How do environmental regulations affect carbon emission and energy efficiency patterns? A provincial-level analysis of Chinese energy-intensive industries

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2 August 2021

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Abstract
This study measures the environmental regulation effect and pattern of carbon emission and energy efficiency through data envelopment analysis and econometric estimation. One of the most important ways to achieve a green transition is promoting technical progress through environmental regulation. Though China has witnessed rapid economic growth over the last two decades, the country can improve it further through adopting sustainable green energy and establishing more energy-efficient industries to strike a good balance between economic and social developments. The oil and carbon dioxide emission perfor-mances form the most important metrics. This study uses panel data from 30 Chinese provinces from 2008 to 2017 to assess the effect of environmental regulation on energy production. The nonradial directional distance function (NDDF) is used to measure the total factor energy efficiency index (TFEEI). The panel system GMM model, which can effectively address endogenous problems and regional variability, is utilized to research the nonlinear relationship between environmental regulations and EEI under various environmental regulations to study it. The findings reveal a considerably modest total average EEI amount for energy-intensive industries, averaging between 0.55 and 0.58, which is way below the ideal value (i.e., 1). Furthermore, the results of the dynamic panel data model revealed a significant U-shaped relationship between China's EEI and environmental regulation. The results show that as the values of market-based environmental regulations (MERs) and command and control environmental regulations (CCERs) exceed the corresponding levels, the impact of environmental regulation on the TFEEI increases gradually. This study will aid policymakers in better understanding the efficacy of different levels of environmental regulations to make more educated decisions.

Keywords Total factor energy efficiency · High energy-intensive industries · Environmental regulation · Nonradial directional distance function

Introduction

China has experienced phenomenal economic growth after the implementation of reform and openness. However, Chinese economic development is clearly dualistic. In other words, the industry is subsidized by agriculture. Further, the GDP share continued to decrease from 27.7% in 1978 to 8.6% in 2016 (Liu et al. 2020a; Akbar et al. 2021; Zhang et al. 2021c). In the primary industry, the Chinese economy's rapid growth relies heavily on industrial production (Othman et al. 2020; Sadiq et al. 2020; Zhang et al. 2020b). The Chinese industry's strong growth has clear characteristics, which are high investments, high energy consumption, and high emissions (Zhang et al. 2020b; Li et al. 2021b). China has become increasingly influential in the context of rapid economic growth in terms of environmental pollution and climate change (Anser et al. 2020b; Khokhar et al. 2020; Mohsin et al. 2021a; Anser et al. 2020b; Anh Tu et al. 2021). The Chinese government proposes the "below China" goal, integrating ecological civilization in economic Mi et al. (2020), political Liu et al. (2020b), cultural, and social (Nguyen et al. 2021; Li et al. 2021b; Zhao et al. 2020) developments to shape the global structure of sustainable development in order to achieve sustainable economic growth and environmental conservation

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(Iqbal et al. 2019a, b; Hou et al. 2019; Chien et al. 2020; Huang et al. 2020; Sadiq et al. 2020; Tiep et al. 2021). The Chinese Government has simultaneously assured a 2020 carbon dioxide emission intensity that is 40%–45% lower than in 2005 (Asbahi et al. 2019; Iqbal et al. 2019b; Chien et al. 2021b; Nguyen et al. 2021). The Chinese government has successively implemented a set of environmental policies limiting the carbon dioxide emission activities of companies and guiding the market process to correct the carbon dioxide release response by introducing a policy on environmental regulation to achieve the objective of developing China and reducing carbon dioxide emissions (Huang et al. 2020; Mohsin et al. 2018a, b; Ikram et al,. 2019). However, some scholars have questioned whether environmental regulation is necessary and efficient in reducing carbon emissions (Chien et al. 2021f, g; Xu et al. 2020a; Yang et al. 2020; Zuo et al. 2020). A consensus has still not been reached on the matter (Mohsin et al. 2018a, b; Mohsin et al. 2020; Mohsin et al. 2021b).

During the Paris Climate Conference, the Chinese government stressed that the growth of the green economy must actively respond to global changes. The primary cause of global warming and climate change is carbon dioxide emissions (He et al. 2020; Li et al. 2021a; Mohsin et al. 2021b; Yang et al. 2021; Xia et al. 2020). China is also the world's largest producer of energy and the second-largest global energy user. It has high carbon levels and their reduction is extremely necessary (Chien et al. 2021c; Purba et al. 2021; Yuan et al. 2021). A key method adopted by China to maintain its position as a major power is strongly encouraging savings in electricity, reduction in emissions, and a low carbon economy. The Chinese government has established a set of environmental standards and policies to improve its investment in environmental pollution management from RMB 25661011 in 2006 to RMB 9, 2 201011 in 2016 to resolve its growing environmental problems and fulfill its major obligations. The investment focuses on "three overlapping" investments in building schemes, urban environmental infrastructure, and industrial emission source control (Ikram et al. 2019; Shah et al. 2019). The Chinese authorities have committed to improving the atmosphere, manufacturing processes, fossil energy use efficiency (such as coal, oil, and natural gas), and CO_2 emission reduction in production through these policy changes (He et al. 2020; Mohsin et al. 2020; Yang et al. 2021).

Promoting technological development across enterprises through environmental policies is one of the most important means to achieve sustainable development and address issues including resource scarcity and pollution (Sun et al. 2020b, d, e). Technological advances are critical to striking a balance between environmental sustainability and economic benefits for businesses (Chandio et al. 2020; Sun et al. 2020c). For example, a company can minimize the cost of pollution treatment by minimizing wastewater, flue gas, and solid waste emissions while also simplifying the manufacturing process (Alemzero et al. 2020a, b; Sun et al. 2020c). Technological advances are now widely acknowledged to benefit environmental pollution management and economic growth (Sun et al. 2020a, b). The Porter hypothesis supports the establishment of environmental legislation from the perspective of the impact of environmental policies on sustainable development (Baloch et al. 2020; Sun et al. 2020e).

This research considers the output scale of the total factor energy efficiency indicator (EEI) for six extremely energy-centric industries in each of China's provinces from 2008 to 2017. The accuracy of the above indices is measured using the nonradial directional distance function (NDDF). This study uses panel data from China's six energy-intensive industries to test the current level of the TFEEI. First, we applied the NDDF to quantify the EEI of China's energy-intensive industries. Second, we applied the System GMM method to investigate the impact of environmental regulations (ER) and other important factors on EEI. Furthermore, environmental regulations are divided into market-based environmental regulations (MER) and command and control environmental regulations (CCER). The interaction term between environmental policy and green finance (GF) is adopted to determine the potential innovation offset and test the innovation offset results.

The rest of the paper is arranged as follows: The "Literature review" section discusses the literature review, "Methodology and variable selection" section the data and methods, "Results and Discussions" section the report results analysis, and "Conclusion and policy implication" section the conclusions and policy recommendations.

Literature review

The literature proposes three key points for determining whether environmental policies can help minimize carbon emissions (El-Aziz 2018; Zhang et al. 2021a). The first viewpoint holds that environmental policy will not only fail to minimize carbon dioxide emissions but also increase them. Lam et al. (2020) proposed the idea of the "green paradox" effect, arguing that policies aimed at limiting climate change would lead to increased fossil oil extraction and aggravated greenhouse gas emissions (Agyekum et al. 2021; (Zhang et al. 2021b). Environmental regulation, according to the second viewpoint, will increase ecological productivity, foster technical progress in businesses, and achieve the objective of energy conservation and pollution reduction. Zhang et al. (2020a) studied 30 Chinese provinces and cities and discovered a strong environmental regulatory framework to be the most important factor in ensuring regional eco-efficiency (Hsu et al. 2021; (Ehsanullah et al. 2021). The third point of view is that the effect of environmental regulations on carbon emissions is speculative. Environmental regulations can improve the green total factor in the short term, but they can also squeeze out R&D input in the long run, according to Shan and Wang (2019). Labor productivity and green total factor productivity fall as energy use efficiency rises (Chien et al. 2021d; Iqbal et al. 2021; Li et al. 2021b).

Due to the extensive acceleration of ecological degradation, governments have undertaken a panoply of corrective measures to tackle and promote sustainable development. Research by Poudineh et al. (2020) claims that the application of taxation can internalize the cost of external pollution, and according to this proposition, several policies have been adopted, such as command and CCER and MER. Other studies have shown that the formulation of regulations forces companies to increase expenditures or conduct environmental management and governance, and such enforcement inflates their operating costs and reduces economic benefits (Greenstone and Hanna 2014; Peng 2020; Zhang et al. 2021d). However, according to Porter's hypothesis, a well-structured environmental regulatory framework can accelerate technological innovation, thereby reducing compliance costs.

Environmental regulations have a significant causal relationship with both energy and environmental performance. For example, Jefferson et al. (2013) state that in China, such regulations can improve the performance of the industry sector. Bi et al. (2014) also propose that the thermal power generation sector of China can be made energy efficient if a well-regulated environmental atmosphere is in place. Recently, Lin and Chen (2020) showed that for both long-run and short-run energy efficiency, the contribution of MER is noteworthy, but CCER performed better in the short run. Zhang and Song (2021) also explored the nexus between environmental regulations and environmental control in the metal sector of Chinese territory and confirmed a nonlinear causal relationship between CCER and environmental control. However, they also concluded that CCER had no causality with environmental control. Moreover, few studies measure the degree of relationship between other control factors of energy efficiency. For example, Antonietti and Fontini (2019) considered economic development level, Zhang et al. (2020b) considered technology enhancement, and Xin-gang and Shu-ran (2020) considered energy price as the affecting variable in measuring energy efficiency. Particularly, it is currently unclear from the existing studies how different types of environmental regulations affect the TFEEI of the Chinese high energy-intensive industries. These are the most polluting industries in China. Therefore, investigating the effect of environmental regulations on these industries is a timely attempt at ensuring an environmentally sustainable developed economy in China.

Furthermore, China's environmental regulation policies can generally restrain carbon emissions, and the average environmental protection investment exceeds the threshold of 5.73%. The following are the key contributions of this research to the current literature: The marginal and heterogeneous effects of environmental regulation on technological progress are first examined by Ding et al. (2018) and Costa et al. (2018). This research examines not only the marginal effect of environmental regulation on technological innovations by resource allocation but also the heterogeneous effects of environmental regulation on technological innovations by influencing the technological spillover effect of foreign enterprises, the scale effect of large enterprises, the human capital innovation effect, and the market clout effect.

Methodology and variable selection

The nonradial directional distance function (NDDF) model

The DEA method is mainly an input–output-based measure of production efficiency. The importance of environmental management sophistication in improving internal oversight of managers, restricting "pure profit-seeking" and opportunistic activities of enterprise managers, and promoting environmental conservation practices of enterprises is asserted in this report, which uses the environmental management system as an internal control mechanism for enterprises. It confirms that enterprise environmental control is an important signal system and transmission tool for resolving agency issues (Dlalisa and Govender 2020; Li et al. 2017; Malla and Brewin 2020; Niyimbanira et al. 2020). First, enterprises can strengthen internal environmental control, actively improve the enterprise environmental management system and methods based on their own characteristics, and implement voluntary environmental management and improvements, according to the research findings of (Lin and Chen 2020 ; Liu et al. 2020c). Second, corporate managers' environmental consciousness should be recognized as a significant internal impetus for fair use of slack capital to encourage businesses to effectively pursue their environmental obligations (Forrester and Reames 2020, Jun et al. 2020). By embedding the environmental management scheme, business owners will improve the oversight and rewards of enterprise administrators, as well as correctly directing managers to effectively assume environmental conservation obligations and spend slack capital in environmental protection programs (Chien et al. 2021a; Chien et al. 2021e;Zhang et al. 2021c). Third, this essay emphasizes the value of identifying and judging the various life cycles of an organization and proposes that organizations should follow environmental management strategies appropriate for their internal and external environments, enhancing the critical function of internal governance capacities in achieving long-term development (Anke et al. 2020).

Capital (KC), labor (L), and electricity (E) are considered inputs in the NDDF approach, whereas business production (ZY) is considered the output. CO2, on the other hand, is viewed as unacceptable or poor performance. The development of an output possibility set (PPS) is required before applying DEA in any efficiency measure. Resultantly, this research develops a PPS expressed as an equation (Yousaf et al. 2020; Tehreem et al. 2020; Wasif Rasheed and Anser 2017; Xu et al. 2020b).

$$P = \{(L, CC, E, GDP, CO2) : (L, CC, E) \text{ can produce } (GDP, CO2)\} \tag{1}$$

P stands for the PPS whereas L, C, and E stand for labor, money, and resources in the above equation. According to the PPE, the inputs C, L, and E may be used to generate Z and C.

Furthermore, eco-environmental governance forms a critical component of achieving the long-term sustainability of a society with a common vision for humanity. It necessitates the government's strengthening of environmental regulations and guidelines to encourage society's green and concerted growth (Anser et al. 2018; Anser 2019; Anser et al. 2020b). This study examines the important factors and transmission pathways influencing business environmental security expenditure from the perspective of internal management. It is critical for the government to develop relevant environmental policies, link the organization's internal governance system organically, communicate the efficacy of external restrictions, and correctly direct the enterprise to effectively engage in environmental activities (Ahmad et al. 2020; Wasif Rasheed and Anser 2017; Xu et al. 2020a)

1: If $(L, CC, E, GDP, CO2 \in P \text{ and } 0 \leq \theta \leq 1 \text{ when } (L, CC, E, \theta GDP, \theta CO2)$

2: If $L, CC, E, GDP, CO2 \in P \text{ and } GDP = 0,\ CO2 = 0)$

First, the government should concentrate on creating a favorable business environment by promoting the implementation of preferential policies such as government environmental protection subsidies, environmental protection taxes, corporate income tax on special equipment for environmental protection, third-party governance corporate income tax, and so on, as well as comprehensively strengthening governmental support for entrants. Second, the government can develop differentiated environmental legislation focused on differences in business voluntariness and zeal for environmental sustainability, as well as differences in enterprise life cycles. For example, to increase the actual operational efficiency of environmental legislation, the government should devise various government incentives and green financial policies.

It is assumed that there are n DMUs and that T is represented by the constant return to scale in Eq. (2):

$$P = \left\{(L, CC, E, GDP, CO2) : \sum_{n=1}^{N} Z_n CC_n \leq CC,\ \sum_{n=1}^{N} Z_n L_n \leq L,\ \sum_{n=1}^{N} Z_n E_n \leq E,\ \sum_{n=1}^{N} Z_n GDP_n \geq GDP,\ \sum_{n=1}^{N} Z_n CO2_n = CO2 \right. \tag{2}$$

Z_n stands for the intensity variable to form constructing T as a convex expression. The NDDF is further used to calculate the EEP of each DMU which is represented as Eq. (3):

$$\vec{D}(L, CC, E, GDP, CO2) = \sup\{W^T B : (L, CC, E, GDP, CO2) + G \times dkagonal(\beta)\} \in T \tag{3}$$

where W^T is regarded as a normalized weight vector; and G as the directional vector and β as the vector for scaling factor. Third, the government can periodically hold workshops for businesses to develop new environmental management skills and enable businesses to implement advanced environmental conservation technology. During the slowdown, the government could allow highly polluting businesses to pursue technical advancement in environmental protection, create innovative green technologies to boost economic benefits, and channelize environmental protection and renewable energy efficiency into the market competition. In terms of internal organization priorities, it will monitor the organizational management's impacts on environmental policies, processes, and operations, and ensure that all workers are aware of the company's environmental responsibilities. In terms of external agency priorities, it will disseminate knowledge regarding environmental enterprises to external audiences and demonstrate its authority. If a company wants to receive an environmental protection fund, it must thoroughly evaluate its environmental policies, follow environmental laws to avoid emissions, and dedicate itself to continuous environmental progress. After obtaining approval, businesses must obey the "plan-do-check-act" method. Furthermore, to achieve the credential, businesses must allow periodic third-party testing to ensure their compliance with the environmental requirement. Enterprises must also conduct a rigorous recertification audit every three years if they wish to keep their credentials current.

The total-factor NDDF (TNDDF) is constructed to evaluate the EEI by taking into account the existence substitution effect between the energy and other variables. According to the resource-based perspective, heterogeneous services are critical to achieving business sustainability objectives (Sadiq et al. 2021; Li et al. 2021c). The environmental management system constantly raises environmental knowledge to managers and enhances managers' environmental consciousness across the cycle and environmental management engagement. The environmental consciousness of corporate management has been more consistent as the operational time of the environmental management system has increased, which inevitably raises the heterogeneous tools separate from the environmental agreement of other organizations, which would ultimately mitigate the department's dilemma and the restrain manager's opportunistic conduct. Therefore, the environmental management system is critical in directing administrators to spend slack capital. Managers must adopt the general investing criteria when making environmental investment choices, much as they must when making other conventional project investments. They must note both stakeholder pressure and the benefit impact of environmental sustainability investments (Ang and Wang 2015; Choi and Ang 2012; Wang and Feng 2018; Xueying et al. 2021). The gains of environmental expenditure are also larger in heavy-polluting industries than in non-heavy-polluting industries, since heavy-polluting industries experience higher levels of environmental protection and public interest. Consequently, having a higher level of environmental policy maturity in heavy-polluting sectors would reduce knowledge asymmetry, raise managers' environmental consciousness, and pay heed to the advantages of business environmental conservation spending. To accomplish the optimization of business value, managers are more inclined to consciously spend slack capital on environmental conservation programs. Companies with a poor level of environmental policy sophistication, on the other hand, are more prone to spend slack capital in private programs, neglecting adequate oversight and rewards. The construction of the model is portrayed below:

$$\begin{gathered}\overrightarrow{D_T}(L, CC, E, GDP, CO2; \mathrm{G}) = max.w_k\beta_{\mathrm{k}} + w_L\beta_L + w_E\beta_E + w_{GDP}\beta_{GDP} + w_{CO2}\beta_{CO2} \\ s.w. \quad \sum_{n=1}^{N} Z_nC_n \le C - \beta_C g_C, \sum_{n=1}^{N} Z_nL_n \le L - \beta_L g_L, \sum_{n=1}^{N} Z_nE_n \le E - \beta_E g_E, \\ \sum_{n=1}^{N} Z_nGDP_n \ge GDP + \beta_{GDP} g_{GDP}, \sum_{n=1}^{N} Z_nCO2_n = CO2 - \beta_{co2} g_{co2} \\ Z_n \ge 0, n = 1, 2, 3, \ldots, N, \beta_C, \beta_L, \beta_E, \beta_{GDP}, \beta_{CO2} \ge 0\end{gathered} \tag{4}$$

If $\overrightarrow{D}(L, CC, E, GDP, CO2) = 0$, it denotes that the DMU moves toward the efficient frontier in the G direction. Here the weight vector is $W^T = \left(\frac{1}{9}, \frac{1}{9}, \frac{1}{9}, \frac{1}{3}, \frac{1}{3}\right)$. By following the studies undertaken by Zhao et al. (2020) and Baloch et al. (2020), this study treats the inputs and both the desirable and undesirable outputs with the same weight. Therefore, each of the variables is assigned a weight of 1/3. Moreover, the weight of the input variables is evenly distributed through *C*, *L,* and *E*; i.e., the weight for each input factor is 1/9. Furthermore, the directional vector is set as G = (−*C*, −*L*, −*E*, −*GDP*, −*CO*2). The optimal solution might be attained through solving Eq. (4) to get the EEI.

$$\begin{gathered}TFEEI_n = \frac{1}{4}\left[\frac{GDP_n/C_n}{(GDP_n + \beta^*_{n0}GDP_n)/(C_n + \beta^*_{nc}C_n)} + \frac{GDP_n/L_n}{(GDP_n + \beta^*_{n0}GDP_n)/(L_n + \beta^*_{nL}L_n)} + \frac{GDP_n/E_n}{(GDP_n + \beta^*_{n0}GDP_n)/(E_n + \beta^*_{nE}E_n)} + \frac{GDP_n/CO2_n}{(GDP_n + \beta^*_{n0}GDP_n)/(CO2_n + \beta^*_{\mathrm{nco2}}CO2_n)}\right] \\ TFEEI_n = \frac{1 - \frac{1}{4}(\beta^*_{nc} + \beta^*_{nL} + \beta^*_{nE} + \beta^*_{nco2})}{1 + \beta^*_{n0}} \quad \mathrm{n} = 1, 2, 3 \ldots \mathrm{N}\end{gathered} \tag{5}$$

An environmental challenge significantly impacts the investment decisions of modern businesses. Managers are more inclined to make personal benefits by slack capital in companies lacking effective rewards or supervision mechanisms. Internal management capabilities must be strengthened, internal operating performance improved, and organization expenses reduced. Businesses often use environmental management to enhance internal construction and increase the quality of corporate processes when coping with environmental problems. According to existing evidence, an enterprise's internal management capability will successfully facilitate the accomplishment of corporate social responsibility. The maturity in environmental protection is one of them and represents an organization's internal control capability.

Econometric modeling and variable selection

The dynamic panel data model effect

The following equation is constructed to establish the relationship between environmental regulation and total factor energy efficiency:

$$\mathrm{TFEEI}_{it} = \alpha + \beta\mathrm{TFEEI}_{i,t-1} + \gamma\mathrm{ER}_{it} + \theta X_{it} + u_t + v_i + \varepsilon_{it} \tag{6}$$

In this equation, α represents the intercept and β γ and θ are coefficients to be estimated. ER_{it} is the independent variable, i.e., the vector that represents the CCER and MER stringency? $\mathrm{EEI}_{i,\ t-1}$ is the first lag term of EEI_{it}. This lagged dependent variable $EEI_{i,\ t-1}$ is added as the independent variable in constructing the equation considering the impact of lagged EEI on the current EEI and lagged environmental performance index on the current environmental performance index. X_{it} matrix indicates the control variables set. u_t is fixed time effect, v_i is a single fixed-effect, and ε_{it} is a random error term.

The dynamic threshold model

The above-mentioned study has some limitations as the model of moderating effects fails to identify the key areas and relevant breaks of environmental regulation. This study considers a single threshold model in line with the idea of (Hansen 1999; Piñeros 2020; van Vuuren 2020) nondynamic panel threshold model, to explore the nonlinear causality between the environmental regulation and TFEEI, to confirm the rationality of the sample interval segment and reduce the errors in the model estimate. The following section of this study addresses the environmental regulation variable as the threshold dependent variable to form a threshold effect model as below:

$$TFEEI_{it} = \alpha + \beta_1 EEI_{it-1} + \beta_2 ER_{i,t} \circ I(Q_i \leq \mathrm{C}) + \delta_1 ER_{i,t} \circ I(Q_i > \mathrm{C}) + \sum_{k=1}^{5} \delta_k X_{kit} + \alpha_i + u_t + \varepsilon_{it} \quad (7)$$

In this model above, C is the estimated threshold value, and $I(\cdot)$ is the symptomatic function that will be true if the corresponding condition equals 1 and false if the value is 0. The results of the test might come up with the presence of multiple thresholds that can further be stretched to double and multiple threshold models from the base single threshold model.

Variable and data source

For two reasons, this study chose Chinese energy-intensive industries as observational samples (e.g., iron and steel, nonmetallic, chemical, power, petroleum and cooking, and nonfurious metal industry). First, because energy-intensive industries produce and process certain pollutants, they must adhere to environmental regulations. Second, energy-intensive industries have more frequent innovation activities and more innovation output than traditional industries. We chose 2008 as the starting year of the data because this study requires environmental data from industry reports that have not been formally standardized since 2008. Furthermore, due to a severe lack of innovation data after 2018 in the China statistical year book, the data's end year has been set to 2017.

Dependent variable

The explanatory variable in this paper is the TFEEI.

Independent variable

This study takes (i) command and control environmental regulation (CCER) and (ii) market-based environmental regulation (MER) as the independent variables. The rationale behind choosing CCER as one of the independent variables is that the significant part of the funding for environmental protection in China comes from public finance and the rest from corporate and social financing. Therefore, the opportunity to invest in environmental development projects is huge, and investment in this sector can be in concurrent avenues such as infrastructure, fixing problems with industrial pollution generation sites, and ensuring environmental safety. Funding in identifying the source of industrial pollution (water or air disposal points, for example) involves investing in environmental protection for a particular year and may also involve investing in the previous years' pollution treatment projects. Present studies revealed a positive link between the CCER and technological advancements and total factor production performance on the environmental front. The cost of pollution control in the form of spending in pollution treatments was considered a proxy for CCER measurement by the previous researchers. Therefore, this study follows the earlier studies in framing the CCER index. Meanwhile, the market incentive environmental regulation (MIER) is considered with the thought that sewerage charges are in many cases substituted for the pollution tax and this choice is adopted by the government to internalize the environmental cost and stop industrial pollution. In this regard, the MIER offers economic incentives to attain environmental quality by disguising the cost. Some studies have also considered levying fees on pollution to encourage companies to be innovative, thereby helping the government to strengthen environmental governance.

Control variables

This study considers exports, foreign direct investment (FDI), R&D spending, energy use, inflation, and economic growth as the control variables. All these variables are taken in support of the previous studies showing that these variables have either a unidirectional or a bidirectional relationship with energy and environmental efficiency. This study uses the panel data for thirty Chinese provinces from 2003 to 2017. All the data were collected from the National Bureau of Statistics of China. In Table 1, the descriptive statistics of all the variables are presented and can be checked.

Table 1 input and output indicators for energy efficiency

		Bad output	Good output	Input 1	Input 2	Input 3
2008	Max	9.775	127.19	44.16	519.57	71.53
	0.115	1.495	0.69	0.805	0.0575	0.05
	2.99	23.805	12.19	150.65	15.41	13.4
	2.415	27.255	9.66	115.345	17.595	15.3
2012	Max	18.4	329.245	51.52	1213.825	89.01
	0.115	3.45	0.575	20.125	0.115	0.1
	4.255	56.465	12.995	249.435	24.38	21.2
	4.14	76.475	11.73	244.49	23	20.0
2015	Max	27.485	861.235	75.21	3395.145	231.035
	0.115	9.085	0.46	44.62	1.38	1.2
	5.865	144.44	18.17	800.285	37.72	32.8
	6.555	199.985	17.94	756.7	49.68	43.2
2017	Max	20.7	1673.48	80.96	14651.23	265.42
	0.115	20.815	0.46	61.87	1.955	1.7
	5.52	265.42	18.86	3233.455	46.46	40.4
	5.29	391.805	19.205	3428.265	61.18	53.2

Results and discussions

Table 2 depicts the results of the federal government retaining only political control over urban planning and leaving local councils with considerable independence in implementing environmental policies. Local officials would evade sustainability policies by protecting polluting manufacturing businesses contributing significantly to community economic development if promotion benefits were based only on GDP. The Chinese central government introduced the Mandatory Target System (MTS) as a modern environmental governance measure in the 11th Five-Year Plan (2006–2010). MTS created a top-down hierarchical staff appraisal structure by establishing highly prioritized environmental quantitative priorities to encourage municipal governments to safeguard the atmosphere. The MTS' environmental performance-based compensation and penalty policies have few clear effects on officials' core priorities, implying that they cannot effectively affect their promotion. The introduction of municipal environmental policies was also inadequate within the system of environmental decentralization. Environmental policies were often only partly enforced, and polluting mining businesses continued to be protected by municipal councils.

Table 2 The average EEI of China's high energy intensive industries from 2008 to 2017

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
EEI	0.	0.4	0.39	0.8	0.49	0.43	0.38	0.60	0.49	0.57

The empirical findings endorse the hypothesis that the new law's enforcement has a greatly impacts green innovation behavior of state-owned enterprises than that of private companies. Furthermore, variability is primarily seen in patent applications for inventions. Patents on inventions are most apt to give businesses a comparative edge. This finding is in line with a number of studies on China's tight relations between state-owned businesses and the government. The findings reinforce the bureaucratic hypothesis, which states that companies owned by the government pay greater heed to fulfilling the government's wishes. This research has many shortcomings, including the fact that it was done in a novel setting and coincides with current studies that rule out the effects of all subsequent events influencing corporate green creativity. Second, we looked at how the new legislation affected businesses with a variety of features, such as different ownership structures, economic reliance on secondary industries, and commodity sector rivalry. Future studies will look at this process to see if the incentive for corporate green creativity differs depending on the various variables contributing to the firms' heterogeneity.

Table 2 and Fig. 1 presents the provincial level EEI. EEI has the following features as opposed to previous campaign-style compliance in China's environmental governance. The EEI squad, for starters, represents the CPC Central Committee and the State Council. Members of the team are influential politicians from the party's main offices and government agencies. They also serve as heads of regional governments and central ministries, as well as judges and prosecutor generals. Second, the EEI wields unparalleled authority. It monitors the leading representatives of the party and government in the inspected regions, in addition to overseeing polluting businesses. This means that the EEI team can not only prosecute polluting companies contributing to lax implementation of environmental laws but also tackle local protectionism. Third, EEI assigns target appraisal and oversight structures to municipal councils, exerting significant political leverage on them to ensure that environmental quality laws are enforced and that they are sensitive to popular demand. Table 3 shows energy efficiency score.

The empirical results of the benchmark model

The system GMM approach is applied to fix the issues relevant to dynamic panel estimation stated in Eq. (5). It takes into consideration the absence of autocorrelation within the disturbance terms. This approach also solves the endogeneity issue by taking lag variables. Apart from GMM, the study also conducted Arellano-bond (AR), Sargan-Hansen, and Wald chi-square tests to attain a more robust estimation result. The Arellano-Bond (AR) test comprises both first and second-order autocorrelation of residuals tests known as AR (1) and AR (2), respectively. The residuals of the equation are

Table 3 The EEI of China's six high energy-intensive industries at the provincial level from 2008 to 2017

Province	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean
Anhui	0.51	0.55	0.59	0.51	0.55	0.59	0.55	0.69	0.59	0.63	0.55
Beijing	0.88	0.87	0.94	0.88	0.97	0.93	0.88	1	1	1	0.94
Chongqing	0.47	0.45	0.41	0.51	0.37	0.44	0.26	0.34	0.33	0.38	0.4
Fujian	0.88	0.82	0.86	0.77	0.69	0.77	0.72	0.66	0.74	0.76	0.77
Gansu	0.52	0.54	0.61	0.45	0.26	0.26	0.21	0.24	0.19	0.22	0.35
Guangdong	1	1	1	0.99	1	1	0.98	1	0.95	0.98	0.99
Guangxi	0.46	0.45	0.41	0.46	0.34	0.35	0.37	0.39	0.37	0.39	0.4
Guizhou	0.4	0.24	0.25	0.3	0.17	0.2	0.15	0.32	0.27	0.37	0.27
Hainan	1	1	1	1	1	1	1	1	1	1	1
Hebei	0.58	0.5	0.48	0.58	0.5	0.52	0.56	0.52	0.52	0.54	0.53
Heilongjiang	0.21	0.18	0.16	0.18	0.13	0.13	0.4	0.12	0.09	0.12	0.17
Henan	0.62	0.7	0.59	0.61	0.47	0.5	0.44	0.43	0.38	0.42	0.52
Hubei	0.43	0.39	0.43	0.4	0.38	0.44	0.39	0.51	0.47	0.57	0.44
Hunan	0.28	0.28	0.3	0.25	0.3	0.35	0.3	0.34	0.31	0.68	0.34
Inner Mongolia	0.3	0.27	0.35	0.42	0.38	0.39	0.39	0.52	0.44	0.36	0.38
Jiangsu	1	1	0.99	0.99	0.98	0.97	0.97	0.99	1	1	0.99
Jiangxi	0.47	0.48	0.62	0.52	0.49	0.52	0.57	0.48	0.46	0.51	0.51
Jilin	0.33	0.37	0.41	0.54	0.52	0.53	0.51	0.55	0.36	0.53	0.47
Liaoning	0.58	0.55	0.56	0.59	0.55	0.55	0.55	0.6	0.53	0.39	0.55
Ningxia	0.62	0.46	0.55	0.52	0.42	0.38	0.31	0.37	0.32	0.43	0.44
Qinghai	0.76	0.78	0.73	0.85	0.76	0.75	0.58	0.6	0.59	0.59	0.7
Shaanxi	0.44	0.25	0.29	0.27	0.21	0.75	0.2	0.27	0.28	0.36	0.33
Shanghai	1	1	1	1	1	1	0.9	1	1	1	0.99
Shanxi	0.18	0.16	0.15	0.15	0.14	0.12	0.11	0.11	0.08	0.1	0.13
Sichuan	0.51	0.57	0.51	0.39	0.31	0.35	0.27	0.27	0.22	0.32	0.37
Tianjin	0.92	0.88	0.84	0.78	0.79	0.92	0.78	0.86	0.82	0.89	0.85
Xinjiang	0.24	0.18	0.18	0.43	0.19	0.12	0.12	0.17	0.09	0.23	0.2
Yunnan	0.23	0.24	0.24	0.2	0.18	0.18	0.19	0.22	0.19	0.24	0.21
Zhejiang	1	1	1	1	0.99	1	0.95	0.94	0.97	0.92	0.98

regarded as not autocorrelated if AR (2) is accepted and AR (1) is rejected. Meanwhile, to check exogeneity among the variables, the Sargan-Hansen test is applied. Moreover, the Wald test is performed to check the significance level of each regression. Table 4 shows dynamic threshold regression.

We discovered that environmental compliance in the form of a campaign is linked to significant improvements in corporate environmental behavior. Many polluting businesses have shut down within a short period after EEI was implemented. Furthermore, EEI greatly decreased the surviving firms' carbon emissions while having a negligible effect on their pollution efficiency. These findings are consistent with a series of checks which can be used in emission situations characterized by COD and SO_2. Our findings suggest that campaign-style regulation encourages businesses to comply with central government targets by reducing end-of-pipe costs, but it can also stifle local markets due to "one-size-fits-all" issues. Our study has drawbacks, including the fact that we offer proof of the effect of campaign-style compliance on corporate conduct. First, due to data constraints, we can only look at EEI's short-term effect. As EEI becomes a more popular instrument for environmental regulation in China, considering the long-term effect of EEI on time-series data in the future is critical. Second, since we just use data from a single province, we disregard regional variability. Since each province in China has a different level of growth, campaign-style compliance can have different effects, and distinct firm-level strategies may produce different outcomes in each province. Future observational research may be required to bolster the case any further. Third, this article focuses solely on the effects of EEI on firms' carbon efficiency and emissions, leaving the influence of EEI on other aspects of businesses to be studied in the future. Fourth, one problem of utilizing regression discontinuity in time for annual records is that other confounding variables that have been modified after the cut-off point will influence the estimate performance. To minimize the effect of

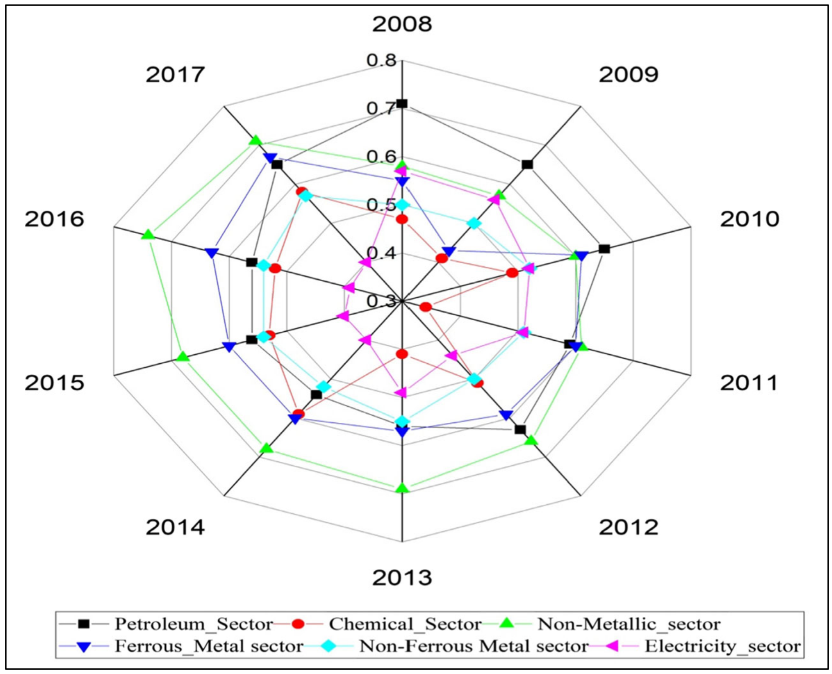

Fig. 1 The EEI of China's six high energy-intensive industries from 2008 to 2017

other variables, one approach is to use higher frequency data (quarterly, weekly, or daily). However, the best we can do right now is yearly emission results.

The empirical results of the moderating effect of R&D

We check the cross term of the R&D and environmental regulation on green efficiency. Table 5 presents the results of moderating effect of R&D on green efficiency. The findings showed that all the moderating coefficients are seen positive, only MER and R&D are statistically significant with a 5% level. This proposes that the moderating effect pretty existent for environmental regulation. The result of the regression estimation shows that more R&D spending can boost green efficiency and contemplate the innovation offset effect steamed from market-based environmental regulation. R&D spending has both direct and indirect impact on the green efficiency of manufacturing sector. China controls the industrial pollution emission through command-and-control environment regulation by setting stringent emission limits and advanced technological standards. However, unlike MER, the command-and-control environmental regulation has little flexibleness and this makes the improvement of green efficiency through accelerating the effect of "innovation offset" for the short run. Porter argues that, by making well-structured environmental regulation based on the innovation effect, a positive effect can be established on R&D and technology empowerment. Therefore, the impact of moderation effect of R&D and environmental regulation on green efficiency needs to be studied further to enhance green efficiency to the highest level possible in view of that, the moderating factors of R& D and CER are includes in the dynamic panel modeling of this study.

Policymakers, administrators, and investors should all be aware of the findings of this report. We believe that the Environmental Protection Law is an important tool for encouraging renewable energy growth and that market forces alone will be insufficient to encourage high-quality economic production. First, our findings indicate that the new Environmental Protection Law in China has a smaller effect on businesses in cities where secondary industries are more significant. Both GDP growth and carbon emissions are aided by secondary industries. Local officials would be required to choose between environmental conservation and economic growth as the current legislation takes effect. To ensure a broad policy effect, central government policymakers can recommend adopting comprehensive complementary plans as part of the new Environmental Protection Law, taking into account firm characteristics and local officials' tenure. Furthermore, the federal government could allow municipalities to create specific environmental conservation institutions tailored to their communities' unique features, as well as improving government audits of the new law's enforcement. This would help determine the true consequences of the Environmental Protection Law by reducing the knowledge asymmetry between the federal and local governments. Second, our cross-sectional findings reveal that under the current regulation, SOEs are consistently engaged in green innovation practices. Concentrated industry firms have more opportunities and incentives to nurture green technologies than competitive industry firms do. Table 5 shows Regression results of green finance effect on EEI.

Table 4 The result of the Dynamic panel threshold regression

	CCER		MER	
	(1)	(2)	(3)	(4)
Green Efficiency	0.3625***	0.3837***	0.3802***	0.5255***
	(0.0025)	(0.0027)	(0.0033)	0.0038)
CCER	0.0386			
	(0.2552)			
CCER Lag_1		0.0353		
		(0.2237)		
MER			0.0785***	
			(0.0882)	
MER Lag_1				0.0302***
				(0.0325)
Export	0.0252***	0.0260***	0.0308***	0.0352***
	(0.0025)	(0.0027)	(0.0258)	(0.0033)
FDI	0.3352***	0.3607***	0.5352***	0.5388***
	(0.0555)	(0.0550)	(0.0635)	(0.0662)
R&D	−0.0008**	−0.0022***	−0.0020***	−0.0023***
	(0.0006)	(0.0008)	(0.0008)	(0.0020)
EU	0.0220***	0.0245***	0.0202***	0.0254***
	(0.0048)	(0.0040)	(0.0224)	(0.0228)
Inflation	−0.0284***	−0.0422***	−0.0424***	−0.0448***
	(0.0045)	(0.0054)	(0.0058)	(0.0058)
Constant	2.0484***	2.0585***	2.2222***	2.2477***
	(0.2270)	(0.2225)	(0.0528)	(0.0702)
AR (1) test	−2.0542	−2.0842	−2.4248	−2.5244
	[0.024]	[0.024]	[0.028]	[0.024]
AR (2) test	−2.2582	−2.2474	−2.2580	−2.4002
	[0.272]	[0.248]	[0.255]	[0.254]
Sargan test	22.4787	28.8804	24.5522	28.5542
	[0.058]	[0.058]	[0.22]	[0.248]
Wald test	275485	280448	282244	405255
	[0]	[0]	[0]	[0]

Note: Standard errors are in parentheses (). ***= 1% significant level; **= 5% significant level and *=10% significant level

Table 5 Regression results of R&D effect on EEI

	CER		MER	
	(5)	(6)	(7)	(8)
Green Efficiency	0.2811***	0.4028***	0.2996***	0.4164***
	(0.0026)	(0.0021)	(0.0011)	(0.0012)
CCER	0.0373			
	(0.2706)			
*CCER**R&D		0.0426***		
		(0.0602)		
MER			0.0743***	
			(0.0937)	
*MER*R&D*				0.041***
				(0.0069)
Export	0.0262***	0.0260***	0.0308***	0.0352***
	(0.0035)	(0.0027)	(0.0258)	(0.0033)
FDI	0.3752***	0.3657***	0.5452***	0.5488***
	(0.0555)	(0.0550)	(0.0635)	(0.0662)
R&D	−0.0008***	−0.0022***	−0.0020***	−0.0023***
	(0.0006)	(0.0008)	(0.0008)	(0.0020)
EU	0.0220***	0.0245***	0.0202***	0.0254***
	(0.0048)	(0.0040)	(0.0224)	(0.0228)
Inflation	−0.0289***	−0.0483***	−0.0432***	−0.0438***
	(0.0045)	(0.0054)	(0.0058)	(0.0058)
Economic growth	−0.2491*	−0.2168	−0.2466	0.0112
	−0.0248	−0.0246	−0.0616	−0.1828
	−0.0177	−0.0186	−0.017	−0.0188
Constant	1.1484***	1.2434***	1.1088***	1.0724***
	−0.048	−0.048	−0.038	−0.038
AR(1) test	−2.2842	−2.4024	−2.1373	−2.1243
	[0.024]	[0.024]	[0.018]	[0.014]
AR(2) test	−1.4401	−1.2332	−1.2480	−1.1883
	[0.1748]	[0.1411]	[0.1482]	[0.1412]
Sargan test	21.4771	20.1088	17.8683	13.386
	[0.0732]	[0.0706]	[0.1124]	[0.1268]
Wald test	188472.4	400248.2	242216	281644.1
	[0]	[0]	[0]	[0]

Note: Standard errors are in parentheses (). ***= 1% significant level; **= 5% significant level and *=10% significant level

Product industry rivalry is an effective mechanism for external corporate governance and significantly affects firm conduct. In economics, the relationship between competitiveness and creativity is a well-known yet contentious subject. The fundamental guiding factor of creativity, according to is rivalry. Through R&D spending, firms in dynamic industries may gain better returns than firms in consolidated industries. Perfect rivalry, on the other hand, is not always the most effective business structure for promoting research and development; according to (Iqbal et al. 2020) the desire to innovate is determined by the availability of capital and the potential to innovate. We selected a panel of companies from the eight most polluting sectors as well as a control group of non-high-polluting classified companies to evaluate our hypotheses. The eight most polluting sectors were chosen based on the Ministry of Ecology and Environment of the People's Republic of China's 'Notice on the Introduction of the Detailed Emission Norm for Industrial Emissions Sources' released in November 2016 (Anser et al. 2020a). Steel, thermal power, cement, gas, paper, printing, and dyeing, as well as sewage treatment and waste incineration facilities, are among them. The two-digit industry codes referring to these industries were listed by the China Securities Regulatory

Commission (CSRC), and a list of Chinese companies belonging to these industries was collected from China Stock Market and Accounting Research (CSMAR). Firms that did not operate between 2010 and 2017, those whose sector codes were modified during that period, and those that did not fall into one of the eight most polluting sectors according to the CSRC's quarterly revised industry classification for classified firms were all exempt.

The results of the threshold model

Results present the threshold econometric results. In three aspects, our research adds to the current body of knowledge. The treatment category consists of eight high-polluting sectors, while the control group comprises companies chosen through a propensity score matching strategy. Omitted variable bias and other endogeneity problems may be mitigated with this study design. Second, data from microenterprises were selected for analytical research. Analyzing the firm-level economic effects of environmental policy, as opposed to macro and market statistics, has significant consequences for policymakers, lawmakers, administrators, and investors seeking to make the best choices possible. Second, it made government agencies and leaders more accountable. The new legislation explicitly holds the government liable for environmental quality in its regulatory region; the law's ecological protection red line establishes the bottom line for environmental sustainability requirements and critical benchmarks for evaluating government officials' environmental responsibility during their tenure. Furthermore, state environmental authorities are authorized to close down activities violating environmental regulations. Third, it significantly improved polluters' transparency. According to the new legislation, businesses must discourage and mitigate emissions and ecological harm, as well as taking liability. It proposes a daily basis penalty scheme ensuring that companies embroiled in emissions lawsuits may be liable to penalties assessed and added on a daily basis with no upper cap before they amend their unlawful contaminants discharge conduct.

Our conclusions, as a research report on environmental conservation and performance, have many policy consequences. First, environmental degradation presents a significant challenge to the atmosphere as well as human and animal well-being, necessitating the creation of metrics that can aid in improving environmental sustainability. According to this report, spending on environmental protection significantly impacts environmental performance, implying that policymakers can invest more in environmental protection. Even if environmental spending improves the environmental performance in the long run, the impact is insignificant in the short term, meaning that policymakers can rely primarily on the short-term effectiveness of environmental spending to increase environmental performance. Furthermore, policymakers can continue to invest in environmental conservation, such as by developing long-term policies for environmental spending. Additionally, according to our findings, other countries are unable to drive environmental performance through spending on environmental protection, and policymakers in those countries, especially China, could make greater efforts to effectively utilize environmental expenditure. Furthermore, since the relationship between environmental protection spending and environmental performance is long-term, lawmakers can prioritize environmental quality while managing public spending. Finally, developing countries can invest more in environmental conservation than industrialized countries, which is important to boost their long-term environmental efficiency. Table 6 Regression results of the threshold effect model.

Sensitivity analysis

The other point of view, known as the Porter Hypothesis, proposes that stringent and effective environmental control will offer possible rewards for an individual firm's technical advancement. Firms can deliberately select strategies satisfying environmental protection requirements after the government imposes effective environmental regulation. Resultantly, environmental regulations could incentivize innovation beneficial to environmental conservation. These activities not only comply with applicable laws and legislation but also improve the efficiency of the manufacturing process. Meanwhile, expense cuts were necessary to cover enforcement expenses. This is one of the main reasons that environmental policy is portrayed as a win–win approach improving both environmental sustainability and business productivity. As a result, stringent environmental legislation is likely to influence a firm's strategic judgment and further encourage innovation activity, thus impacting the pace of green innovation. Furthermore, the results of sensitivity analysis are displayed in Table 7.

Prior to 2015, while the current environmental regulation was not in place, large polluters had a much lower degree of green creativity than regulated companies. Green engineering is a time-consuming and expensive endeavor with a poor performance rate. With the lack of proper oversight, polluting companies are more likely to flee rather than take the opportunity to pursue green creativity. The recent environmental conservation bill significantly affects emission practices and makes stringent provisions for environmental knowledge transparency and encourages certain highly polluting companies to go green. This suggests that the current environmental conservation bill has a stronger incentive influence on highly polluting companies' green creativity. Furthermore, missing variables could also affect the analytical findings of this article. We often use the lagged-one and lagged-two terms of the dependent variable in

Table 6 Regression results of the threshold effect model

Variable	CCER (9) SYS-GMM	MER (10) SYS-GMM
*Green Efficiency*_lag1	0.7317***	0.7743***
	−44.43	−42.4
CCER≤−3.3403	0.571	
	(0.004)	
−2.2223<*CCER*≤ −2.231	1.200***	
	(0.011)	
CCER>−2.332	2.232**	
	(0.007)	
MER≤3.336		0.132***
		(0.025)
MER>5.331		0.078
		(0.131)
Export	0.025***	0.017 ***
	(0.013)	(0.022)
FDI	0.051***	0.082***
	(0.000)	(0.001)
R&D	−0.320***	−0.553***
	(0.017)	(0.128)
EU	−0.007***	−0.014**
	(0.002)	(0.010)
Inflation	0.012 ***	0.022***
	(0.138)	(0.207)
Economic growth	0.073***	0.081***
	(0.054)	(0.030)
Constant	0.733***	1.052***
	(0.234)	(0.521)
AR(2)	1.1	1.11
	[0.271]	[0.237]
Hansen test	27.85	27.13
	[0.758]	[0.828]
Wald test	182,845.17***	120,553.07***
	[0.000]	[0.000]
N	220	220

Note: Standard errors are in parentheses (). ***= 1% significant level; **= 5% significant level and *=10% significant level

the panel regression model, as suggested by to monitor the effect of certain missing variables and unobserved causes. After correcting for the possible effect of lagged corporate green innovation, the coefficients of Post are still significantly optimistic. The above findings suggest that mentioned firms' new green innovation is influenced by their previous green innovation successes in the short term (2 years). Our regression findings are still stable when accounting for the effects of previous causes.

Conclusion and policy implication

This work examines the environmental regulations of China's energy-intensive industries in the light of the country's expanding economy and global warming issues, sourcing panel data from China's 30 provinces from 2008 to 2017. The NDDF is used to calculate the TFEEI, which is then used to evaluate two environmental laws using dynamic panel models. While the EEI of the chosen industries has increased significantly, there is still more space for growth, with the total average EEI between 0.55 and 0.58. Compared to the western and north-eastern provinces, most eastern provinces have a higher EEI. Furthermore, due to backward infrastructure and a poor economic base, the EEI of the western provinces is lower than that of the central and eastern provinces as the old industrial areas of north-eastern China, Heilongjiang and Liaoning, established high energy-intensive factories first. As a consequence of the obsolete technologies in these industries, the EEI is poor. During the study era, the nonmetallic and ferrous metal sectors produced the most, while the chemical and nonferrous metal sectors produced a mixed trend. This is ascribed to rising economic trends, more modern manufacturing and energy structures, and higher technical levels in countries with higher economic levels. Hence, in the eastern area, the current legislation could be more effective in promoting businesses to engage in green innovation. Pollution-related issues have altered people's lifestyles and harmed land, earth, trees, natural processes, and even whole economies. Environmental performance is now the subject of an increasing body of research since it is at the center of human wellbeing, plant efficiency, firm behavior, manufacturing operations, and a sustainable economy. Thus, boosting environmental sustainability has become a priority for people, businesses, academics, and politicians alike. Since people are less able to engage in environmental conservation because of its optimistic externality and noninclusive nature, policymakers must take meaningful steps to have adequate environmental protection spending to create a low-carbon economy.

The findings reveal that in high-energy-intensive industries, CCER, MER, and EEI have a good inverted U-shaped relationship. Both the CER and MER coefficients (0.0286 and 0.0304) were statistically significant. Only MER is statistically relevant at a 5% range, implying that market-based environmental policy could positively impact EEI enhancement and that appropriate regulations help to improve EEI. The study's findings support the effectiveness of environmental legislation in promoting EEI in China's energy-intensive industries.

Policymakers should be aware of the different degrees of effectiveness of environmental regulation to make more educated choices, according to the conclusions of this report. CCERs are necessary, resulting in a scarcity of renewable innovative technology for the

Table 7 The regression results of robustness test

Variables	10th	20th	30th	50th	70th	90th
Green efficiency_lag1	1.771***	0.026	0.875***	0.568**	0.878**	1.762***
	(0.4704)	(0.468)	(0.226)	(0.278)	(0.402)	(0.588)
CCER	1.484	1.484*	1.484*	1.084**	1.0867***	1.0654***
	(1.036)	(1.276)	(1.346)	(0.276)	(1.246)	(0.0846)
MER	1.484***	1.484***	1.484***	1.484***	1.484***	1.484***
	(0.2846)	(0.2846)	(0.2846)	(0.2846)	(0.2846)	(0.2846)
Export	0.148***	0.02***	0.070***	0.104***	0.156**	0.212***
	(0.0475	(0.062)	(0.0282)	(0.0287)	(0.0622)	(0.0668)
FDI	0.439**	0.008***	0.167**	0.180***	0.243***	0.173*
	(0.0642)	(0.128)	(0.0982)	(0.0636)	(0.0872)	(0.0903)
R&D	−0.63***	−0.446***	−0.447**	−0.482**	−0.408***	−0.409***
	(0.017)	(0.129)	(0.871)	(0.241)	(0.343)	(0.647)
EU	0.008***	0.014***	0.014**	0.008***	0.014**	0.014**
	(0.0026)	(0.0123)	(0.0187)	(0.0182)	(0.0266)	(0.0246)
Inflation	0.012***	0.033***	0.033***	0.044***	0.074***	0.074***
	−0.169	−0.208	−0.208	−0.247	(0.286	−0.286
Economic growth	0.086***	0.091***	0.091***	0.086***	0.091***	0.091***
	(0.044)	(0.06)	(0.94)	(0.066)	(0.072)	(0.928)
Constant	3.284***	0.169***	0.126***	0.464**	0.701**	1.218***
	(0.9409)	(0.3268)	(0.1417)	(0.1686)	(0.2804)	(0.2909)

Note: Standard errors are in parentheses (). ***= 1% significant level; **= 5% significant level and *=10% significant level

organization. Policymakers can use market-based environmental policies actively to extend the regional market platform, promote fresh studies on emissions taxes and carbon pricing, and achieve better pollution reduction in the long run. The government should take effective environmental governance measures to increase the EEI of energy-intensive sectors and pay close attention to each sector at the regional level.

We discovered that after EEI was implemented, the number of polluting companies decreased by 48% (and the shrinkage may be even greater for small and micro-businesses). EEI also decreases agricultural COD pollution by at least 46.5% without impacting COD output in remaining businesses. Our findings indicate that compliance in the form of a campaign may change corporate environmental behavior while slowing down local economies. This discovery has regulatory consequences for EEI practice in the future. First, our findings warn the government to understand the long-term consequences of large-scale manufacturing plant closures. Meanwhile, the government could stop taking short-term policy decisions in favor of long-term inspection systems for manufacturing companies. Last but not the least, rather than depending on end-of-pipe abatement, the government can direct businesses toward renewable transitions and industrial upgrades.

Policy implications

The following are the policy recommendations in this article:

To begin with, increase the severity of environmental regulations as required. The environmental regulation has had the anticipated "back-forced reduction" impact at this stage. As a result, improving environmental policies would aid in the reduction of carbon emissions.

Second, the government should set the level of environmental regulation based on regional economic growth and carbon intensity heterogeneity. It is recommended that the eastern developed provinces adopt a higher degree of environmental regulation severity, considering the growing demand for environmental quality and green goods.

Third, technical innovation should positively impact carbon emission reduction. The empirical findings indicate that technological progress has not substantially decreased carbon emissions under the constraints of environmental regulation. As a result, the government should build an external climate conducive to corporate environmental protection technology innovation as well as direct the transition of innovation inputs to environmental protection technologies based on local conditions. Enterprises should aggressively adopt environmental management technologies compatible with their own productivity levels and technical absorption capability, undertake reverse learning and secondary growth, fully exploit the advantages of late development, and realize the dynamic evolution from technology import to technology imitation to independent innovation.

Author contribution Thanh Quang, Ngo: Conceptualization, Data curation, Methodology, Writing—original draft, Data curation, Visualization. review and editing, Writing—review and editing and software, Visualization, supervision, editing.

Funding This research is funded by University of Economics Ho Chi Minh City, Vietnam.

Data availability The data that support the findings of this study are openly available on request.

Declarations

Ethical approval and consent to participate The authors declare that they have no Known competing financial interests or personal relationships that seem to affect the work reported in this article. We declare that we have no human participants, human data or human tissues.

Consent for publication We do not have any individual person's data in any form.

Competing interest The authors declare no competing interests.

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