 + \alpha_1 PITI_{i,t} \times INT_{i,t} + \alpha_2 PITI_{i,t}$$
$$+ \alpha_3 INT_{i,t} + \sum Controls_{i,t} + YEAR + FIRM + CITY + \varepsilon$$
$$(4)$$

The $CEP_{i,t}$ represents the carbon emission intensity of firms; $PITI_{i,t}$ denotes a city's pollution information transparency index; $INT_{i,t}$ refers to the urban Internet penetration rate. $Controls_{i,t}$ is the control variable. In addition, the use of firm fixed effect (FIRM), annual fixed effect (YEAR) and city fixed effect (CITY)

can also alleviate the problem of missing variables to a certain extent; i denotes the firm; t is the time; and ε indicates the random interference term of the model. This study focuses on β_1 and α_1, where β_1 indicates whether GEID affects firms carbon emission intensity, and α_1 determines whether Internet penetration affects the relationship between GEID and firms carbon emission intensity.

4 Results

4.1 Descriptive statistics

Table 4 presents the descriptive statistics of the main variables. As shown in Table 4, the minimum and maximum carbon emission intensities of firms were 0.01 and 16.29, respectively, with a large difference in CEP among listed companies. Under the same operating revenue, the carbon emissions of some firms differ thousand-fold, which may be because the firms with high carbon emissions are mainly involved in oil processing, coking and nuclear fuel processing industries, and power and heat production and supply industries. Their operating costs mainly focus on coal, coke, oil and other energy sources, so their carbon emissions intensity is high. The standard deviation of PITI is 14.974, which indicates a large difference in the degree of environmental information disclosure among cities, with an average of 57.6242. Thus, the overall level of environmental information disclosure in China is not high.

TABLE 3 Variable definition.

Variable	Variable symbol	Definition
Corporate carbon performance	CEPI	Measured by corporate carbon emission intensity (CEP). The higher the carbon emission intensity, the lower the carbon performance
Government environmental information disclosure	GEID	Measured by Pollution Information Transparency Index (PITI). Annual score of each city's pollution information transparency index released by the Environmental Research Center
Public participation	PUB	Measured by Internet penetration rate (INT) (the number of Internet penetration per 100 people in the city)
Regional economic development speed	GDPG	GDP growth rate
Regional economic development level	AGDP	GDP *per capita*
company size	SIZE	Natural logarithm of annual total assets
Asset liability ratio	LEV	Total liabilities at the end of the year/total assets at the end of the year
Net interest rate of total assets	ROA	Net interest rate/average balance of total assets
Total asset turnover	ATO	Operating income/total average assets
Growth rate of operating revenue	GROWTH	Operating income of this year/operating income of last year - 1
Listing period	AGE	Ln (current year - listing year+1)
Tobin Q value	TQ	(value of circulating stock market + net assets per share of non-circulating shares + book value of liabilities)/total assets
Shareholding ratio of management	MS	Management shareholding data/total equity
Equity balance	BAL	Number of shares held by the second to fifth shareholders/number of shares held by the largest shareholder
Management expense rate	MFEE	Administrative expenses/operating income
Year effect	YEAR	Annual dummy variable
Corporate effect	FIRM	Company dummy variable
Urban effect	CITY	Urban dummy variable

4.2 Correlation analysis

Table 5 presents the correlation coefficient matrix of each variable. The explanatory variables CEP and PITI show a significant negative correlation at the level of 1%, indicating that the GEID is negatively related with the CEP of firms, which preliminarily verifies the Hypothesis H1. The correlation coefficient between other variables does not exceed 0.5, indicating that the introduction of the above variables into the model does not lead to serious multicollinearity problems.

4.3 Empirical results

4.3.1 Main effect

In order to further verify Hypothesis H1, this study conducted multiple linear regression analysis (2). Table 6 shows the results of inspection. Column (1) provides the results of regression of the fixed effect of the year and company under control, and column (2) indicates the results of regression analysis of the fixed effects of the city. The results show that the coefficient of PITI is negative and significant at the level of 5% with CEP, indicating that the higher the degree of GEID, the lower the $CEP_{i,t}$, and the better the CEPI. Hypothesis H1 is verified.

4.3.2 Test of moderating effect of internet penetration

In order to verify the moderating effect of public participation on the relationship between GEID and CEPI, this study conducted a multiple linear regression analysis of model (4). Table 7 presents the results of regression. Column (1) is the main effect of regression analysis. Item (2) is listed as Internet penetration rate and PITI transportation item (INT×PITI). The results of column (2) show that the coefficient of the cross-multiplication term is significantly positive at the level of 5%, while the coefficient of the explanatory variable PITI in the main regression is negative, which means that public participation has an attenuating effect on the main effect. Thus, the degree of public participation has a substitution effect on GEID, thereby H2 is verified.

According to the coefficient of PITI listed in column (1) and (2), public participation did not play a positive role in promoting the effect of GEID on carbon emission intensity. Previous studies have shown that Internet penetration can affect the direction of China's regulation on enterprise pollution emissions to a certain extent, and when the Internet penetration rate is lower than a certain extent, regulation will aggravate the pollution emission intensity of enterprises (Zhang and Kou, 2018). However, China's Internet penetration rate has already crossed the threshold. China's Internet advantages have not been effectively utilized (Tao et al.,

TABLE 4 Full sample descriptive statistics.

Variable	Sample size	Mean	Sd.	Min	Median	Max
CEP	7705	0.5242	1.355	0.01	0.06	16.29
PITI	7705	57.6320	14.974	8.40	60.80	82.40
INT	7705	32.7119	21.553	5.08	26.55	71.38
GDPG	7705	0.0809	0.019	−0.06	0.08	0.19
AGDP	7705	11.5047	0.471	9.77	11.58	13.06
SIZE	7705	22.1096	1.224	19.52	21.93	26.25
LEV	7705	0.3979	0.197	0.05	0.38	0.92
ROA	7705	0.0409	0.063	−0.41	0.04	0.22
ATO	7705	0.6352	0.376	0.05	0.56	2.78
GROWTH	7705	0.1825	0.427	−0.59	0.12	4.81
AGE	7705	2.0572	0.768	0.00	2.08	3.30
TQ	7705	2.1931	1.419	0.82	1.77	17.68
MS	7705	0.1613	0.208	0.00	0.03	0.70
BAL	7705	0.7517	0.617	0.02	0.59	2.96
MFEE	7705	0.1014	0.073	0.01	0.09	0.77

Note: * * *, * * and * represent the significance levels of 1%, 5% and 10% respectively.

2023), resulting in public participation not enhancing the effect of GEID on carbon emission intensity.

4.3.3 Robustness
1) Replacement of the interpreted variable

In order to avoid errors in the results of single carbon emission calculation and measurement method, this study obtained industry carbon emission data calculated by a third-party authority based on "carbon neutrality" database of CSMAR, and then re-estimated corporate carbon emissions based on the proportion of operating costs in the operating costs of the industry. The corporate carbon emission intensity CEP2 was calculated based on the ratio of corporate carbon emission data and operating income. The higher the corporate carbon emission intensity, the lower the CEPI.

The empirical results are shown in Table 8. Columns (1) to (2) present the regression results of control year, firm and control year, firm and city, respectively, and the results are basically consistent with the main test above. The adjustment effect test of adding INT×PITI cross item was listed in column (3), which obtained the same result as the previous test. Therefore, the measurement of CEPI in this study is robust, and the replacement of industry carbon emission data did not affect the results of the test hypothesis. Thus, the results again suggest that GEID improves CEPI and public participation has a substitution effect on GEID.

2) Subsample test

According to the industry classification standards mentioned in the Guidelines for Industrial Classification of Listed Companies issued by the CSRC in 2012, nearly 90% of the sample firms in this

study represent manufacturing industry. Most of the energy consumption and carbon emissions of listed manufacturing companies directly affect the production process, so the carbon emission intensity of manufacturing firms more directly reflect the relationship between input and output to a certain extent.

Table 9 shows the results of robustness test involving manufacturing companies in the whole sample. The columns (1) and (2) represent the results of regression of the manufacturing subsamples of control year, firm and control year, firm and city, respectively. Column (3) represents the adjustment effect of adding INT×PITI cross item, which confirms the robustness of the regression analysis.

3) Eliminate other policy shocks

The National Development and Reform Commission issued the *Notice on Pilot Work of Low Carbon Provinces and Cities* on 19 July 2010, which identified the first batch of low carbon cities as Guangdong, Liaoning, Hubei, Shaanxi, and Yunnan provinces, and eight cities as Tianjin, Chongqing, Shenzhen, Xiamen, Hangzhou, Nanchang, Guiyang, and Baoding. The second batch of pilot cities was organized in April 2012. Currently, there are 42 low-carbon pilot provinces and cities in China. China requires pilot areas to set carbon dioxide emission targets, establish carbon emission trading systems, and perform efficiently to develop leading low-carbon cities. The timing of low-carbon city pilot policy coincides with the time of sample selection in this study, and the existing literature shows that the low-carbon environment pilot policy reduces the carbon emissions of firms. In order to ensure the robustness of the study conclusions reported here, we excluded firms in the low-carbon city pilot policy, and only ensured GEID for the remaining 57 cities, but not in the low-carbon city pilot policy. Regression analysis of samples was conducted again.

The results of regression analysis are shown in Table 10. The columns (1)–(2) represent the results of regression analysis involving the sample firms whose control year, firm and control year, firm and city were not in the low-carbon city pilot policy, respectively. The column (3) represents the adjustment effect due to the addition of the INT×PITI cross-item. It shows that excluding firms in low-carbon pilot cities, the negative impact of GEID on CEP was strengthened, which proves the robustness of the conclusions.

4.4 Endogenous test

In the PITI sample of explanatory variables analyzed in this study, only cities participating in environmental information disclosure scoring were included. Other cities may not participate in environmental information disclosure scoring due to the high carbon emission intensity level of local firms. Therefore, the conclusions of this study may be affected by sample selection errors. In order to eliminate such issues, this study matched the PSM propensity scores of firms belonging to cities with GEID with those of firms not belonging to cities with GEID. The results are shown in Table 11. Column (1) in the table represents the kernel matching result, and column (2) is the radius (0.01) matching regression. After controlling for sample self-selection error, the coefficient of PITI was still significantly negative, which was consistent with the results of main regression analysis.

TABLE 5 Pearson correlation coefficient test.

Variable	CEACTP	PITI	INT	GDPG	AGDP	SIZE	LEV	ROA
CEP	1	—	—	—	—	—	—	—
PITI	−0.087***	1	—	—	—	—	—	—
INT	−0.218***	0.130***	1	—	—	—	—	—
GDPG	−0.056***	−0.369***	0.015	1	—	—	—	—
AGDP	−0.090***	0.384***	0.184***	−0.024**	1	—	—	—
SIZE	0.239***	0.027**	−0.175***	−0.074***	−0.076***	1	—	—
LEV	0.155***	−0.080***	−0.163***	−0.011	−0.091***	0.532***	1	—
ROA	−0.005	0.079***	0.162***	0.018	0.080***	−0.019*	−0.374***	1
ATO	−0.025**	0.003	0.193***	0.028**	0.033***	0.102***	0.146***	0.208***
GROWTH	−0.034***	0.052***	0.044***	0.020	0.077**	0.042***	0.019*	0.224***
AGE	0.117***	−0.122***	−0.196***	−0.025**	−0.156***	0.454***	0.389***	−0.242***
TQ	−0.091***	0.033***	0.179***	0.043***	−0.012	−0.419***	−0.250***	0.107***
MS	−0.120***	0.105***	0.159***	0.006	0.161***	−0.373***	−0.328***	0.186***
BAL	−0.073***	0.091***	0.058***	−0.011***	0.049***	−0.171***	−0.235***	0.005
MFEE	−0.171***	−0.121*	0.080***	0.057***	0.01	−0.336***	−0.240***	−0.185***
Variable	ATO	GROWTH	AGE	TQ	MS	BAL	MFEE	—
ATO	1	—	—	—	—	—	—	—
GROWTH	0.124***	1	—	—	—	—	—	—
AGE	0.064***	−0.056***	1	—	—	—	—	—
TQ	−0.043***	−0.021*	−0.01	1	—	—	—	—
MS	−0.075***	0.088***	−0.571***	−0.009	1	—	—	—
BAL	−0.081***	0.078***	−0.187***	0.027**	0.254***	1	—	—
MFEE	−0.460***	−0.104***	−0.095***	0.377***	0.096***	0.089***	1	—

Note: * * *, * * and * represent the significance levels of 1%, 5% and 10% respectively.

5 Mechanism inspection

With the strengthening of environmental protection education in recent years, the public attention on environmental protection issues has increased. With the emergence of informal environmental systems (such as GEID), the public can monitor the performance of environmental protection obligations of firms in several ways. The firm and its stakeholders interact and benefit each other. Firms are subject to dual supervision of the government and the public under GEID. The strengthening of the environmental protection concept of stakeholders has increased the corporate cost of environmental default (Ren et al., 2023). Therefore, considering their own reputation and image, firms tend to increase R&D investment in green product innovation (Zeng et al., 2022) and promote the transformation of green technology innovation from "end management" to "source management" (Li et al., 2022).

In order to further investigate whether the internal green innovation of firms is an important strategy for GEID to improve CEPI, based on the practices of (Dong and Wang, 2019; Xu and Cui, 2020), the number of green patent applications in Chinese

Research Data Services (CNRDS) was used as an indicator to measure green innovation. The number of green patent applications of firms was divided into two categories: the number of green inventions and the number of green practical inventions. In order to eliminate the right-biased distribution of green patent application data, based on the study of (Wang and Wang, 2021), the number of green inventions and the number of green practical inventions were treated logarithmically, represented by PAT1 and PAT2, respectively, to determine whether GEID affects corporate green innovation. The higher the green patent applications of the firm in the current year, the stronger the green innovation of the firm. The intermediary effect model constructed was as follows:

$$PAT_{i,t} = \alpha_0 + \alpha_1 PITI_{i,t} + \sum Controls_{i,t} + YEAR + FIRM + CITY + \varepsilon \quad (5)$$

$$CEP_{i,t} = \gamma_0 + \gamma_1 PITI_{i,t} + \gamma_2 PAT_{i,t} + \sum Controls_{i,t} + YEAR + FIRM + CITY + \varepsilon \quad (6)$$

In the model, PAT refers to the number of green patent applications of the company in the current year, and is represented by PAT1 and PAT2. Other variables are defined as above.

TABLE 6 Main effect regression test results.

Variable	CEP	
	(1)	(2)
PITT	−0.0022**	−0.0023**
	(−2.1597)	(−2.2547)
GDPG	0.0620	0.0687
	(0.1173)	(0.1295)
AGDP	0.0280	0.0222
	(0.8153)	(0.6200)
SIZE	−0.0810	−0.0806
	(−1.3544)	(−1.3376)
LEV	0.1063	0.1053
	(0.6959)	(0.6729)
ROA	0.9547***	0.9951***
	(3.2479)	(3.2223)
ATO	−0.2622**	−0.2788**
	(−2.1296)	(−2.1710)
GROWTH	0.0817**	0.0816**
	(2.2532)	(2.2274)
AGE	0.1113*	0.1129*
	(1.9537)	(1.9173)
TQ	−0.0284	−0.0285
	(−1.0737)	(−1.0685)
MS	0.0581	0.0671
	(0.5738)	(0.6558)
BAL	−0.0259	−0.0266
	(−0.5826)	(−0.5937)
MFEE	1.4530**	1.4726**
	(2.2471)	(2.2140)
_cons	2.0745*	2.1481*
	(1.6384)	(1.6490)
YEAR	Y	Y
FIRM	Y	Y
CITY	N	Y
N	7705	7705
adj.R2	0.424	0.423

Note: * * *, * * and * represent the significance levels of 1%, 5% and 10% respectively.

TABLE 7 Adjustment of Internet penetration.

Variable	CEP	
	(1)	(2)
PITT	−0.0023**	−0.0022**
	(−2.2547)	(−2.4278)
INT	—	−0.0040
	—	(−0.1213)
INT×PITI	—	0.0045**
	—	(2.0902)
GDPG	0.0687	0.0397
	(0.1295)	(0.0755)
AGDP	0.0222	0.0997*
	(0.6200)	(1.6489)
SIZE	−0.0806	−0.0824
	(−1.3376)	(−1.3572)
LEV	0.1053	0.0997
	(0.6729)	(0.6336)
ROA	0.9951***	1.0082***
	(3.2223)	(3.2671)
ATO	−0.2788**	−0.2799**
	(−2.1710)	(−2.1802)
GROWTH	0.0816**	0.0812**
	(2.2274)	(2.2056)
AGE	0.1129*	0.1042**
	(1.9173)	(1.9696)
TQ	−0.0285	−0.0290
	(−1.0685)	(−1.0734)
MS	0.0671	0.0651
	(0.6558)	(0.6276)
BAL	−0.0266	−0.0271
	(−0.5937)	(−0.5990)
MFEE	1.4726**	1.4906**
	(2.2140)	(2.2226)
_cons	2.1481*	1.2961*
	(1.6490)	(1.1108)
YEAR	Y	Y
FIRM	Y	Y
CITY	Y	Y
N	7705	7705
adj. R2	0.432	0.422

Note: * * *, * * and * represent the significance levels of 1%, 5% and 10% respectively.

Table 12 shows the intermediary effect of green innovation of firms tested by model (5) and model (6). Columns (1) and (2) represent the results of model (5), which shows that the higher the GEID, the stronger the green innovation of local firms. Columns (3)

TABLE 8 Regression results of alternative carbon performance indicators.

Variable	CEP		
	(1)	(2)	(3)
PITT	−0.0107**	−0.0109**	−0.0121**
	(−2.0500)	(−2.0766)	(−2.3625)
INT	—	—	−0.0305
	—	—	(-0.1886)
INT×PITI	—	—	0.0214**
	—	—	(1.9580)
GDPG	1.0948	1.0789	0.9282
	(0.4640)	(0.4546)	(0.3982)
AGDP	0.1085	0.0957	0.4694
	(0.7583)	(0.6476)	(1.5665)
SIZE	−0.3771	−0.3775	−0.3886
	(−1.2517)	(−1.2373)	(−1.2598)
LEV	0.2164	0.2140	0.1932
	(0.3723)	(0.3611)	(0.3246)
ROA	3.2031***	3.3378***	3.3937***
	(3.2135)	(3.2247)	(3.2473)
ATO	−0.8491*	−0.9029**	−0.9076**
	(−1.9531)	(−2.0102)	(−2.0172)
GROWTH	0.2557*	0.2559*	0.2593*
	(1.7007)	(1.6751)	(1.6669)
AGE	0.7098**	0.7137**	0.6898**
	(2.4982)	(2.4744)	(2.4572)
TQ	−0.1006	−0.1013	−0.1026
	(−1.4344)	(−1.4319)	(−1.4389)
MS	−0.1006	−0.0697	−0.0776
	(−0.2747)	(−0.1880)	(−0.2051)
BAL	−0.1309	−0.1349	−0.1352
	(−0.7511)	(−0.7681)	(−0.7600)
MFEE	4.3398**	4.4189**	4.5153**
	(2.4373)	(2.4155)	(2.4525)
_cons	8.9185*	9.1040*	5.1967*
	(1.5485)	(1.5597)	(1.0247)
YEAR	Y	Y	Y
FIRM	Y	Y	Y
CITY	N	Y	Y
N	7705	7705	7705
adj. R2	0.454	0.454	0.453

Note: *** , ** and * represent the significance levels of 1%, 5% and 10% respectively.

TABLE 9 Regression results of subsamples.

Variable	CEP		
	(1)	(2)	(3)
PITT	−0.0017**	−0.0018**	−0.0021**
	(−2.2776)	(−2.0674)	(−2.0944)
INT	—	—	−0.0377
	—	—	(−1.0071)
INT×PITI	—	—	0.0021**
	—	—	(2.3495)
GDPG	−0.6211	−0.5663	−0.5582
	(−1.1380)	(−1.1103)	(−1.0097)
AGDP	0.0012	−0.0365	0.0358
	(0.0512)	(−1.2851)	(0.9583)
SIZE	0.0033	0.0046	0.0028
	(0.1182)	(0.1647)	(0.0964)
LEV	0.1115**	0.1106**	0.1201*
	(0.7333)	(0.7267)	(0.7834)
ROA	0.2626	0.2358	0.2834
	(0.9372)	(0.8558)	(1.0026)
ATO	0.1403**	0.1381**	0.1437**
	(1.3045)	(1.2892)	(1.3240)
GROWTH	0.0029**	−0.0006	0.0006**
	(0.0753)	(−0.0144)	(0.246)
AGE	0.0429	0.0421*	0.0436
	(1.5216)	(1.4985)	(1.5256)
TQ	0.0085	0.0113	0.0077
	(0.5005)	(0.7278)	(0.4450)
MS	0.0436	0.0481	0.0488
	(0.5454)	(0.6030)	(0.6056)
BAL	−0.0085	−0.0094	−0.0078
	(−0.3480)	(−0.3819)	(−0.3151)
MFEE	−0.2269	−0.2601	−0.2189
	(−0.5149)	(−0.6237)	(−0.4955)
_cons	0.2233	0.6407	−0.1250
	(0.3145)	(0.9450)	(−0.1625)
YEAR	Y	Y	Y
FIRM	Y	Y	Y
CITY	N	Y	Y
N	7399	7399	7399
adj. R2	0.468	0.469	0.469

Note: *** , ** and * represent the significance levels of 1%, 5% and 10% respectively.

TABLE 10 Excluding other policy shocks.

Variable	CEP		
	(1)	(2)	(3)
PITT	−0.0046**	−0.0046**	−0.0032**
	(−2.4088)	(−2.4130)	(−2.4087)
INT	—	—	0.0502
	—	—	(0.3487)
INT×PITI	—	—	0.0094**
	—	—	(2.0266)
GDPG	−0.2639	−0.2539	−0.3840
	(−0.2406)	(−0.2344)	(−0.3734)
AGDP	−0.0731	−0.0699	−0.0356
	(−0.5547)	(−0.5556)	(−0.2570)
SIZE	0.0532	0.0533	0.0531
	(0.8905)	(0.9069)	(0.8994)
LEV	−0.0893*	−0.0925*	−0.0881
	(−0.2631)	(−0.2808)	(−0.2601)
ROA	0.7660*	0.7620**	0.7573*
	(1.9210)	(1.9641)	(1.8857)
ATO	−0.1666**	−0.1650*	−0.1625**
	(−1.3290)	(−1.3433)	(−1.2909)
GROWTH	0.0462	0.0460	0.0478
	(1.1354)	(1.1493)	(1.1615)
AGE	0.0072**	0.0081*	−0.0143
	(0.0755)	(0.0880)	(−0.1548)
TQ	−0.0241	−0.0240	−0.0241
	(−0.5834)	(−0.5868)	(−0.5830)
MS	0.3327	0.3323	0.3409
	(1.3591)	(1.3739)	(1.3886)
BAL	−0.1474*	−0.1471*	−0.1512*
	(−1.7510)	(−1.7714)	(−1.7695)
MFEE	1.2476**	1.2425**	1.2752**
	(2.2474)	(2.3294)	(2.2856)
_cons	0.7719*	0.7285*	0.2966*
	(0.5286)	(0.5127)	(0.1893)
YEAR	Y	Y	Y
FIRM	Y	Y	Y
CITY	N	Y	Y
N	2930	2930	2930
adj. R2	0.404	0.406	0.404

Note: * * *, * * and * represent the significance levels of 1%, 5% and 10% respectively.

TABLE 11 PSM propensity score matching.

Variable	CEP	
	(1) Kernel matching	(2) Radius (0.01) matching
PITT	−0.0023**	−0.0024**
	(−2.3075)	(−2.3955)
GDPG	0.0795	0.0153
	(0.1782)	(0.0347)
AGDP	0.0264	0.0278
	(0.7144)	(0.7586)
SIZE	−0.0815***	−0.0668***
	(−3.4110)	(−2.8089)
LEV	0.0894	0.0787
	(1.0929)	(0.9707)
ROA	0.9480***	0.9326***
	(6.0533)	(5.8384)
ATO	−0.2593***	−0.2038***
	(−5.9355)	(−4.6775)
GROWTH	0.0825***	0.0724***
	(5.0694)	(4.4740)
AGE	0.1122***	0.1046**
	(2.5837)	(2.4284)
TQ	−0.0376***	−0.0279***
	(−4.9955)	(−3.5633)
MS	0.0505	0.0505
	(0.5285)	(0.5294)
BAL	−0.0225	−0.0275
	(−0.9429)	(−1.1629)
MFEE	1.3631***	1.2430***
	(7.7637)	(7.3286)
_cons	2.1656*	1.9140
	(1.7256)	(1.4771)
YEAR	Y	Y
FIRM	Y	Y
CITY	Y	Y
N	7705	7705
adj. R2	0.441	0.423

Note: * * *, * * and * represent the significance levels of 1%, 5% and 10% respectively.

and (4) list the results of model (6) and verify the previous conclusion, suggesting that GEID can reduce the intensity of corporate carbon emissions and improve CEPI by improving corporate green innovation.

TABLE 12 Mediation effect test.

Variable	PAT		CEP	
	(1)PAT1	(2)PAT2	(3)	(4)
PITI	0.0034*	0.0049**	−0.0024**	−0.0024**
	(1.6843)	(2.0255)	(−2.1453)	(−2.1479)
PAT1	—	—	−0.0243***	—
	—	—	(−2.7003)	—
PAT2	—	—	—	−0.0246***
	—	—	—	(−2.8254)
GDPG	3.5152***	5.2237***	0.0865	0.0835
	(3.3850)	(4.1790)	(0.1639)	(0.1580)
AGDP	0.0900	0.0362	0.0233	0.0214
	(1.6323)	(0.5712)	(0.6483)	(0.5944)
SIZE	0.7309***	0.8195***	−0.0663	−0.0686
	(25.9590)	(25.8214)	(−1.0621)	(−1.0997)
LEV	−0.2763*	−0.4379**	0.1024	0.1068
	(−1.8664)	(−2.4755)	(0.6547)	(0.6826)
ROA	1.0750***	1.1490***	0.9948***	1.0001***
	(2.9844)	(2.6888)	(3.2552)	(3.2727)
ATO	0.4814***	0.5386***	−0.2755**	−0.2766**
	(5.6657)	(5.4548)	(−2.1582)	(−2.1654)
GROWTH	−0.0741**	−0.1113***	0.0815**	0.0810**
	(−2.1898)	(−2.5939)	(2.2113)	(2.1972)
AGE	−0.1007***	−0.1697***	0.1095**	0.1113**
	(−2.7408)	(−3.8687)	(2.0109)	(2.0539)
TQ	0.0137	−−0.0338*	−0.0290	−0.0287
	(0.8462)	(−1.6941)	(−1.0781)	(−1.0682)
MS	−0.0317	0.0840	0.0636	0.0626
	(−0.2478)	(0.5663)	(0.6200)	(0.6100)
BAL	0.0565	0.0615	−0.0251	−0.0256
	(1.5474)	(1.4086)	(−0.5573)	(−0.5693)
MFEE	1.8186***	1.0949**	1.4891**	1.4810**
	(4.9309)	(2.4513)	(2.2340)	(2.2243)
_cons	−15.7819***	−15.4278***	1.8736*	1.9140*
	(−18.9163)	(−15.9641)	(1.4420)	(1.4706)
YEAR	Y	Y	Y	Y
FIRM	Y	Y	Y	Y
CITY	Y	Y	Y	Y
N	7705	7705	7705	7705
adj. R2	0.426	0.438	0.423	0.424

Note: * * *, * * and * represent the significance levels of 1%, 5% and 10% respectively.

6 Further analysis

Firms with different property rights exhibit different responses to policies. First, as a subsidiary of the government, state-owned enterprises need to take more responsibility for carbon emission reduction (Li et al., 2019). The leaders of state-owned enterprises are appointed and evaluated by their subordinate government agencies, and their management is composed of government officials. Their performance is mainly evaluated by government officials, who may not focus on profitability, but on the implementation of government policy authorization (Zhuang et al., 2022). State-owned enterprises are largely influenced by national policies and assist the government in achieving its broader political and social goals. However, state-owned enterprises not only bear the economic responsibility of increasing GDP and fiscal revenue, but also bear specific social and environmental responsibilities. Therefore, state-owned enterprises are more likely to reduce carbon emissions under the impact of greater responsibilities and obligations.

Second, compared with other firms, state-owned enterprises have a natural "blood relationship" with the government, and have several resource advantages in carbon emission reduction (Shi, 2022). Compared with non-state-owned enterprises, state-owned enterprises have closer political relations with the government and are more likely to obtain government resources (Liu and Hu, 2020), such as short-term bank loans, lower price equity than the stock market, government firm assistance and financial subsidies, tax incentives and other policies, which facilitate environmental protection activities by firms. Therefore, state-owned enterprises can obtain additional resource subsidies related to carbon emission reduction and respond more positively to government policies.

To test the effect of ownership type on the relationship between GEID and CEPI, this study conducted multiple linear regression analysis of state-owned and non-state-owned enterprises. Table 13 presents the results of regression analysis of property heterogeneity test.

Column (1) represents the results of regression of state-owned enterprises. The coefficient of PITI is negative and significant at the level of 1%. Column (2) lists the results of regression of non-state-owned enterprises. The coefficient of PITI is negative and the result is not significant. The controlling shareholders of state-owned listed companies are directly or indirectly governments. It indicates that the higher the degree of GEID, the greater the environmental supervision that state-owned enterprises may be subjected to. Compared with non-state-owned enterprises, state-owned enterprises have more obligations to reduce their CEP and improve their carbon performance in order to improve their regional environmentally-friendly image.

7 Conclusion and policy suggestions

As China pays more and more attention to environmental issues, how to guide firms to save energy and reduce carbon dioxide emissions has become a key issue to explore. As an informal environmental regulation system, GEID combines the participation of the public, the government and enterprises,

TABLE 13 Property right heterogeneity test.

Variable	CEP	
	(1) State-owned enterprises	(2) Non-state-owned enterprises
PITI	−0.0065***	−0.0001
	(−2.6228)	(−0.1986)
GDPG	−0.3694	0.3778
	(−0.4099)	(0.7003)
AGDP	0.0329	0.0327
	(0.3639)	(0.7376)
SIZE	−0.0521	−0.0850
	(−0.3628)	(−1.3789)
LEV	−0.1501	0.2607
	(−0.4778)	(1.3656)
ROA	1.8385***	0.7228*
	(3.5089)	(1.8754)
ATO	−0.3497***	−0.2485
	(−2.8124)	(−1.4137)
GROWTH	0.0694	0.0952**
	(1.0045)	(2.0570)
AGE	0.4299**	−0.0848**
	(2.2037)	(−2.2253)
TQ	−0.0150	−0.0237
	(−0.7312)	(−0.7277)
MS	−1.3025	0.0856
	(-0.9083)	(0.8366)
BAL	−0.1225	−0.0063
	(−1.1998)	(−0.1370)
MFEE	0.1991	1.7294**
	(0.4789)	(2.0203)
_cons	1.7838	1.8305
	(0.6412)	(1.2543)
YEAR	Y	Y
FIRM	Y	Y
CITY	Y	Y
N	2365	5340
adj.R2	0.464	0.374

Note: * * *, * * and * represent the significance levels of 1%, 5% and 10% respectively.

which can not only enable the public to monitor enterprise emission information, but also urge the government to participate in enterprise environmental protection and emission reduction through the government information disclosure platform. In this context, literature research shows that local government carbon emissions indicators, promotion of government officials and the promulgation of local environmental laws and regulations are directly related to local carbon performance. When the degree of government environmental information disclosure is higher, the government mainly exposes the excessive emission behavior of

enterprises through public supervision. Good government information disclosure can improve the carbon performance level of enterprises.

This study analyzed a sample of China's A-share listed companies in manufacturing and mining industries from 2013 to 2018, and empirically tested whether GEID affected CEPI. The results show that the higher the degree of GEID where the firm is registered, the greater the attention on its carbon-use efficiency, and the better its carbon performance. In addition, the higher the degree of local public participation, the greater the public supervision of firms and governments. Public participation weakens the positive impact of GEID on CEPI, and acts as a substitute for GEID. In terms of mechanism, GEID improves carbon performance by promoting green innovation of firms. Further analysis shows that compared with non-state-owned enterprises, state-owned enterprises are more closely connected with the government, and experience greater pressure to reduce carbon emissions and improve carbon performance independently. The policy implications of this study include:

1) Continuous improvement of the environmental regulation system is needed and the combination of informal and formal environmental system should be promoted. GEID can effectively improve the carbon performance of firms, and promote and encourage firms to improve carbon-use efficiency via technological innovation and other ways. Therefore, it is necessary to further expand the scope of cities participating in PITI scoring and improve the quality and frequency of GEID. It is necessary to establish a diversified environmental governance system involving local governments, firms, non-governmental environmental organizations and the public, ensure the sustainability of PITI in promoting environmental efficiency, and develop a coordinated and complementary environmental community. It is necessary to enhance the advantages of formal environmental systems (such as mandatory environmental information disclosure), clearly regulate relevant environmental standards, and urge firms to independently improve carbon utilization efficiency and fulfill environmental protection obligations.

2) The government should play the role of guide and supervisor to promote energy conservation and emission reduction by firms. Governments at all levels should provide subsidies for green innovation to firms and encourage corporate investment. At the same time, through the Internet and other channels, the corporate performance and environmental responsibility should be evaluated in a timely manner to ensure the public's right to information. Firms that discharge emissions in violation of regulations should be reported promptly to urge them to comply with environmental protection agreements.

3) Firms should increase investment in green innovation and improve carbon-use efficiency. GEID can improve CEPI via corporate green innovation. Firms should improve their environmental awareness and carry out green innovation independently, so as to ease the pressure of GEID on corporate carbon emissions, improve their competitiveness

while improving carbon performance, and promote sustainable development.

The study limitations may be addressed in the future. First, this study estimates corporate carbon emissions based on industry carbon emissions. Although this method of calculation is similar at the firm level, different firms were not analyzed. Thus, the data may be biased. In the future, if corporate carbon emissions are included in the mandatory disclosure project, further accurate data can be collected for additional research. Second, the study data only include the main board listed companies, so whether the relationship between regional environmental information disclosure and CEPI in non-listed companies is similar to that of listed companies is unknown. In the future, data of non-listed companies that independently disclose carbon emission data should be collected to further validate the results.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: The datasets for this study can be found in the China Stock Market and Accounting Research Database (https://www.gtarsc.com) and National Bureau of Statistics of China (www.stats.gov.cn).

Author contributions

MP, SP, YJ, and SW contributed to conceptualization, formal investigation, analysis, methodology, and writing and editing of the original draft. All authors contributed to the article and approved the submitted version.

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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

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