frontiers | Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 04 January 2023
DOI 10.3389/fenvs.2022.1074267

OPEN ACCESS

EDITED BY
Shuhong Wang,
Shandong University of Finance and Economics, China

REVIEWED BY
Binbin Lu,
Nankai University, China
Elkhan Richard Sadik-Zada,
Ruhr University Bochum, Germany

*CORRESPONDENCE
Haitao Zhang,
20190201028@stu.cqu.edu.cn
Jingrong Dong,
2758099292@qq.com

SPECIALTY SECTION
This article was submitted to Environmental Economics and Management, a section of the journal Frontiers in Environmental Science

RECEIVED 19 October 2022
ACCEPTED 16 December 2022
PUBLISHED 04 January 2023

CITATION
Zhang H, Dong J, Zhang W and Luo J (2023), Public environmental supervision, environmental non-governmental organizations, and industrial green and low-carbon transformation.
Front. Environ. Sci. 10:1074267.
doi: 10.3389/fenvs.2022.1074267

Public environmental supervision, environmental non-governmental organizations, and industrial green and low-carbon transformation

Haitao Zhang[1]*, Jingrong Dong[2]*, Wenqing Zhang[1] and Jiahui Luo[1]

[1]School of Economics and Business Administration, Chongqing University, Chongqing, China, [2]School of Economics and Management, Chongqing Normal University, Chongqing, China

The existing literature on China's industrial green and low-carbon transformation primarily concerns the government's top-down formal environmental regulation. A few studies have systematically investigated the role of informal environmental regulation represented by public environmental supervision and environmental non-governmental organizations The impact of public environmental supervision and ENGOs on industrial green and low-carbon transformation and its mechanism is empirically examined in this paper using a system GMM model and provincial panel data from 2005 to 2018. According to the findings, both Public environmental supervision and ENGOs can achieve green and low-carbon industrial transformation by promoting green technology progress; Public environmental supervision cannot collaborate with ENGOs to promote green and low-carbon industrial transformation based on national data. Further analysis indicates that the effect of public environmental supervision and ENGOs on industrial green and low-carbon transformation has significant regional heterogeneity. Public environmental supervision has a positive impact on industrial green and low-carbon transformation in the eastern and central regions. It has a negative impact on industrial green and low-carbon transformation in the western region. ENGOs promote green and low-carbon industrial transformation in the eastern and western regions. Only the eastern region has a synergistic effect on industrial greening and low-carbon transformation.

KEYWORDS

public environmental supervision, ENGOs, green total factor productivity, green and low-carbon transformation, China's industry

1 Introduction

Since the 1990s, China's industry has depended on the demographic dividend, land dividend, policy dividend, and low environmental regulation costs comprehensive comparative advantage in the depth into the global value chain division of labor system rapidly grew into the world's first industrial power. However, this enormous material wealth led to a severe resource shortage and ecological damage that was hard to remedy, and pollution emissions have reached their maximum limit (Cheng and Kong, 2022). Effectively promoting industrial energy conservation and carbon reduction, as well as green low carbon transformation, is to implement the carbon peak and carbon neutral strategy, which is also the key to ecological civilization construction, as well as to crack the current industrial development and resources and environment conflict, harmonious industrial civilization and ecological civilization, economic performance and environmental performance win-win choice, is also one of the key problems in the industry (Lü et al., 2015).

According to theoretical and empirical studies, green and low-carbon transformation largely depend on reasonable environmental regulations (Hou et al., 2018). There are two types of environmental regulation based on different subjects of implementation: formal environmental regulation led by the government and informal environmental regulation that relies on the participation of the public and social organizations (Pargal and Wheeler, 1996). Several existing studies focus on the top-down formal environmental regulation of the government and find that formal environmental regulation plays an important role in promoting green industrial transformation or low-carbon transformation (Zhai and An, 2020; Wang et al., 2023).

Formal environmental regulation, however, has some limitations in the area of low-carbon and green transformation. This includes the following two aspects: first, it is common for formal environmental regulations to be implemented in an ineffective manner. Both makers (the central government) and the implementers (local governments) have inconsistent objective functions. Local governments will choose the strength of regulations based on their own interests to attract liquid resources to realize rapid economic development and reduce the intensity of regulation. This causes vicious environmental competition in various regions(Sadik-Zada and Ferrari, 2020), and the result of environmental management is less than ideal (Fedyukin, 2018; Liu et al., 2022). Second, formal environmental regulation does not bind enterprises strongly. First, a large number of scattered and small-scale micro and small industrial enterprises that are not easy to supervise are difficult to carry out emission reduction activities according to regulations (Tang and Li, 2022), which results in higher implementation costs than implementation benefits and relatively low efficiency. In addition, local administrative departments may lack the funds and legislation to monitor the emission status of polluting enterprises (Arias, 2020), and local administrative personnel may collude with polluting enterprises, resulting in "regulation capture" (Wang et al., 2020a; Zhang and Song, 2021).

In view of the limitations and problems of formal environmental regulation in practice, informal environmental regulation, as a regulatory force often ignored, is an important addition to formal environmental regulation (Féres and Reynaud, 2012; Zhao et al., 2022) and plays a significant role in promoting green and low-carbon industrial transformation and upgrading, as well as environmental protection. Informal environment regulation refers to the formal environment when the government's implementation of regulation does not look well or fails; the social public, formed by the spontaneous action of environmental groups or other spontaneous forces, with pollution enterprises to carry out consultations or negotiations, or through the crowd to appeal to the local government, media exposure, and polluting enterprises pressure, aiming to reduce pollution (Pargal and Wheeler, 1996).

Informal environmental regulation varies from formal environmental regulation in the following ways: first, ENGOs can facilitate information exchange between central and local governments. The evaluation of environmental information disclosure by ENGOs for government at a higher level as well as at a lower level of environmental performance provides a scientific and objective basis, avoids whitewashed environmental data, and even increases the information communication between the environmental monitoring departments to help monitor the environmental management of the central government to local governments (Pien, 2020; Zhang and Huang, 2022). Second, public environmental oversight has a greater binding effect on businesses. The public's demand for corporate environmental governance is "immediate," requiring polluting businesses to not only stop treatment and reduce pollution emissions but also to conduct green technology research and development to reduce corporate pollution to maintain the corporate image and social reputation (Fu and Geng, 2019; Long et al., 2022). The limitations of formal environmental regulation can be supplemented by ENGOs and public environmental supervision. Then, do ENGOs and public environmental supervision have any impact on industrial green and low-carbon transformation? How does this mechanism work? And is there heterogeneity across regions?

As an attempt to answer the above questions, this paper examines the impact and mechanism of informal environmental regulation represented by public environmental supervision and ENGOS on industrial green and low-carbon transformation. Here is a list of possible marginal contributions to this paper. First, most of the existing literature studies the impact of formal environmental regulation on green technology innovation or industrial transformation and upgrading, while the research on public environmental supervision and non-governmental environmental protection organizations for green and low-

carbon industrial transformation is relatively rare. A deeper understanding of related fields can be gained from the results of this article; Second, the study of informal environmental regulation in industrial green and low-carbon transformation is investigated, as well as the synergistic effect of public environmental supervision and ENGOS on industrial green and low-carbon transformation. The third aspect of this paper discusses the regional heterogeneity of the impact of informal environmental regulation on industrial green and low-carbon transformation. The impacts of public environmental supervision and ENGOS on industrial green and low-carbon transformation may show heterogeneity in regions with different levels of economic development and different environmental standards.

2 A brief literature review

Informal environmental regulation was first proposed by Pargal and Wheeler (1996), which means that when formal environmental regulation is absent or weak, the public, media, and social groups negotiate or negotiate with polluting enterprises so as to reduce pollution emissions and achieve the purpose of protecting the environment. With the deepening understanding of the theory of information asymmetry, the academic community has gradually realized that in addition to formal environmental regulation, there are other informal environmental regulation methods that can affect the environmental behavior of polluters and also play an important role in environmental protection (Kathuria and Sterner, 2006). Scholars have conducted a large number of studies on the relationship between informal environmental regulation and pollution control since then, with the majority of these studies focusing on ENGOs and public environmental supervision.

ENGOs information disclosure on environmental pollution is an essential means and tool in environmental governance, and its positive role has been verified by many research results. Some scholars use Pollution Information Transparency Index (PITI) to examine the role of ENGOs. Tian et al. (2016) found a negative correlation between PITI and local environmental pollution emission levels and increased investment of enterprises in industrial pollution control. Li G et al. (2018) used the PITI to test the role of ENGOs and found that PITI had a significant positive effect on the environmental governance of Chinese cities. Zhang et al. (2022) conducted the panel dataset of China's 285 cities from 2003 to 2018 to investigate the causal impact of the data environmental information disclosure on environmental efficiency. The empirical results show that compared with non-PITI cities, environmental efficiency in PITI cities improves by 21.11% relative to the sample average. Other scholars choose the number of regional ENGOs to study their role. Pien (2020) collected the number of national ENGOs and local ENGOs in China and found that both types of ENGOs could effectively disclose environmental pollution information, thereby reducing environmental pollution. The more local NGOs, the better the local environment. Wu et al. (2020) selects the sum of the number of unofficial organizations in the environmental category to measure ENGOs participation. The results show that environmental non-government organizations' participation has a significant positive effect on regional environmental quality improvement; Tang and Li (2022) collected the number of ENGOs in each region and found that the greater the number of ENGOs in each region, the more conducive to local green development.

Public environmental supervision can directly supervise polluting enterprises' emission status, putting tremendous pressure on local governments and polluting enterprises while also helping to improve local environmental quality. Many empirical findings have also supported its positive role. For example, Kathuria and Sterner (2006) studied the impact of public participation on corporate pollution and found that public participation has a lagging inhibitory effect on corporate pollution. Langpap and Shimshack (2010) investigated public lawsuits against environmental pollution. The results showed that public environmental supervision, as an informal environmental regulation, played a significant role in controlling water pollution in the United States. Liao and Shi (2018) used panel data from 30 provinces in China from 1998 to 2014 and found that public appeal tends to have a positive effect on increasing green investment in China's context. Fu and Geng (2019) used the panel data of China's 30 provinces from 2004 to 2014 and found that the degree of public participation has a positive effect on the improvement of the green development mode in the eastern and central regions, and it has an obvious effect on the green development effect in the western region. Sadik-Zada and Gatto (2022) addressed the nexus between civic engagement and energy transition in 11 countries of the Nordic-Baltic Sea Region. The study detects a strong positive relationship between civic engagement within environmental organizations and the share of renewable energy sources in the domestic electricity mixes of the countries of the Nordic-Baltic Sea Region.

From the above literature review, it can be seen that the existing literature has studied the impact of ENGOS and public environmental supervision on environmental governance, enterprise pollution emission, and green development, but there are also some limitations. First, there is a lack of research on whether ENGOs and public environmental supervision can promote green and low-carbon industrial transformations, particularly the internal mechanisms by which the two can do so. Because the industry is China's largest polluter, it should be the primary industry studied to determine the impact of environmental governance. Second, most studies focus on a single informal environmental regulation, with few investigating the synergistic effect of ENGOS and public environmental oversight on industrial

green and low-carbon transformation. Therefore, this paper attempts to study the influence of ENGOS and public environmental supervision on industrial green and low-carbon transformation through theoretical analysis and empirical tests, as well as the influence mechanism and synergistic effect of two kinds of informal environmental regulations on industrial green and low carbon transformation, so it makes up for the shortcomings of existing research to a certain extent.

3 Theoretical framework

As part of this part, we will theoretically analyze the impact of ENGOs and public environmental supervision on industrial green and low-carbon transformation.

3.1 Public environmental supervision and industrial green and low-carbon transformation

In one sense, public environmental supervision may limit enterprises' green and low-carbon transformation. First, it might crowd out R&D funds. Public environmental supervision exerts pressure on polluting enterprises through the news media, network, and other channels, forcing them to increase investment in pollution control. This may occupy the original R&D funds will result in reduced innovation (Quesnel and Ajami, 2017; Du et al., 2019). Second, public environmental regulation may reduce corporate profits. When an enterprise fails to discharge pollution following regulations, the public may take action to penalize the enterprise. For example, boycotting pollutes companies' production goods, interfering with normal production and thus compressing the company's income and opposing its transition to low green carbon (Li et al., 2017). Third, public environmental supervision may negatively impact corporate decision-making. Enterprises may bring public demands into the decision-making process, however, public participation may not improve scientific management decisions. On the contrary, it may increase the management cost and time of the enterprise (Zhang et al., 2022).

In contrast, public environmental oversight may compel businesses to implement green technological innovation to promote green and low-carbon transformation. First, in response to public opinion pressure brought on by public complaints, polluting enterprises will take the initiative to introduce or develop green products, thereby shifting from "terminal pollution control" to "source control" (Du et al., 2019; Tang and Li, 2022). Second, improving public preference for "clean" products helps encourage enterprises to conduct green innovation to meet consumer needs and increase the investment, research, and development of green products (Li L et al., 2018). Third, the social public can protect their legitimate rights and interests by petitioning government departments, writing letters or reporting, fines, and even shutting down pollution enterprises for their own interests through formal environmental regulation, forcing enterprises to innovate green technology, promoting low carbon enterprise transformation (Quesnel and Ajami, 2017; Liu et al., 2021).

Based on this, we present the following hypothesis 1:

Hypothesis 1: The impact of public environmental supervision on the green and low-carbon industrial transformation is uncertain in different situations.

3.2 ENGOs and industrial green and low-carbon transformation

ENGOs promote green and low-carbon transformation primarily through the following two aspects:

First, ENGOs could affect the formulation of government environmental policies. With relevant environmental expertise, ENGOs can participate in the formulation of government environmental regulation policies to a certain extent or indirectly influence the formulation of government environmental policies by means of publicizing environmental protection policies to the public(Li G et al., 2018; Fu and Geng, 2019).

Second, ENGOs can have an impact on how government environmental policies are implemented. Due to the lack of oversight over the distribution and use of resources in this process, many officials have ample opportunity to exploit this power for financial gain, resulting in high levels of corruption in local governments (Wang et al., 2020b; Wu et al., 2020). Therefore, the implementation effect of environmental policies is not good. While ENGOs will collect, sort out and analyze the pollution source supervision information released by local governments at all levels, score the environmental information disclosure level of local governments, and make reports for the whole society (Bentata and Faure, 2015). This can not only reflect the current environmental governance effect of local governments but also force local governments with low scores to implement strict environmental regulations and improve environmental quality by putting public pressure on them to avoid accountability from higher levels of government and establish a good urban image in front of the public (Tian et al., 2016; H. Zhang et al., 2022). Furthermore, ENGOs can monitor whether local enterprises' pollution emissions are consistent with environmental policy requirements, disclose enterprise pollution emissions, and compel enterprises to conduct pollution control or green innovation to promote enterprises' green and low-carbon transformation (Pien, 2020).

Based on this, we present the following hypothesis 2:

Hypothesis 2: ENGOs can promote the green and low-carbon transition of industry.

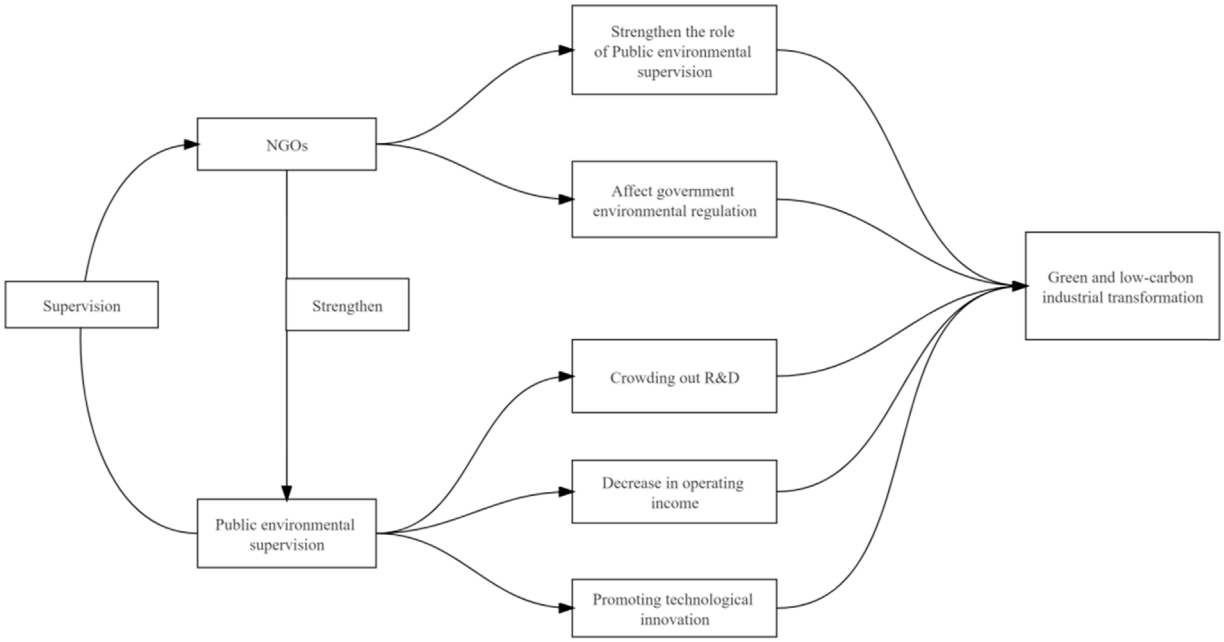

FIGURE 1
The impact of public environmental supervision and ENGOs on industrial green and low-carbon transition.

3.3 Public environmental supervision and ENGOs to promote green and low-carbon industrial transformation

On the one hand, ENGOs can strengthen the role of the public in supervising the government and enterprises. First of all, relevant environmental documents issued by the government need to be further interpreted and analyzed by ENGOs, so that it becomes easier for enterprises and the public to understand and feel, easing the asymmetry of information between the government, enterprises, and the public right into the problem, enriching public participation in monitoring the behavior of the government and the enterprises (Wu et al., 2020). Secondly, ENGOs enhance public awareness of environmental protection and promote citizens' active participation in environmental protection actions through social appeals and information disclosure (Xin and Lai, 2022), which undoubtedly puts greater pressure on polluting enterprises' pollution emissions (Zhang and Chen, 2018). To reduce pollution emissions, businesses must take steps such as increasing pollution control spending, introducing pollution emission terminal treatment equipment, or developing green products.

On the other hand, ENGOs are subject to stricter requirements regarding public environmental oversight. With the rapid development of the internet, the urgency of public participation in supervision has gradually increased, and the awareness of justice and equality has been further aroused, the public demands more from ENGOs. The social public supervision reinforces the supervision by the public opinion of the ENGOs can efficiently ease the NGO participation mechanism, and lack of interactive mechanism (Mohamad Saifudin, 2017), organization and management mechanism is not sound, and ENGOs operating problems, such as information is not public, promote the environmental protection NGOs work (Nur Nasliza, 2013).

Based on this, we present the following hypothesis 3:

Hypothesis 3: Public supervision and environmental protection ENGOs may work together to advance the green and low-carbon industrial transformation.

Based on the theoretical analysis, we obtain the following Figure 1:

4 Data and methodology

4.1 Empirical model

The lag item of industrial green and low carbon transformation is introduced using the Cobb-Douglas production function to establish a systematic GMM model to study the impact of informal environmental regulation of industrial green and low carbon transformation. The specific forms are as follows:

$$\ln gtfp_{it} = \alpha_0 + \alpha_1 \ln gtfp_{it-1} + \alpha_2 \ln ier_{it} + \alpha_3 \ln control_{it} + v_i + \mu_t + \varepsilon_{it} \quad (1)$$

where, $gtfp_{it}$ signifies industrial green and low-carbon transition, $gtfp_{it-1}$ represents the industrial green and low-carbon transformation with a lag period, ier_{it} denotes an informal environmental regulation, including public environmental supervision (pus_{it}) and non-governmental environmental protection organizations ($engo_{it}$), i represents the province, t represents time; control represents other control variables, including R&D investment (rd), foreign direct investment (fdi), population structure (ps), government investment (gov), trade openness (op); α_o is a constant term, u_i represents the unobservable individual effect of the province, v_t represents the time effect, and ε_{it} is the random interference item. In order to analyze whether there is a time-lag effect in the impact of public environmental supervision and ENGOs on industrial green and low-carbon transformation, we added a period of lag to public environmental supervision and ENGOs for comparative analysis.

$$\ln gtfp_{it} = \alpha_0 + \alpha_1 \ln gtfp_{it-1} + \alpha_2 \ln ier_{it-1} + \alpha_3 \ln control_{it} + v_i + \mu_t + \varepsilon_{it} \quad (2)$$

The quadratic term of public environmental supervision is introduced into the empirical model in order to test hypothesis 1:

$$\ln gtfp_{it} = \alpha_0 + \alpha_1 \ln gtfp_{it-1} + \alpha_2 \ln pus_{it} + \alpha_3 (\ln pus_{it})^2 + \alpha_4 \ln control_{it} + v_i + \mu_t + \varepsilon_{it} \quad (3)$$

The following model is constructed to test hypothesis two regarding ENGOs' impact on low-carbon and green industrial transformations separately:

$$\ln gtfp_{it} = \alpha_0 + \alpha_1 \ln gtfp_{it-1} + \alpha_2 \ln engo_{it} + \alpha_3 \ln control_{it} + v_i + \mu_t + \varepsilon_{it} \quad (4)$$

To test whether the synergistic effect of hypothesis three exists, the interaction term public environmental supervision and ENGOS are included in the empirical model to assess the synergistic effect of industrial green technology innovation. The specific model is as follows:

$$\ln gtfp_{it} = \alpha_0 + \alpha_1 \ln gtfp_{it-1} + \alpha_2 \ln engo_{it} + \alpha_3 \ln pus_{it} + \alpha_4 \ln engo_{it}{}^* \ln pus_{it} + \alpha_5 \ln control_{it} + v_i + \mu_t + \varepsilon_{it} \quad (5)$$

4.2 Measurement model selection

For the dynamic panel model (2), (3) and (4) to be estimated, the ordinary least square method and the traditional panel model estimation method (fixed effect model and random effect model) have certain limitations, that is, when the parameter estimator must meet certain assumptions, for example, when the random error term of the model follows a normal distribution or a known distribution, Is a reliable estimator. However, the system GMM model proposed by Arellano and Bover (1995) does not need to know the accurate distribution information of the random error term and allows heteroscedasticity and serial correlation of the random error term, so the parameter estimator obtained is more effective than other parameter estimation methods. Simultaneously, in the system GMM model, the lagged term of GTFP is added as an instrumental variable, effectively avoiding the model's potential endogeneity problems. Therefore, the system GMM model is chosen as the benchmark model for regression in this paper. In addition, according to the practice of standard literature, we conduct two tests on the results of system GMM model estimation: one is the Sargan test, which is mainly used to test the validity of instrumental variables; The second is the AR (2) test, which is mainly used to test whether there is second-order serial correlation in the residuals.

4.3 Variable definition

(1) Green and low-carbon transformation (lngtfp): Green and low-carbon transformation is difficult to be measured directly. Its common measures mainly focus on three methods. Firstly, the number of green patent applications is directly used as the proxy index of green and low-carbon transformation (Liu and Chen, 2022; Wen et al., 2022). Secondly, a multi-dimensional index system is adopted to build statistical indexes of green and low-carbon transformation, such as the "green growth index" of the Organization for Economic Cooperation and Development, and the green and low-carbon transformation index system (Wang, 2016). Thirdly, green total factor productivity (Zeng et al., 2023) or its green technology progress is adopted (Tian et al., 2022) as a proxy indicator. Due to the difficulty of green patent application in reflecting the connotation of green low carbon transformation, multi-dimensional index system is easily disturbed by subjective factors, there are several limitations. Therefore, this paper employs the third method, which employs green total factor productivity as a measure of industrial green low carbon transformation.

(2) Explanatory variables: Public environmental supervision (lnpus): Scholars measure public environmental supervision primarily through the exposure of social pollution incidents (Glucker et al., 2013; Fu and Geng, 2019), or use the attention degree of environmental pollution in search engines such as "Baidu" or "Google" to measure (Long et al., 2022), or select the number of letters related to environmental issues (Dong et al., 2011; Tang and Li, 2022), This paper draws on Tang and Li (2022), the

number of letters related to environmental issues was selected to measure the social public environmental supervision, The public in all regions can directly report environmental issues to local environmental protection agencies through letters. The greater the number of letters, the more actively and willingly the local community participates in the environment.

Environmental NGOs (lnengo): Presently, ENGOs are measured in two categories. Virtual variables based on the report jointly published by the Public Environmental Research Center and Natural Resources Protective Association (Tian et al., 2016; Li G et al., 2018; Zhang et al., 2022). Another method is to calculate the ratio of provincial non-governmental organizations at the end of the fiscal year, the actual fund, and the actual private, non-enterprise units at the end of the fiscal year (Pien, 2020; Wu et al., 2020; Tang and Li, 2022). This paper proposes a second approach based on the availability of the data.

(3) Other control variables. The perpetual inventory method is used to convert R&D internal expenditure into the ratio of R&D capital stock to actual GDP (lnrd). Foreign direct investment (lnfdi) is measured by the proportion of provincial foreign direct investment in its actual GDP. Trade openness (lnop) reflects the exchanges between foreign investors and local enterprises reflected in technical exchange and commodity trade. Based on the proportion of imports and exports in GDP over time. The internal expenditure of government R&D investment is used to calculate government investment (lngov). To express demographic structure, a regional elderly dependency ratio is used (lnps). The specific value is the proportion of people aged 65 and up in the population aged 15 to 64.

5 Empirical results and analysis

In this paper, we conducted empirical research on both benchmark and heterogeneity analysis to explore whether ENGOs are involved in informal environmental regulation and public environmental supervision, promoting industrial green low carbon transformation, ENGOs and public environmental supervision, whether green, low carbon transformation, promoting the industry and ENGOs and the public environment supervision effects on the industrial green low carbon transformation, whether there is a regional heterogeneity analysis.

5.1 Sample descriptive statistics

The majority of the statistical data for this paper came from the China Industrial Statistical Yearbook, China Environment Yearbook, China Science and Technology Statistical Yearbook, China Labor Statistical Yearbook, and the websites of the relevant National Bureau of Statistics. Considering the availability of data, the inter-provincial panel data in China industry was selected from 2005 to 2018. Descriptive statistics of related variables are presented in Table 1:

5.2 Stability inspection and cointegration inspection

The panel data used in this paper are from 2005 to 2018, with a 14-year time span; therefore, requiring the test of the stationarity of the data. IPS (different root) and LLC (same root) test results are as follows:

Table 2 shows that neither the IPS test nor the LLC test has unit roots after the first-order difference, demonstrating that the data are stable. The cointegration test was followed by Kao test, which indicated an association between dependent and independent variables.

5.3 Benchmark analysis

1) This paper evaluated the promoting effect and mechanism of public environmental supervision on industrial green and low-carbon transformation from three aspects, including the impact of public environmental supervision on GTFP, technical efficiency change index, and technological progress change index. Table 3 displays the correlation regression results:

First of all, the current and one-period-lagged public environmental supervision are chosen for comparative analysis to determine whether there is a time-lag effect in the impact of public environmental supervision on industrial green and low-carbon transformation. According to the findings of Model (1) and Model (2), the current public environmental supervision has no significant impact on industrial GTFP. In contrast, the lagged one-period public environmental supervision has a significant promotion effect on industrial GTFP. There is a time lag effect of public environmental supervision on industrial green and low-carbon transformation because it takes time for the public to report environmental pollution emissions to the government for the government to control polluting enterprises' emissions and then for polluting enterprises to carry out pollution treatment. Therefore, in the following analysis, public environmental supervision lagged by one period is incorporated within the model as an explanatory variable, which more accurately reflects the impact of public environmental supervision on industrial green and low-carbon transformations.

Secondly, for testing hypothesis 1, in the model after the item joined the supervision from the public square, we got Model (3). The result shows that once the coefficient is positive, the squared coefficient is negative, indicating that public environmental

TABLE 1 Descriptive statistics of the variables.

Variable	Observations	Mean	Standard deviation	Min	Max
lngtfp	420	0.0398	0.145	−1.019	1.050
lnpus	420	9.465	1.531	2.996	12.56
lnengo	420	9.174	1.019	5.537	11.43
lnrd	420	−6.528	0.987	−8.240	−3.489
lnfdi	420	−2.707	0.988	−4.706	0.522
lnop	420	−3.627	0.980	−5.986	−1.409
lngov	420	10.42	3.649	6.069	17.45
lnps	420	4.155	0.114	3.748	4.415

TABLE 2 Root of Unit inspection.

Method of calibration	LLC checkout	IPS checkout
Δ lngtfp	−35.880***	−5.582***
Δ lnpus	−32.779***	−5.431***
Δ lnengo	−31.516***	−5.224***
Δ lnrd	−25.233***	−4.202***
Δ lnfdi	−18.753***	−3.223***
Δ lnop	−16.606***	−2.997***
Δ lngov	−18.077***	−3.146***
Δ lnps	−24.230***	−4.078***

Δ* * *, * * and * are significant at 1%, 5% and 10% respectively; represent the first order difference; LLC and IPS test results correspond to deviation corrected t *, Z-t-tilde-bar values respectively.

supervision has declined after the rise of the inverted "U" type curve by the influence of the industrial green low carbon transformation. This shows that the impact of public environmental supervision on industrial green and low-carbon transformation is uncertain in different stages. Hypothesis one is supported by empirical results.

In Models (4) and (5), the explained variables are substituted by the technical efficiency change index and the technical progress change index to study the effect mechanism of public environmental supervision on green and low-carbon transformation. Based on the results of this study, public environmental supervision has no significant impact on the technical efficiency index, whereas the coefficient in Model (5) is significantly positive, indicating that public environmental supervision promotes industrial green and low-carbon transformation through green technology progress. The reason for this result may be that public environmental supervision can force industrial enterprises to carry out green technology innovation in terms of the production process and manufacturing skills but has little impact on the improvement of green technology innovation efficiency in terms of management system and organization mode of industrial enterprises.

Additionally, other control variables are analyzed together with the regression results of Model (3). The impact of R&D expenditure on green and low-carbon transformation is significant, it demonstrates that increased R&D investment by enterprises can stimulate green technology innovation, thereby promoting green and low-carbon transformation. Foreign investment has no significant impact, demonstrating that while foreign investment can bring some funds, it also sacrifices the environment for economic benefits, implying that foreign investment cannot affect green and low-carbon transformation. Government support promotes green and low-carbon transformation, government financial support alleviates the financial pressure and R&D risk of enterprises, and can effectively carry out green innovation activities to promote green and low-carbon industrial transformation, The coefficient of trade openness is significantly negative, this shows that regions with

10.3389/fenvs.2022.1074267

TABLE 3 Test of the promotion effect of public supervision on the green and low-carbon transformation.

Variable	lngtfp	lngtfp	lngtfp	lnte	lntc
	(1)	(2)	(3)	(4)	(5)
L.lngtfp/lnte/lntc	−0.0350**	−0.0436[a]	−0.0357**	0.0522[a]	0.179[a]
	(−2.471)	(−3.718)	(−2.099)	(10.87)	(8.030)
lnpus	−0.00773				
	(−1.326)				
F.lnpus		0.00535[a]	0.00376[a]	0.00376[a]	0.010
		(3.605)	(2.987)	(3.241)	(1.384)
$(F.lnpus)^2$			−0.000147**	−2.77e-05	−0.000215
			(−2.147)	(−0.0793)	(−0.895)
lnrd	0.0922[a]	0.0919[a]	0.0952[a]	0.240[a]	−0.139[a]
	(4.208)	(4.324)	(3.219)	(7.909)	(−6.942)
lnfdi	0.0252	0.0240	0.0222	−0.0687[a]	0.0568[a]
	(1.465)	(1.373)	(1.117)	(−2.868)	(2.887)
lnps	−0.133**	−0.191[a]	−0.205[a]	−0.556[a]	0.486[a]
	(−2.169)	(−3.510)	(−2.843)	(−4.850)	(4.207)
lngov	0.00563[a]	0.00567[a]	0.00513[a]	0.00400	−0.00312
	(3.633)	(3.472)	(3.175)	(1.249)	(−1.301)
lnop	−0.114[a]	−0.111[a]	−0.108[a]	−0.0951[a]	0.0575[a]
	(−4.868)	(−4.828)	(−4.039)	(−2.886)	(2.856)
AR(2)	0.510	0.537	0.529	0.500	0.421
Sagan	0.717	0.608	0.528	0.915	0.963
Constant	0.852[a]	0.975[a]	1.100[a]	3.377[a]	−2.543[a]
	(2.929)	(3.873)	(2.598)	(6.720)	(-4.804)
Observations	390	390	390	390	390

[a], **, and * show statistical significance at 1%, 5%, and 10% levels, respectively. In parentheses are t values. Results of AR, and Sargan tests are *p* values.

higher trade openness are more unfavorable to industrial green and low-carbon transformation.

(2) Similarly, this paper examined the promotion effect and mechanism of ENGOs on industrial green and low-carbon transformation using three aspects, including GTFP, technical efficiency change index, and technological progress change index. Table 4 displays the correlation regression results:

The number of ENGOs that are lagged by one period and the current period is selected for analysis to analyze whether there is a time-lag effect in the impact of ENGOs on industrial green and low-carbon transformation. According to the results of Model (1) and Model (2), the impact of ENGOs in the current period on industrial GTFP is not significant, whereas the ENGOs lagging one period have a significant promotion effect on industrial GTFP (Table 4). This is because ENGOs monitor the behavior of enterprises, and there is a certain time lag before they take countermeasures. Hypothesis two is supported by empirical results. Therefore, ENGOs lagged by one period are examined as explanatory variables in the following model.

To investigate the action mechanism of ENGOs on industrial GTFP, Models (3) and (4) examined the regression results after the explained variable was replaced with the technical efficiency change index and the technical progress change index, respectively. According to the regression results, ENGOs have a significant inhibitory effect on the change index of technical efficiency, whereas the coefficient of ENGOs in Model (4) is significantly positive. This means that ENGOs can compel businesses to implement green technology innovation to achieve green and low-carbon industrial transformation. However, compared to public supervision, environmental

TABLE 4 Test of the promotion effect of ENGOs on the green and low-carbon transformation.

Variable	lngtfp	lngtfp	lnte	lntc
	(1)	(2)	(3)	(4)
L.lngtfp	−0.0400[a]	−0.0436[a]	0.0554[a]	0.186[a]
	(-2.986)	(−3.718)	(16.02)	(9.675)
lnengo	−0.00332			
	(−1.525)			
F.lnengo		0.00715[a]	−0.0163[a]	0.0800[a]
		(3.560)	(−2.722)	(3.229)
lnrd	0.0808[a]	0.0980[a]	0.278[a]	−0.158[a]
	(4.143)	(3.523)	(13.48)	(−8.781)
lnfdi	0.0282	0.00887	−0.0781[a]	0.0707[a]
	(1.615)	(0.449)	(−3.468)	(3.574)
lnps	−0.162[a]	−0.184[a]	−0.460[a]	0.542[a]
	(−2.704)	(−2.775)	(−6.808)	(6.019)
lngov	0.00554[a]	0.00518[a]	0.00673**	−0.00366*
	(3.670)	(4.464)	(2.282)	(−1.739)
lnop	−0.110[a]	−0.0920[a]	−0.117[a]	0.0544[a]
	(−5.024)	(−3.924)	(−4.568)	(3.192)
AR(2)	0.508	0.566	0.660	0.559
Sagan	0.651	0.778	0.776	0.959
constant	0.874[a]	1.002**	3.154[a]	−3.032[a]
	(3.203)	(2.439)	(10.42)	(−6.911)
Observations	390	390	390	390

[a], **, and * show statistical significance at 1%, 5%, and 10% levels, respectively. In parentheses are t values. Results of AR, and Sargan tests are *p* values.

non-governmental organizations (NGOs) put more environmental pressure on enterprises, which will affect their operation mode to some extent, resulting in a decline in technical efficiency.

Other control variables are also analyzed together with the regression results of Model (2). R&D expenditure has a significant promotion effect on green innovation, foreign investment does not have a significant impact, government support promotes green technology innovation, and trade openness has a negative impact. The results are basically consistent with the regression results in Table 3 and will not be analyzed in detail here.

(3) Similarly, this paper examined the synergistic effect and mechanism of ENGOs and public environmental supervision on industrial green and low-carbon transformation from three aspects, including GTFP, technical efficiency change index, and technological progress change index. Table 5 displays the correlation regression results:

According to the findings of Model (1), from a national perspective, ENGOs and public environmental supervision do not have synergistic effects on industrial green and low-carbon transformation (Table 5). To investigate the action mechanism of ENGOs on industrial GTFP, Model (2) and Model (3) examined the regression results after the explained variable is substituted with the technical efficiency change index and the technical progress change index, respectively. Again, the results show that again there is no synergy effect. This means that ENGOs and public environmental oversight are not working together to promote green and low-carbon industrial transformation on a national scale. This result may be due to significant regional differences in the number of environmental non-governmental organizations and the level of public environmental participation in the country. Due to the different economic, environmental, and technological levels in different regions, the synergy effect of the two is not good. From this point of view, whether the synergistic effect exists in each region needs to be further verified.

TABLE 5 Synergy test.

Variable	lngtfp	lnte	lntc
	(1)	(3)	(4)
L.lngtfp	−0.0176[a]	−0.0122[a]	−0.0323[a]
	(−4.734)	(−3.982)	(−4.891)
F.lnpus	0.0197[a]	0.0113[a]	−0.0221[a]
	(2.981)	(4.878)	(−5.310)
F.lnengo	0.00854[a]	−0.0213	0.0889[a]
	(3.839)	(−1.421)	(5.917)
F.lnpus*F.lnengo	0.00101	0.00112	−0.00310
	(0.812)	(1.407)	(−1.101)
Controlled variable	YES	YES	YES
AR(2)	0.327	0.231	0.562
Sagan	0.458	0.787	0.998
Constant	0.0476	0.478[a]	−1.349
	(0.336)	(3.177)	(−0.941)
Observations	390	390	390

[a], **, and * show statistical significance at 1%, 5%, and 10% levels, respectively. In parentheses are t values. Results of AR, and Sargan tests are *p* values.

TABLE 6 The regression results for the robustness test of the missing variables.

Variable	lngtfp	lngtfp	lnte	lntc	lngtfp	lnte	lntc
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
L.lngtfp	−0.00579*	−0.00733**	0.0475[a]	0.183[a]	−0.00579[a]	0.0529[a]	0.155[a]
	(−1.941)	(−2.387)	(3.606)	(5.009)	(−2.735)	(4.426)	(5.602)
F.lnpus	0.00537[a]	0.00642[a]	0.00636[a]	−0.00886			
	(9.271)	(3.211)	(4.811)	(−1.434)			
$(F.lnpus)^2$		−0.292[a]	0.136	−0.005			
		(−9.073)	(0.481)	(−0.0581)			
F.lnengo					0.00100[a]	−0.0223[a]	0.0184[a]
					(3.068)	(−6.410)	(2.931)
Controlled variable	YES	YES	YES	YES	YES	YES	YES
AR(2)	0.348	0.344	0.145	0.522	0.469	0.181	0.442
Sagan	0.567	0.693	0.816	0.947	0.939	0.791	0.847
Constant	0.356[a]	0.275[a]	2.168[a]	−2.454[a]	0.207[a]	2.130[a]	−2.716[a]
	(4.905)	(3.408)	(3.134)	(−5.005)	(5.795)	(4.581)	(−6.092)
Observations	390	390	390	390	390	390	390

[a], **, and * show statistical significance at 1%, 5%, and 10% levels, respectively. In parentheses are t values. Results of AR, and Sargan tests are *p* values.

TABLE 7 The robustness test of the removed interference samples.

Variable	lngtfp	lngtfp	lnte	lntc	lngtfp	lnte	lntc
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
L.lngtfp	−0.00646	0.00874	0.0351[a]	0.127[a]	−0.0364**	0.0260[a]	0.145[a]
	(−0.509)	(0.527)	(3.393)	(2.929)	(−2.168)	(5.223)	(5.143)
F.lnpus	0.00218[a]	0.00118[a]	0.0126[a]	−0.00429			
	(3.933)	(4.278)	(3.472)	(−1.018)			
$(F.lnpus)^2$		−0.000376**	-0.000110	1.65e-05			
		(−2.249)	(-0.285)	(0.0384)			
F.lnengo					0.00334[a]	-0.0159**	0.0297[a]
					(3.852)	(-2.088)	(6.046)
Controlled variable	YES	YES	YES	YES	YES	YES	YES
AR(2)	0.413	0.402	0.741	0.329	0.521	0.774	0.553
Sagan	0.854	0.861	0.973	0.878	0.835	0.956	0.791
Constant	0.816[a]	0.830**	2.748[a]	−2.907[a]	0.765**	3.281[a]	−2.602[a]
	(2.587)	(2.521)	(4.154)	(−4.200)	(2.506)	(6.138)	(−4.205)
Observations	338	338	338	338	338	338	338

[a], **, and * show statistical significance at 1%, 5%, and 10% levels, respectively. In parentheses are t values. Results of AR, and Sargan tests are *p* values.

5.4 Robustness test

(1) Missing variables. Using independent variables and variables explained to solve the endogenous problem caused by insufficient control variables, Y. Zhang and Song (2021) solved the estimation bias caused by missing variables. Moreover, considering that this interaction term may result in new bidirectional causal endogenous problems in the model. Using X. Liu and Chen (2022), all explanatory variables were considered as endogenous variables and introduced with lag and difference items as instrumental variables for regression. The regression results in Table 6 are principally consistent with the coefficients and significance of the variables concerned by the benchmark regression in Table 3 and Table 4, demonstrating that the regression results are robust.

(2) Delete the possible interference samples. Because the municipalities of Beijing, Shanghai, Chongqing, and Tianjin fall under the direct jurisdiction of the central government, they have special administrative status, which eliminates interference from benchmark regression results Xia et al. (2022). Table 7 shows the benchmark regression results from the whole sample, while Table 3 and Table 4 show the variable coefficient and significance results, indicating that the regression results are robust.

5.5 Heterogeneity analysis and combined effect test

From the above analysis, it is evident that both public environmental supervision and ENGOS have a significant role in promoting industrial green total factor productivity. Which is more effective in promoting industrial green total factor productivity, public supervision or ENGOS? And is there any regional heterogeneity in its effects?

(1) Testing and analysis of promotion effect heterogeneity. The country is divided into three regions based on the grouping method commonly used in existing research to empirically test whether there is regional heterogeneity in the impact of public environmental supervision and ENGOs on industrial green and low-carbon transformation. Table 8 displays the correlation regression results:

Models (1), (2), (3), and (4) are the regression results of the national, eastern, central, and western regions, respectively (Table 8). Regression results show that the coefficients of public environmental supervision and ENGOs in Model (1) are both positive and significant, demonstrating that both have a significant promoting influence on industrial green and low-carbon transformation. ENGOs play a stronger role in promoting industrial green and low-carbon transformation.

TABLE 8 Promotion effect size test.

Variable	lngtfp	lngtfp	lngtfp	lngtfp
	(1)	(2)	(3)	(4)
L.lngtfp	−0.0419[a]	−0.121[a]	−0.0547[a]	−0.0289[a]
	(−2.893)	(−3.597)	(−2.749)	(−3.363)
F.lnpus	0.00122[a]	0.0321[a]	0.00117[a]	−0.0454*
	(3.241)	(4.331)	(5.132)	(−1.816)
F.lnengo	0.00455[a]	0.00179[a]	−0.00288	0.0321[a]
	(3.133)	(3.911)	(−0.430)	(3.452)
Controlled variable	YES	YES	YES	YES
AR(2)	0.510	0.537	0.529	0.500
Sagan	0.717	0.608	0.528	0.915
Constant	0.969**	0.269[a]	0.870*	1.910[a]
	(2.258)	(4.0395)	(1.891)	(3.242)
Observations	390	143	104	143

**, and * show statistical significance at 1%, 5%, and 10% levels, respectively. In parentheses are t values. Results of AR and Sargan tests are P values.

TABLE 9 Synergy test.

Variable	lngtfp	lngtfp	lngtfp	lngtfp
	(1)	(2)	(3)	(4)
L.lngtfp	−0.0176[a]	−0.442[a]	−0.0137[a]	−0.0550[a]
	(−4.734)	(−6.330)	(−4.670)	(−3.326)
F.lnpus	0.0197[a]	0.00222[a]	0.0130[a]	−0.0336[a]
	(2.981)	(3.0643)	(5.250)	(−7.280)
F.lnengo	0.00854[a]	0.00532[a]	−0.0111	0.0797[a]
	(3.839)	(4.178)	(−1.094)	(6.993)
F.lnpus*F.lnengo	0.00101	0.00209[a]	0.00109	−0.00215
	(0.812)	(4.472)	(1.335)	(−0.903)
Controlled variable	YES	YES	YES	YES
AR(2)	0.327	0.892	0.309	0.592
Sagan	0.458	0.999	0.803	0.999
Constant	0.0476	6.642	0.537**	−1.153
	(0.336)	(0.720)	(2.065)	(−1.256)
Observations	390	143	104	143

[a], **, and * show statistical significance at 1%, 5%, and 10% levels, respectively. In parentheses are t values. Results of AR, and Sargan tests are *p* values.

The empirical results at the sub-regional level show that the effect of public environmental supervision and ENGOs on industrial green and low-carbon transformation shows significant heterogeneity in the eastern, central, and western regions. Eastern regions have a positive coefficient of public environmental monitoring, and ENGOs have a significantly

positive coefficient. This indicates that public environmental supervision in the eastern region can promote industrial green and low-carbon transformation, and ENGOs can also promote industrial green and low-carbon transformation. In the central region, public environmental supervision has a positive effect on industrial GTFP, whereas ENGOs have no significant effect on industrial GTFP. This suggests that the role of ENGOs in our country's central region has not been fully reflected. Currently, the central region's public environmental supervision is the primary driving force to promote the green and low-carbon industrial transformation. Public environmental supervision significantly negatively affects industrial GTFP in the western region, whereas ENGOs have a significant positive effect on industrial GTFP. Overall, the regression results suggest that public environmental supervision and ENGOs have different impacts on industrial green and low-carbon transformation in different regions.

(2) Testing and analysis of collaborative effect heterogeneity. Table 9 displays the correlation regression results:

After adding the interaction term of public supervision and ENGOs, Models (1), (2), (3), and (4) represent the regression results of the national, eastern, central, and western regions, respectively. The coefficient of the interaction term in Model (1) is insignificant, indicating that there is no synergistic effect between public environmental supervision and ENGOs in promoting China's industrial green and low-carbon transformation from a national perspective. In the eastern region, the coefficient of the interaction term is positive, indicating that public environmental supervision and ENGOs have a synergistic effect on the impact of industrial green and low-carbon transformation in the eastern region. This empirical result also confirms hypothesis 3. In contrast, the coefficient of the interaction term is not significant in the central and western regions. This represents that there is no synergistic effect between public environmental supervision and ENGOs on industrial green and low-carbon transformation in the central and western regions. Based on the above regression results, public environmental supervision and ENGOs can synergistically promote industrial green and low-carbon transformation, but only in the eastern region. There are several reasons for this kind of result: first, the letter from the environment and ENGOs by contrast, the number of the eastern region was significantly higher in the Midwest, which means that the eastern region of public environmental monitoring and ENGOs are more active. Because of the realistic conditions, a collaboration between the two ensures more opportunities; thus, coordination is achieved to promote a green low-carbon industrial transformation. Furthermore, regional factor endowment, formal environmental regulation, enterprise characteristics, and other factors influence the impact of informal environmental regulation and the synergistic effect of public environmental supervision and ENGOs to some extent.

6. Conclusions and policy recommendations

It is mainly the top-down formal environmental regulation of the government that is examined in the existing literature on the green and low-carbon transformation of China's industry. Informal environmental regulation represented by public environmental supervision and ENGOS is rarely examined systematically. This paper used the systematic GMM model to empirically investigate the impact of public environmental supervision and ENGOS on the transformation and its mechanism of action by taking the inter-provincial panel data from the Chinese industry from 2002 to 2018 as a research sample. The results were as follows. Public environmental supervision and ENGOS help to promote green and low-carbon industrial transformation. The mechanism research found that public environmental supervision and ENGOs are promoting the progress of green technology to develop green total factor productivity. There is significant regional heterogeneity in the impact of public environmental supervision and ENGOs on the green and low-carbon industrial transition. According to the above research conclusions, the policy recommendations of this paper are as follows.

The public should be guided to rationally protect the environment, and public environmental supervision should ensure that environmental and economic developments are coordinated. First of all, environmental protection publicity should be conducted, and public awareness of environmental protection and supervision must be improved. Secondly, an effective and smooth information feedback mechanism should be established. Lastly, government departments or regulatory agencies should actively respond to the environmental pollution problems raised by the public, solve the existing environmental pollution problems effectively and quickly, and make the treatment results public as soon as possible. In addition, because social public environmental supervision and unreasonable behavior can negatively affect an enterprise's normal production, a government department or regulatory organization can issue policies that can constrain social, environmental supervision and unreasonable behavior to protect the lawful rights and interests of enterprises while allowing them to successfully implement green, low-carbon transformation.

Furthermore, ENGOs should be encouraged to improve the intensity of environmental information disclosure and provide full play to their professional advantages to cooperate with industrial enterprises. Due to the enthusiasm of social public participation in environmental monitoring, environmental protection consciousness is weak compared with developed countries. Environmental information disclosure of ENGOs and policy propaganda provide information that supports the social public participation in environmental supervision, as well

as providing more convenient conditions for environmental control as a government department or regulatory organization. In addition, the environmental protection society organizations can gain their own professional benefit, cooperate with the enterprise to develop green low carbon products, and actively promote the enterprise's green innovation achievements to shape a group of less environmental pollution, green products more representative of the enterprise, from the perspective of market demand will pull the enterprise green innovation which in turn will promote enterprise voluntary green low carbon transformation.

Moreover, we should establish an informal environmental regulation system in which ENGOs and the public cooperate. This study finds that ENGOs and public environmental supervision play a synergistic role in promoting industrial green and low-carbon transformation. In light of this, ENGOs should be encouraged to timely disclose environmental information on their official websites and to open channels of communication with the public, such as public communication columns and WeChat official accounts. Green and low-carbon industrial transformation and high-quality economic development are more likely to occur if ENGOs, the public, and government functional departments work closely together to form a powerful informal environmental regulation force.

Data availability statement

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

Author contributions

ZH was responsible for the logical reasoning of the research topic. DJ and ZW were responsible for experimental materials and data. LJ was responsible for collecting literature. All authors contributed to the article and approved the submitted version.

Funding

This study was supported by the National Social Science Fund of China (14AJL015) and Chongqing Social Science Foundation (2020ZDJJ01).

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

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Arellano, M., and Bover, O. (1995). Another look at the instrumental variable estimation of error-components models. *J. Econ.* 68 (1), 29–51. doi:10.1016/0304-4076(94)01642-D

Arias, M. R. (2020). Corporate environmental criminal liability in Spain and the participation of the environmental non-governmental organizations (engos). *Actual. Juríd. Ambient.* 101, 34

Bentata, P., and Faure, M. (2015). The role of engos in environmental litigation: A French case study. *Environ. Policy Gov.* 25 (6), 459–473. doi:10.1002/eet.1682

Cheng, Z., and Kong, S. (2022). The effect of environmental regulation on green total-factor productivity in China's industry. *Environ. Impact Assess. Rev.* 94, 106757. doi:10.1016/j.eiar.2022.106757

Dong, Y., Ishikawa, M., Liu, X., and Hamori, S. (2011). The determinants of citizen complaints on environmental pollution: An empirical study from China. *J. Clean. Prod.* 19 (12), 1306–1314. doi:10.1016/j.jclepro.2011.03.015

Du, Y., Li, Z., Du, J., Li, N., and Yan, B. (2019). Public environmental appeal and innovation of heavy-polluting enterprises. *J. Clean. Prod.* 222, 1009–1022. doi:10.1016/j.jclepro.2019.03.035

Fedyukin, I. (2018). Westernizations" from peter I to meiji: War, political competition, and institutional change. *Theory Soc.* 47 (2), 207–231. doi:10.1007/s11186-018-9313-y

Féres, J., and Reynaud, A. (2012). Assessing the impact of formal and informal regulations on environmental and economic performance of Brazilian manufacturing firms. *Environ. Resour. Econ.* 52 (1), 65–85. doi:10.1007/s10640-011-9520-8

Fu, J., and Geng, Y. (2019). Public participation, regulatory compliance and green development in China based on provincial panel data. *J. Clean. Prod.* 230, 1344–1353. doi:10.1016/j.jclepro.2019.05.093

Glucker, A. N., Driessen, P. P. J., Kolhoff, A., and Runhaar, H. A. C. (2013). Public participation in environmental impact assessment: Why, who and how? *Environ. Impact Assess. Rev.* 43, 104–111. doi:10.1016/j.eiar.2013.06.003

Hou, J., Teo, T. S. H., Zhou, F., Lim, M. K., and Chen, H. (2018). Does industrial green transformation successfully facilitate a decrease in carbon intensity in China? An environmental regulation perspective. *J. Clean. Prod.* 184, 1060–1071. doi:10.1016/j.jclepro.2018.02.311

Kathuria, V., and Sterner, T. (2006). Monitoring and enforcement: Is two-tier regulation robust? — a case study of ankleshwar, India. *Ecol. Econ.* 57 (3), 477–493. doi:10.1016/j.ecolecon.2005.05.004

Langpap, C., and Shimshack, J. P. (2010). Private citizen suits and public enforcement: Substitutes or complements? *J. Environ. Econ. Manag.* 59 (3), 235–249. doi:10.1016/j.jeem.2010.01.001

Li, Q., Liu, G., Cai, B., Leamon, G., Liu, L.-C., Chen, Z.-A., et al. (2017). Public awareness of the environmental impact and management of carbon dioxide capture, utilization and storage technology: The views of educated people in China. *CLEAN Technol. Environ. POLICY* 19 (8), 2041–2056. doi:10.1007/s10098-017-1387-0

Li, G, G., He, Q., Shao, S., and Cao, J. (2018). Environmental non-governmental organizations and urban environmental governance: Evidence from China. *J. Environ. Manag.* 206, 1296–1307. doi:10.1016/j.jenvman.2017.09.076

Li, L, L., Xia, X. H., Chen, B., and Sun, L. (2018). Public participation in achieving sustainable development goals in China: Evidence from the practice

of air pollution control. *J. Clean. Prod.* 201, 499–506. doi:10.1016/j.jclepro.2018.08.046

Liao, X., and Shi, X. (2018). Public appeal, environmental regulation and green investment: Evidence from China. *Energy Policy* 119, 554–562. doi:10.1016/j.enpol.2018.05.020

Liu, H., Zhu, G., and Li, Y. (2021). Research on the impact of environmental risk perception and public participation on evaluation of local government environmental regulation implementation behavior. *Environ. Challenges* 5, 100213. doi:10.1016/j.envc.2021.100213

Liu, X., and Chen, S. (2022). Has environmental regulation facilitated the green transformation of the marine industry? *Mar. Policy* 144, 105238. doi:10.1016/j.marpol.2022.105238

Liu, Y., She, Y., Liu, S., and Lan, H. (2022). Supply-shock, demand-induced or superposition effect? The impacts of formal and informal environmental regulations on total factor productivity of Chinese agricultural enterprises. *J. Clean. Prod.* 380, 135052. doi:10.1016/j.jclepro.2022.135052

Long, F., Liu, J., and Zheng, L. (2022). The effects of public environmental concern on urban-rural environmental inequality: Evidence from Chinese industrial enterprises. *Sustain. Cities Soc.* 80, 103787. doi:10.1016/j.scs.2022.103787

Lü, Y.-L., Geng, J., and He, G.-Z. (2015). Industrial transformation and green production to reduce environmental emissions: Taking cement industry as a case. *Adv. Clim. Change Res.* 6 (3), 202–209. doi:10.1016/j.accre.2015.10.002

Mohamad Saifudin, M. S. (2017). Media and environmental non-governmental organizations (ENGOs) roles in environmental sustainability communication in Malaysia. *Discourse Commun. Sustain. Educ.* 8 (1), 90–101. doi:10.1515/dcse-2017-0007

Nur Nasliza, A. (2013). Effective environmental communication: A case study of environmental non-government organization (engo) in Malaysia. *J. Soc. Dev. Sci.* 4 (6), 242–248. doi:10.22610/jsds.v4i6.758

Pargal, S., and Wheeler, D. (1996). Informal regulation of industrial pollution in developing countries: Evidence from Indonesia. *J. POLITICAL Econ.* 104 (6), 1314–1327. doi:10.1086/262061

Pien, C.-p. (2020). Local environmental information disclosure and environmental non-governmental organizations in Chinese prefecture-level cities. *J. Environ. Manag.* 275, 111225. doi:10.1016/j.jenvman.2020.111225

Quesnel, K. J., and Ajami, N. K. (2017). Changes in water consumption linked to heavy news media coverage of extreme climatic events. *Sci. Adv.* 3 (10), e1700784. doi:10.1126/sciadv.1700784

Sadik-Zada, E. R., and Ferrari, M. (2020). Environmental policy stringency, technical progress and pollution haven hypothesis. *Sustainability* 12 (9), 3880. doi:10.3390/su12093880

Sadik-Zada, E. R., and Gatto, A. (2022). *Civic engagement and energy transition in the Nordic-Baltic Sea Region: Parametric and nonparametric inquiries*. New York, NY: Socio-Economic Planning Sciences. doi:10.1016/j.seps.2022.101347

Tang, J., and Li, S. (2022). Can public participation promote regional green innovation?——threshold effect of environmental regulation analysis. *Heliyon* 8 (10), e11157. doi:10.1016/j.heliyon.2022.e11157

Tian, C., Li, X., Xiao, L., and Zhu, B. (2022). Exploring the impact of green credit policy on green transformation of heavy polluting industries. *J. Clean. Prod.* 335, 130257. doi:10.1016/j.jclepro.2021.130257

Tian, X.-L., Guo, Q.-G., Han, C., and Ahmad, N. (2016). Different extent of environmental information disclosure across Chinese cities: Contributing factors and correlation with local pollution. *Glob. Environ. Change* 39, 244–257. doi:10.1016/j.gloenvcha.2016.05.014

Wang, C. (2016). Study on the dynamic evaluation of the regional green low-carbon transformation in China evidence from Qingdao, Yantai and Weihai. *Chaos, Solit. Fractals* 89, 147–152. doi:10.1016/j.chaos.2015.10.014

Wang, S., Zhao, D., and Chen, H. (2020b). A spatial analysis of corruption, misallocation, and efficiency. *Environ. Sci. Pollut. Res.* 27 (29), 36845–36856. doi:10.1007/s11356-020-09707-y

Wang, S., Zhao, D., and Chen, H. (2020a). Government corruption, resource misallocation, and ecological efficiency. *Energy Econ.* 85, 104573. doi:10.1016/j.eneco.2019.104573

Wang, X., Chu, B., Ding, H., and Chiu, A. S. F. (2023). Impacts of heterogeneous environmental regulation on green transformation of China's iron and steel industry: Evidence from dynamic panel threshold regression. *J. Clean. Prod.* 382, 135214. doi:10.1016/j.jclepro.2022.135214

Wen, J., Li, L., Zhao, X., Jiao, C., and Li, W. (2022). How government size expansion can affect green innovation—an empirical analysis of data on cross-country green patent filings. *Int. J. Environ. Res. Public Health* 19, 7328. doi:10.3390/ijerph19127328

Wu, L., Ma, T., Bian, Y., Li, S., and Yi, Z. (2020). Improvement of regional environmental quality: Government environmental governance and public participation. *Sci. Total Environ.* 717, 137265. doi:10.1016/j.scitotenv.2020.137265

Xia, Q., Han, M., Guan, S., Wu, X., and Zhang, B. (2022). Tracking embodied energy flows of China's megacities via multi-scale supply chains. *Energy* 260, 125043. doi:10.1016/j.energy.2022.125043

Xin, C., and Lai, X. (2022). Does the environmental information disclosure promote the high-quality development of China's resource-based cities? *Sustainability* 14, 6518. doi:10.3390/su14116518

Zeng, M., Zheng, L., Huang, Z., Cheng, X., and Zeng, H. (2023). Does vertical supervision promote regional green transformation? Evidence from central environmental protection inspection. *J. Environ. Manag.* 326, 116681. doi:10.1016/j.jenvman.2022.116681

Zhai, X., and An, Y. (2020). Analyzing influencing factors of green transformation in China's manufacturing industry under environmental regulation: A structural equation model. *J. Clean. Prod.* 251, 119760. doi:10.1016/j.jclepro.2019.119760

Zhang, H., Xu, T., and Feng, C. (2022). Does public participation promote environmental efficiency? Evidence from a quasi-natural experiment of environmental information disclosure in China. *Energy Econ.* 108, 105871. doi:10.1016/j.eneco.2022.105871

Zhang, M., and Huang, M. (2022). Study on the impact of informal environmental regulation on substantive green innovation in China: Evidence from PITI disclosure. *Environ. Sci. Pollut. Res.* doi:10.1007/s11356-022-22868-2

Zhang, T., and Chen, C. (2018). The effect of public participation on environmental governance in China–based on the analysis of pollutants emissions employing a provincial quantification. *Sustainability* 10 (7), 2302. doi:10.3390/su10072302

Zhang, Y., and Song, Y. (2021). Environmental regulations, energy and environment efficiency of China's metal industries: A provincial panel data analysis. *J. Clean. Prod.* 280, 124437. doi:10.1016/j.jclepro.2020.124437

Zhao, C., Dong, K., Wang, K., and Dong, X. (2022). How does energy trilemma eradication reduce carbon emissions? The role of dual environmental regulation for China. *Energy Econ.* 116, 106418. doi:10.1016/j.eneco.2022.106418