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Research article

The impact of the energy-consuming right trading system on corporate environmental performance: Based on empirical evidence from panel data of industrial enterprises listed in pilot regions

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ABSTRACT

The energy-consuming right trading system (ECRTS) is a significant institutional innovation in China to address the increasingly severe energy crisis and environmental issues. Identifying the policy effects of energy consumption rights on corporate environmental performance (CEP) is conducive to achieving a win-win situation for China's economic growth and carbon neutrality. This study aims to analyze the impact of energy-consuming right trading system on corporate environmental performance and provide empirical evidence and policy implications for the full implementation of future policies. Using data from Chinese listed industrial enterprises from 2012 to 2019 and adopting the difference-in-differences method and mediation analysis, we empirically analyze the policy effects of energy-consuming right trading system. We find that the energy-consuming right trading system significantly promotes the improvement of corporate environmental performance, and the conclusion remains valid after a series of robustness tests. Further mechanism examinations indicate that the system mainly enhances environmental performance by affecting corporate green technological innovation. Heterogeneity tests suggest that the energy-consuming right trading system has a stronger impact on companies in economically developed regions, non-state-owned enterprises, and those with higher asset flexibility. Our research results can aid in the green transformation of enterprises and provide practical evidence for China to accelerate the comprehensive construction of the energy consumption rights trading market.

1. Introduction

In recent years, China's economic growth has been at the forefront of the world's major economies. However, this growth has been accompanied by a yearly increase in energy consumption and reliance on traditional economic growth models. These factors have inevitably led to the waste of non-renewable resources and a series of issues such as severe environmental pollution and ecological degradation. Currently, China's total energy consumption is the highest in the world [1]. Under these circumstances, how to formulate reasonable and effective environmental policies to promote carbon emission reduction, pollution reduction, and accelerate the shift of

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the economic development model towards green transformation has become an urgent and significant issue that needs to be addressed. To this end, the Chinese government has carried out an important environmental management system innovation—implementing the energy-consuming right trading system (ECRTS), an attempt to promote the green transformation of industries through market-oriented means and to drive the green, high-quality development of the Chinese economy [2].

Since the energy consumption rights system has been implemented for only a short time and most of the early literature is theoretical, the empirical research is still in the developmental stage. Based on this, our study selects 1,281 listed industrial enterprises as a sample to inspect the impact of the energy-consuming right trading system on corporate environmental performance from a micro perspective. The study aims to answer the following three questions: (1) Does the energy-consuming right trading system have an impact on corporate environmental performance? (2) What is the mechanism through which the energy-consuming right trading system affects environmental performance? (3) Is there a heterogeneous impact on corporate environmental performance under the energy-consuming right trading system?

In theoretical research on energy-consuming right trading system, scholars have mainly explored its legal foundation, initial allocation mechanisms, and trading mechanisms. Regarding the legal foundation of rights, Han and Huang [3], along with Li and Wang [4], analyzed the complex legal properties of energy-consuming right trading system. Both defined the right to use energy as a type of property right based on a quota or index of total consumption, but they disagreed on whether it possessed characteristics such as exclusivity. In terms of initial allocation rules, due to the differences in energy endowments, industrial structures, and developmental stages across regions in China, and since regional governments also need to consider local economic development needs, it is particularly important to balance the quota ratios across regions [5]. During the initial stages of the emissions trading system, EU countries largely adopted a free allocation method, but this approach led to low trading prices and did not effectively promote energy conservation and emission reduction [2]. To ensure a focus on both economic growth and efficient emission reduction, China should draw upon the experience of the EU's carbon emissions trade and combine free allocation with auction-based allocation tailored to the energy usage conditions in each region [6]. Regarding the trading mechanism, since energy-consuming right trading system is essentially a market-based operation with the aim of transmitting the impact of market entity's energy consumption to the entire economic operation, the trading price should be jointly determined by participating parties based on market supply and demand [7].

Beyond theoretical studies, most empirical studies concerning the energy-consuming right trading system have primarily investigated the economic and environmental benefits it brings. Regarding the environmental benefits, Qi and Han [8] confirmed, by combining the ARIMA model, STIRPAT model, and Synthetic Control Method (SCM), that the energy-consuming right trading system can achieve dual control of both total and intensity in energy saving and emission reduction. Wang et al. [9] used the Data Envelopment Analysis (DEA) to quantify the optimal energy input and expected output under the energy rights trading model and established a comprehensive model for decomposing changes in energy intensity to verify the system's control effect on total energy consumption and intensity. Liao et al. [10] and Xue and Zhou [11] also confirmed the same results using the difference-in-differences method. Similarly, Chu et al. [12] applied DEA and Index Decomposition Analysis (IDA) to demonstrate that the energy-consuming right trading system could significantly reduce China's carbon intensity. In terms of economic benefits, the rights trading system achieves pollution control objectives at the lowest cost through market pricing mechanisms, drives resource allocation to a Pareto optimum, and ultimately realizes a win-win situation between economic growth and energy saving and emission reduction, reflecting the Porter effect [13]. Zhang and Zhang [14], by establishing a nonparametric optimization model to compare command-and-control and energy rights trading policies, found that the energy-consuming right trading system could bring higher average economic and energy-saving potential. Liu and Wang [15], after comparing command-and-control, mixed, and market-based energy policies, also reached similar conclusions.

Although the majority of the literature has explored the inherent attributes, energy-saving effects, and economic impacts of the energy-consuming right trading system, research on the impact of the energy-consuming right trading system on enterprises is still in an exploratory stage. Shen and Chen [16] explored the spillover effect of energy-consuming right trading system on green technology innovation in enterprises but did not delve into the operating mechanism. Zhang and Chen [17] filled this gap by studying how the energy-consuming right trading system influences corporate green technology innovation. While research similar to this paper has empirically tested the impact of energy rights trading policies on urban environmental performance using a sample of 262 cities [18], few articles directly address the influence of the energy-consuming right trading system on corporate environmental performance, and there is a lack of analysis on the mechanism of the energy-consuming right trading system's impact on corporate environmental performance. Therefore, this study utilizes a data sample of 1,281 listed industrial enterprises from 2012 to 2019, examining the impact of the energy-consuming right trading system on environmental performance and its transmission mechanism through the method of difference-in-differences and mediating effect analysis and investigates the heterogeneous effects of this policy on different enterprises.

The subsequent sections of this article are as follows. Section 2 discusses the background, theoretical mechanisms, and research hypotheses of the energy-consuming right trading system. Section 3 clarifies the research design. Section 4 presents the empirical study. Section 5 conducts mechanism testing and heterogeneity analysis. Section 6 discusses the research findings. Section 7 offers conclusions and future prospects.

2. Policy background and theoretical mechanism

2.1. Energy-consuming right trading system background

The concept of "energy rights trading" first appeared in Article 42 of the "Overall Plan for the Reform of the Ecological Civilization

System" released by the Central Committee of the Communist Party of China and the State Council in September 2015, where it was proposed: "To implement energy rights and carbon emission rights trading systems, establish an energy-consuming right trading system, and a measurement and verification system." This was the first official mention of the term "energy rights trading." Subsequently, the "Proposals of the Central Committee of the Communist Party of China on the Thirteenth Five-Year Plan for National Economic and Social Development" mentioned the need to "establish and improve the initial allocation system for energy rights, water rights, pollution rights, and carbon emission rights, and promote the cultivation and development of the trading market." In 2016, the "Thirteenth Five-Year Plan for Energy Development" suggested by the National Development and Reform Commission and the National Energy Administration proposed "to carry out energy rights trading pilots, promote the construction of a national unified carbon emissions trading market, and improve energy market supervision mechanisms," thereby incorporating the energy-consuming right trading system into the development plan for the next five years. In July of the same year, the "Pilot Scheme for the Paid Use and Trading of Energy Rights" was issued by the National Development and Reform Commission, selecting Henan, Zhejiang, Sichuan, and Fujian as pilot provinces, and in 2017, the specific implementation plans were approved. Subsequently, these provinces, based on their own characteristics, introduced complete work programs and management methods, and conducted pilot trials. By the end of 2019, these provinces had officially begun the paid use and trading of energy rights. The implementation of the energy-consuming right trading system not only helps to reduce energy consumption and optimize the energy structure but also promotes the reduction of carbon emissions and the sustainable development of the economy.

2.2. Theoretical mechanism

Energy use right refers to the right that an energy-using unit can consume a specific type of energy (such as electricity, coal, etc.) within a limited quantity and for a certain time frame, according to the total energy control system. Energy use right trading, on the other hand, pertains to the activity of buying and selling energy usage quotas between trading entities under the condition of a regional total energy consumption cap. Specifically, based on the control over the total amount and intensity of regional energy consumption, the government allocates a certain proportion of free initial energy usage quotas to enterprises according to conditions such as energy-saving potential and resource endowment. It also allows enterprises to trade these quotas in the market to reduce both the total amount and intensity of energy consumption. The energy-consuming right trading system, as one of the government's regulatory tools, is based on the theoretical foundation of the Coase Theorem, which posits that under the premise of clearly defined property rights and extremely low or zero transaction costs, market equilibrium will efficiently result in the Pareto-optimal allocation of resources. Based on this theory, the energy-consuming right trading system clarifies property rights and harnesses market mechanisms to encourage enterprises to reach an efficient Pareto-optimal state in resource allocation, thereby maximizing the effects of energy conservation and emissions reduction. Overall, the energy-consuming right trading system influences the environmental performance of enterprises through both cost pressure and trade compensation.

Firstly, in terms of cost pressure, local governments have allocated a certain amount of free energy usage quotas to energy-consuming enterprises. If a company's energy consumption exceeds these quotas, it must purchase additional quotas in the market, otherwise, it will face fines. Under such a system, companies that maintain their existing production technologies and output, once exceeding the free energy consumption quota, will need to purchase limited market quotas, leading to increased production costs. Conversely, if companies reduce production to lower costs, then their operating income will decrease, affecting their market competitiveness. It is clear that, regardless of which approach is taken, the energy-consuming right trading system indirectly forces companies to face cost pressures. This pressure may prompt companies to adjust their production models, employing advanced energy-saving technologies, equipment, and environmental management practices to enhance environmental performance. Secondly, from the perspective of transaction compensation, energy-consuming enterprises can buy or sell quotas based on actual conditions. When demand increases and supply is limited, quota prices will rise, adding to the costs of companies seeking additional quotas. Companies with higher energy-saving efficiency can profit by selling surplus quotas; when the quota price is low, they can purchase from the

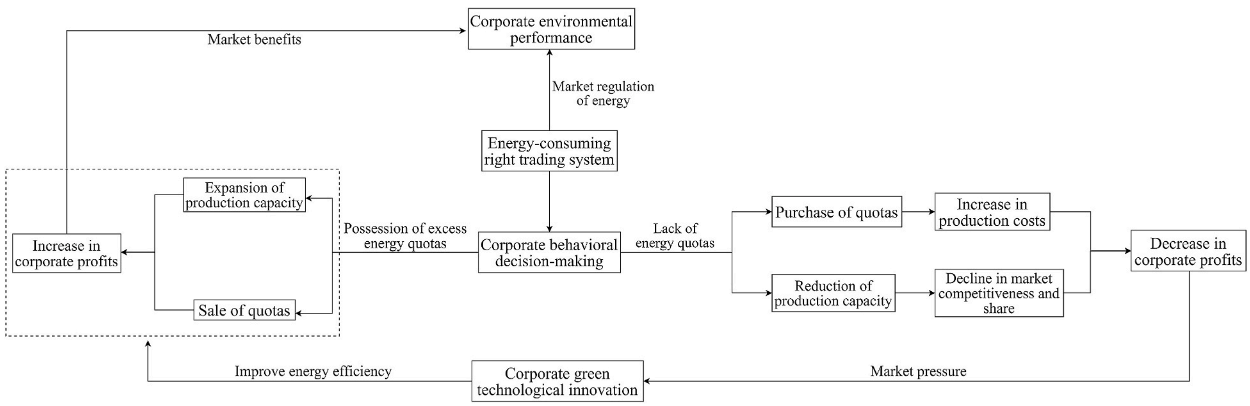


Fig. 1. Influence mechanism of the energy-consuming right trading system on corporate environmental performance.

market. If energy-consuming companies anticipate the quota trading price to rise, they may invest more in energy-saving technology [19]. Therefore, the energy-consuming right trading system incentivizes companies to increase revenue by selling quotas, thereby enhancing the impetus for companies to continue green production and form a virtuous cycle of profit. Based on the above analysis, this paper proposes the following theoretical hypothesis:

Hypothesis 1. The energy-consuming right trading system can improve corporate environmental performance through market regulatory functions.

Existing literature indicates that environmental rights trading systems can trigger green technology innovation activities, marked by green invention patents [20]. As a market-incentive-based environmental regulatory tool, the energy rights trading system could enhance corporate environmental performance through the promotion of green technology innovation (see Fig. 1). Driven by cost pressures, as long as the cost of green innovation or the introduction of clean energy equipment is lower than the revenue from selling energy rights plus the benefits brought by green technologies, companies have the motivation to increase R&D investment and advance green technology innovation. Through green technological innovation, companies can reduce energy consumption needed for daily production, thereby lowering the additional costs of purchasing energy rights and increasing profits. On the other hand, under the incentives of market transactions, green technology innovation can not only reduce a company's energy consumption but also potentially realize economic benefits by selling energy indicators that fall below the set quotas. Therefore, this paper proposes the following theoretical hypothesis:

Hypothesis 2. The energy-consuming right trading system can improve corporate environmental performance by promoting green technology innovation within enterprises.

3. Research and data methodology

3.1. Sample selection and data descriptions

This study selects industrial enterprises listed on the A-share market from 2012 to 2019 as samples, using the implementation year of the pilot energy-consuming right trading as the entry point, to explore the impact of the system on corporate environmental performance. Firstly, listed companies are required to regularly disclose high-quality financial and non-financial information, providing us with reliable data sources. Secondly, industrial listed companies cover an important part of China's economy, and their broad sector and industry representativeness make the research findings highly generalizable and applicable. Thirdly, since industrial companies are the main energy consumers and environmental polluters, analyzing the impact of the energy-consuming right trading system on these enterprises' environmental performance helps to assess the effectiveness of the policy and provides references for policy optimization and pilot expansion. Finally, listed companies, which are subject to stricter regulation, are more likely to follow the energy-consuming right trading system, providing conditions to study the impact of the system in a controlled environment.

In terms of data processing, this paper performed the following operations: (1) excluded samples from companies with ST, ST*, or those delisted; (2) eliminated records with missing or seriously inaccurate data; (3) to eliminate the influence of extreme values, tailoring was conducted for continuous variables at the 1 % and 99 % levels; (4) linear interpolation was used for a small amount of missing data.

The data on corporate environmental performance used in this paper originates from the manual collection and consolidation of listed companies' annual reports, social responsibility reports, and environmental reports. Data on corporate green innovation is sourced from the CNRDS database, whereas data for other variables comes from the Wind database and the CSMAR (Guotai An) database.

3.2. Empirical model design

In this study, we treat the implementation of this policy as a quasi-natural experiment and use the difference-in-differences (DID) method to analyze the effect of the energy-consuming right trading pilot on corporate environmental performance. The DID method, as one of the commonly used approaches to evaluate policy effects, can reveal differences under scenarios with and without policy implementation, assuming parallel trends in the treatment and control groups, and accurately measure the average treatment effect of the policy [21]. Corresponding to other related studies [10,11,16–18], we also employ this method to assess the effect of the energy-consuming right trading system on corporate environmental performance. Specifically, we divide the sample into treatment and control groups based on the timing and targets of policy impact, and by comparing the differences between the two groups before and after the implementation of the pilot system, we evaluate the net impact of the energy-consuming right trading system on corporate environmental performance. The baseline model is constructed as follows:

$$CEP_{it} = \beta_0 + \beta_1 ECRTS_{it} + \Sigma_{m=2}^{13} \beta_m Control_{it} + \mu_i + \tau_t + \varepsilon_{it} \tag{1}$$

Where i and t denote the company and year, respectively; μ_i represents individual fixed effects, which control for factors at the company level that are unaffected by time; τ_t represents time fixed effects, accounting for factors at the time dimension that do not change due to individual variations; ε_{it} is the error term. If the energy-consuming right trading system (ECRTS) coefficient β_1 is positive and statistically significant, it indicates that the energy rights trading system has improved corporate environmental performance.

3.3. Variable construction

3.3.1. Measurement of the main explanatory variable

The core variable discussed in this article is corporate environmental performance (CEP). The International Organization for Standardization (ISO) defines environmental performance as the outcomes of an organization's environmental behavior based on its environmental objectives and strategies. Trumpp et al. [22] systemically analyzed the various definitions of corporate environmental performance from 11 scholars and considered the ISO's definition to be the most appropriate to date. Corporate environmental performance is often viewed as a multidimensional structure. Scholars have long debated how to measure corporate environmental performance precisely and have designed various measurement methods, but no uniform criteria have been established yet [23].

Academic research commonly adopts quantitative or qualitative methods to measure corporate environmental performance. For the quantitative aspect, common metrics include environmental capital expenditure [24], environmental investment [25], and pollution emissions [26], among others. However, the data these metrics rely on are often difficult to obtain. Furthermore, the academic community has not yet formed a unified view on concepts such as environmental expenditure and investment, and there are discrepancies in the scope of related cost and expense data disclosed by companies [27]. On the qualitative side, Klassen and McLaughlin [28] evaluate environmental performance through the environmental awards that a company receives; Campos et al. [29] use a company's environmental violations as a proxy variable. However, these evaluation indicators are relatively singular and fail to fully reflect a company's environmental performance comprehensively.

Therefore, this article refers to Dragomir's [23] summary of the methods for measuring corporate environmental performance and combines it with the research on performance indicators by Henri and Journeault [30], dividing corporate environmental performance into three dimensions, which are further refined into 15 sub-indicators. As shown in Table 1, these indicators cover every phase of a company's operation, from early prevention, through the production process, up to end-stage governance. In the scoring process, this article introduces the content analysis method by Clarkson et al. [31] to convert qualitative descriptions into quantitative indicators, taking inspiration from the scoring method by Wang et al. [27]. This article quantified the information based on the principles of whether the information is disclosed (undisclosed or disclosed) and a combination of qualitative and quantitative factors, with scores ranging from 0 to 2 points. For instance, if a company disclosed information related to its environmental philosophy, it would score 1 point; if it did not disclose, it would score 0 points; and if further quantitative data on the information were provided, it would score 2 points. By adding up the scores of all sub-indicators, we calculated the total corporate environmental performance score for each company.

3.3.2. Setting of the dependent variable

The explained variable in this article is the energy-consuming right trading system (ECRTS). In the process of setting variables, we take the quasi-natural experiment formed by the energy-consuming right trading pilot policy in 2017 as a starting point, and according to the "Pilot Scheme for Paid Use and Trading of Energy Consumption Rights" issued by the State Council, we assign values to enterprises in various regions. If a province implemented the energy-consuming right trading system during that year, enterprises in that pilot area are assigned a value of 1, otherwise, the value is 0.

3.3.3. Selection of the mechanism variable

Corporate green innovation includes green innovation input and green innovation output. However, green innovation input is difficult to separate from corporate R&D expenditures. Compared to other indicators, green invention patents and green utility model patents entail more R&D investment and higher technical content, reflecting substantive green technological innovation outputs of enterprises [32]. Therefore, this article uses the logarithm of the sum of the number of green invention patent applications and the number of green utility model patent applications plus one as the measure of an enterprise's green innovation activities.

Table 1
Selection of environmental performance indicators and variable assignment.

Primary indicators	Secondary indicators	Variable assignment
Environmental strategy performance	Environmental protection concept	0~2
	Environmental goals	
	Environmental management system	
	Environmental education and training	
	Environmental incident response mechanism	
Environmental management performance	Environmental protection special action	
	Environmental petition situation	
	Environmental violations	
	Implementation of the "three simultaneous" system	
	Disclosure of environmental information in social responsibility reports	
	ISO14001 audit status	
Environmental governance performance	Emission of "three wastes" pollutants	
	Management of "three waste" pollutants	
	Cleaner production implementation	
	Environmental honors or awards received	

3.3.4. Selection of control variables

Due to the complexity of the factors affecting corporate environmental performance, to control the influence of other factors and alleviate the endogeneity problem caused by omitted variable bias, this study considers the impact of corporate performance, governance structure, and city conditions on corporate environmental performance based on previous research [33–36]. Therefore, this study has set a series of control variables in the model, including company size (Size), company age (Age), profitability (Roa), cash flow (Cash), growth ability (Growth), financial leverage (Leverage), Tobin's Q value (Tobin), board size (Board), proportion of independent directors (Indd), industrial structure (IS), economic development level (Econ), and population density (PD). Table 2 lists detailed information on these specific research variables.

4. Benchmark results and analysis

4.1. Descriptive statistics

The descriptive statistics for each variable are shown in Table 3. The average value of corporate environmental performance (CEP) is 4.34, indicating that the level of environmental governance is low for most enterprises. With a standard deviation of 3.86, there is a significant variation in environmental governance levels among enterprises. The average value for the energy-consuming right trading system (ECRTS) is 0.0667, showing that a smaller proportion of companies in the sample were operating under this policy during the study period. Fig. 2 displays the trend of changes in corporate environmental performance over time. It can be observed that before the policy shock point in 2017, although there were fluctuations in corporate environmental performance, the overall trend was relatively stable; after being impacted by the policy, corporate environmental performance grew compared to before the shock, with the overall change showing an upward trend. The variation in corporate environmental performance before and after the policy shock is consistent with the expectations of Hypothesis 1.

4.2. Difference-in-differences test results and analysis

Table 4 reports on the impact of implementing the energy-consuming right trading system on corporate environmental performance. Columns (1) and (2) show respectively the results of regression analysis on corporate environmental performance without and with control variables introduced. The results indicate that, regardless of the inclusion of control variables, the regression coefficients for the energy-consuming right trading system are significantly positive at the 1 % level, which proves that the implementation of the system has significantly improved corporate environmental performance in the pilot regions. After controlling for other variables that affect corporate environmental performance, the regression results in column (2) show that the estimated coefficient for the energy-consuming right trading system is 0.571, suggesting that compared to enterprises in non-pilot areas, the implementation of the system has increased the environmental performance score of enterprises in the pilot areas by an average of 0.571 units. Given that the range of changes in corporate environmental performance scores is between 2 and 23, an increase of 0.571 units represents an improvement of over 2.5 % of the potential score. Although this increase might seem small in isolation, when inferred within a broader context, the potential impact highlights the wider importance of this policy. Specifically, if the energy-consuming right trading system were implemented nationwide, this 2.5 % improvement could translate into substantial improvements for each enterprise. This would have profound effects on the environment, stakeholder trust, and the overall responsibility of businesses. The results from Table 4 essentially

Table 2
Descriptions of study variables.

Variable type	Variable name	Variable symbol	Variable definition and measurement
Explained variable	Corporate environmental performance	CEP	Overall score
Main explanatory variable	Energy-consuming right trading system	ECRTS	Enterprises in the pilot area in 2017 and beyond take the value of 1, otherwise 0
Mechanism variable	Green technological innovation	Gren	Natural logarithm of the sum of green invention patent applications and green utility model patent applications plus one
Control variables	Enterprise size	Size	Natural logarithm of total corporate assets
	Enterprise age	Age	Natural logarithm of the current year minus the year of incorporation of the listed company
	Profitability	Roa	Net profit/total assets
	Cash flow	Cash	Cash and cash equivalents balance/total assets at end of period
	Growth capacity	Growth	Operating income growth rate
	Financial leverage	Leverage	Total liabilities/total assets
	Tobin's Q	Tobin	Enterprise market capitalization/total assets
	Board size	Board	Number of directors
	Ratio of independent Directors	Indd	Number of independent directors/number of directors
	Industrial structure	IS	Value added of secondary industry/regional GDP
	Economic development level	Econ	Natural logarithm of per capita regional GDP
	Population density	PD	Natural logarithm of the ratio of permanent population to administrative land area of the region

Table 3
Descriptive statistics of the main variables.

Variables	Observations	Mean	Standard deviation	Min	Max
CEP	10,248	4.338	3.863	2	23
ECRTS	10,248	0.0667	0.250	0	1
Gren	10,248	0.593	1.008	0	4.394
Age	10,248	17.51	5.342	6	31
Size	10,248	13.06	1.270	10.64	16.79
Leverage	10,248	0.425	0.206	0.0551	0.941
Cash	10,248	0.144	0.111	0.0133	0.551
Roa	10,248	0.0227	0.0329	−0.0919	0.124
Growth	10,248	0.188	0.515	−0.530	3.510
Tobin	10,248	2.126	1.299	0.895	7.981
Board	10,248	8.677	1.714	5	15
Indd	10,248	0.374	0.0532	0.333	0.571
IS	10,248	0.429	0.108	0.165	0.659
Econ	10,248	11.33	0.535	9.968	12.58
PD	10,248	6.464	0.763	3.922	7.741

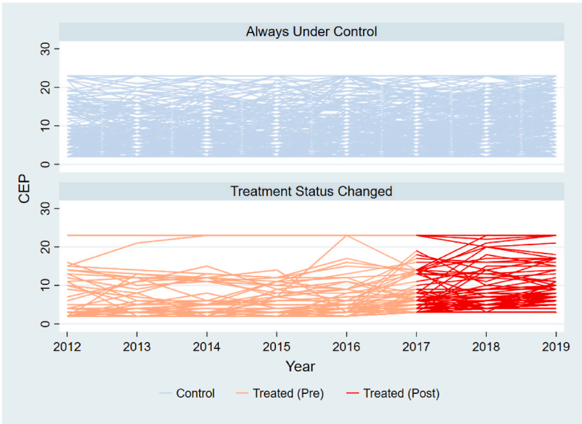


Fig. 2. Temporal dynamics of corporate environmental performance.

validate Hypothesis 1 of the article; the energy-consuming right trading system can indeed promote the improvement of environmental performance in pilot area enterprises.

4.3. Robustness tests

4.3.1. Parallel trend test

When applying the difference-in-differences (DID) model to evaluate the effects of a policy, it is necessary to ensure that before the policy shock, both the treatment group and the control group exhibit the same trend changes. This means that in the absence of the implementation of the energy-consuming right trading system, the trends in environmental performance for firms in both the treatment and control groups should be parallel. To verify this assumption, the article adopts the approach of Beck et al. [37], using a dynamic DID method to test for the dynamic effects of parallel trends. Building upon formula (1), the research model is constructed as follows:

$$CEP_{it} = \alpha_0 + \sum_{j=2013}^{2019} \alpha_j Treat_{i,j} + \sum_{m=1}^{12} \theta_m Control_{it} + \mu_i + \tau_t + \varepsilon_{it} \tag{2}$$

In this model, $Treat_{i,j}$ represents the interaction term between the treatment variable and the year, where enterprise i in the pilot region for the j th year equals 1, otherwise, it is 0. The coefficient α_j represents the difference between the pilot region and the non-pilot region in the j th year. This study takes the year 2012 as the baseline, meaning that in formula (2), the dummy variable for $j = 2012$ is excluded. Fig. 3 presents the graph of the dynamic effects test results for the energy-consuming right trading system, which plots the regression results under a 95 % confidence interval (see Appendix 1). It can be observed that when $j < 2017$, the regression coefficients α_j are not significant at the 5 % level, indicating that before the pilot implementation of the energy-consuming right trading system, there was no significant difference in environmental performance between companies in pilot and non-pilot areas. This satisfies the parallel trend assumption, thus justifying the use of the DID method in this paper. Upon further investigation into the dynamic effects

Table 4
Benchmark regression results.

Variables	CEP	
	(1)	(2)
ECRTS	0.515**	0.571***
	(0.198)	(0.195)
Age		0.058
		(0.056)
Indd		0.709
		(0.706)
Roa		0.078
		(1.066)
Cash		0.691*
		(0.398)
Size		0.347***
		(0.096)
Tobin		−0.015
		(0.026)
Board		0.036
		(0.033)
Leverage		−0.794***
		(0.276)
Growth		−0.045
		(0.057)
IS		−2.220
		(1.387)
Econ		−0.394*
		(0.223)
PD		0.176
		(0.294)
Constant	4.304***	2.717
	(0.013)	(3.371)
Individual fixed effect	Yes	Yes
Time fixed effect	Yes	Yes
Observations	10,248	10,248
R^2	0.816	0.818

Note: *P < 0.10, **P < 0.05, ***P < 0.01; robust standard errors are in parentheses.

after policy implementation, it is observed that the parameters α_{2017}, α_{2018}, and α_{2019} are all significantly positive at the 5 % level. This result suggests that the implementation of the pilot energy-consuming right trading system not only helps improve the environmental performance of enterprises but that the policy effect is also strengthening over time.

4.3.2. Placebo test

To distinguish whether the policy effects are genuinely caused by the implementation of the energy-consuming right trading system, or due to other factors, this study conducted a placebo test following the method of Bakke et al. [38]. In our data set, we randomly selected 300 firms to create a pseudo-treatment group while the remaining firms constituted the control group. Using the setting of formula (1), we performed 1,000 simulation regressions on this random sample. The placebo test results show that the

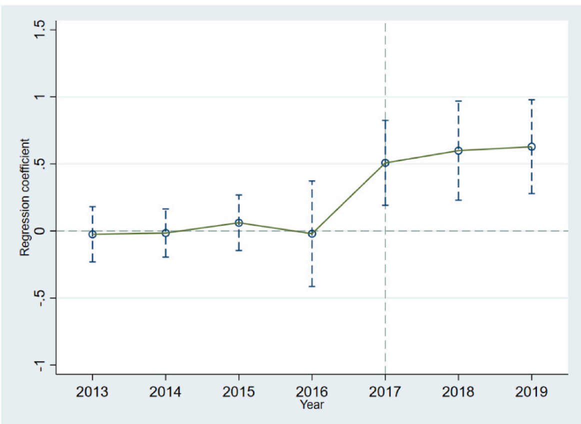


Fig. 3. Parallel trend test.

majority of the simulated coefficients are concentrated near zero, which significantly differs from the estimated coefficients of the baseline model (see Fig. 4). Furthermore, most of the simulated *P*-values exceeded 0.1, indicating that the results are not statistically significant. This finding suggests that the primary analytical results are not driven by inherent differences or omitted variables but are the direct effects of the implementation of the energy-consuming right trading system.

4.3.3. Propensity score matching test

Although the DID method can effectively evaluate policy effects, it may encounter sample selection bias in practice. For example, the differences in characteristics between the treatment and control group firms selected for this study could lead to endogeneity issues, which would interfere with the baseline regression results. To address this issue, this paper introduces the PSM-DID (Propensity Score Matching-Difference in Differences) method to reanalyze the relationship between the energy-consuming right trading system and corporate environmental performance. Before applying the PSM-DID method, we conducted a matching balance test to ensure that the observable characteristics of the treatment and control groups after matching were similar, to avoid the impact of pre-existing differences on the results. The balance test results show that the absolute value of the standard deviation of all covariates is less than 10 %, indicating no significant difference between the treatment and control groups (see Appendix 2).

The steps of applying PSM-DID include: (1) using whether a firm is in the pilot area as the dependent variable, and the control variables as independent variables to perform Probit regression for each period to calculate propensity scores; (2) during each year's regression period, performing caliper nearest-neighbor matching with a caliper width of 0.01, a matching ratio of 1:1, and according to the propensity scores, matching firms from the treatment group with those from non-pilot areas to construct the control group; (3) compiling the matched data for all years and using the DID model to re-estimate the matched sample. The PSM-DID test results show that the coefficient of the energy-consuming right trading system is still positive and significant at the 10 % significance level (see Table 5, column 1). This further confirms the reliability of the baseline results, indicating that the energy-consuming right trading system can effectively enhance corporate environmental performance.

4.3.4. Controlling for the impact of other policies

During the process of economic system reform in China, to achieve certain goals, a series of policies are often implemented simultaneously and in parallel. Before the pilot implementation of the energy-consuming right trading system, the National Development and Reform Commission (NDRC) launched pilot programs for low-carbon provinces and cities in 2010 and pilot programs for carbon emissions trading in 2011. These two pilot programs partially overlap geographically with the energy trading pilot, which may impact the results of this study. Therefore, to avoid the interference of the implementation of other policies on the conclusions of this study, this study conducted another regression analysis after removing the samples from the low-carbon province and city pilot and the carbon emissions trading pilot. Column (2) of Table 5 shows that the coefficient of the energy-consuming right trading system remains significantly positive at the 5 % significance level even after excluding the effects of other policies' implementation. This verifies the stability of the baseline regression results.

5. Extensibility analysis

5.1. Mechanism test

In the baseline model, previous text has already verified that the implementation of an energy rights trading system can significantly enhance the environmental performance of enterprises in pilot areas, and the pathways through which the energy-consuming right trading system takes effect have been sorted out in the theoretical analysis. Therefore, it becomes an important research question to explore whether the energy-consuming right trading system indeed promotes the improvement of corporate environmental performance through these paths. Based on the aforementioned theoretical analysis and referring to the mediating effects model proposed

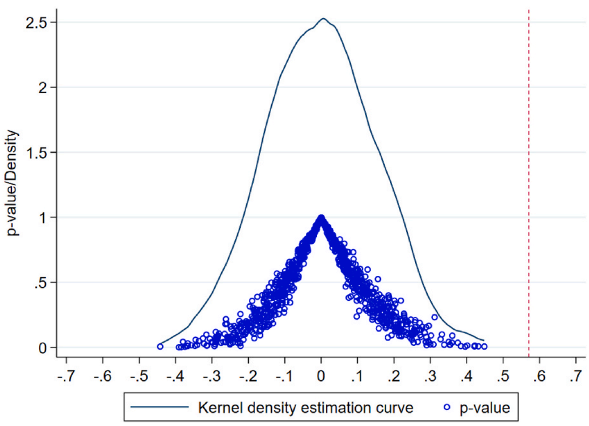


Fig. 4. Placebo test. Note: The red dashed line indicates the baseline regression coefficient of ECRTS (0.571).

Table 5
PSM-DID test and regression results after controlling for other policies.

Variables	CEP	
	(1)	(2)
ECRTS	0.530*	0.574**
	(0.271)	(0.206)
Constant	−1.666	0.774
	(7.130)	(4.315)
Control variables	Yes	Yes
Individual fixed effect	Yes	Yes
Time fixed effect	Yes	Yes
Observations	2,707	5,960
R-squared	0.827	0.806

Note: *P < 0.10, **P < 0.05, ***P < 0.01; robust standard errors are in parentheses.

by Baron et al. [39], this study examines the mechanism of action of the energy-consuming right trading system from the perspective of promoting green technology innovation. The specific model settings are as follows:

$$Gren_{it} = \beta_0 + \beta_2 ECRTS_{it} + \sum\nolimits_{m=3}^{14} \beta_m Control_{it} + \mu_i + \tau_t + \varepsilon_{it} \tag{3}$$

$$CEP = \beta_0 + \beta_3 ECRTS_{it} + \beta_4 Gren_{it} + \sum\nolimits_{m=5}^{16} \beta_m Control_{it} + \mu_i + \tau_t + \varepsilon_{it} \tag{4}$$

If β_2 in equation (3) is significant and both β_3 and β_4 in equation (4) are significant as well, this indicates that the energy-consuming right trading system promotes the enhancement of corporate environmental performance by influencing the mechanism variables. The mechanism test results, as shown in Table 6, contemplate whether the energy-consuming right trading system can improve corporate environmental performance through the promotion of green technology innovation. In column (1), the coefficient for the energy-consuming right trading policy is significantly positive, indicating that the energy-consuming right trading policy can significantly promote corporate technological innovation. In column (2), coefficients for both the energy-consuming right trading system and green technology innovation are significantly positive, suggesting that the energy-consuming right trading system can enhance enterprise environmental performance by means of green technology innovation, thereby validating Hypothesis 2. Overall, the energy-consuming right trading policy can significantly drive green technological innovation in enterprises, which in turn promotes corporate environmental performance through cost pressure and transaction compensation.

5.2. Heterogeneity analysis

5.2.1. Impact of the nature of enterprise ownership

This study classifies the sample enterprises according to their ownership nature into state-owned enterprises and non-state-owned enterprises and conducts separate regression analyses for both to examine the differentiated impact of the energy-consuming right trading system on the environmental performance of enterprises with different ownerships. The results from columns (1) and (2) of Table 7 indicate that the impact of the energy-consuming right trading system on the environmental performance of non-state-owned enterprises is more pronounced. For state-owned enterprises, despite a positive influence from the energy-consuming right trading system on their environmental performance, the effect is not significant. This empirical result supports the notion that the impact of the energy-consuming right trading system on enterprise environmental performance is mainly manifested in non-state-owned enterprises.

Table 6
Mediating effect test results.

Variables	(1)	(2)
	Gren	CEP
ECRTS	0.053*	0.567***
	(0.031)	(0.195)
Gren		0.081**
		(0.030)
Constant	−0.112	2.726
	(1.044)	(3.346)
Control variables	Yes	Yes
Individual fixed effect	Yes	Yes
Time fixed effect	Yes	Yes
Observations	10,248	10,248
R^2	0.749	0.818

Note: *P < 0.10, **P < 0.05, ***P < 0.01; robust standard errors are in parentheses.

5.2.2. Impact of enterprise asset structure

By dividing the sample into high-flexibility and low-flexibility asset structure groups according to the median ratio of enterprise net fixed assets to total assets, this study aims to test the differentiated impacts of the energy-consuming right trading system on the environmental performance of companies with different asset structures. Based on the test results of columns (3) and (4) of Tables 7 and it is observed that the regression coefficient for the high-flexibility asset structure group is 0.763, which is significant at the 5 % level, while the regression coefficient for the low-flexibility asset structure group is lower and not significant. This indicates that the impact of the energy-consuming right trading system on corporate environmental performance is mainly evident in companies with more flexible asset structures.

5.2.3. Impact of enterprise location

Considering that the regional characteristics where enterprises are located might affect the effectiveness of the energy-consuming right trading system, this paper divides the sample according to geographic distribution into the eastern, central, and western regions and conducts separate regression analyses for each region. As per the results in Table 8, the influence of the energy-consuming right trading system on the environmental performance of enterprises in all three regions—eastern, central, and western—is positive, but only the estimation coefficient for the eastern region is significant at the 1 % level, while the coefficients for the central and western regions are not significant and the coefficient for the eastern region is significantly higher than the others. These findings suggest that the impact of the energy-consuming right trading system on enterprise environmental performance is mainly concentrated in enterprises in the eastern region.

6. Discussion

The implementation of the energy-consuming right trading system in China is a key measure under the active promotion of ecological civilization construction and reform of the ecological civilization system. This system aims to leverage the market's central role in resource allocation through market-oriented methods, incentivizing enterprises to increase energy efficiency, reduce emissions, and promote transformation and upgrading. By reviewing the research in this paper, we found that the environmental performance of enterprises in pilot areas has significantly improved due to the implementation of the energy-consuming right trading system, confirming that the system can promote more environmentally friendly operations and more effective environmental management by enterprises. However, the research shows that the average environmental performance of enterprises in pilot areas only increased by 0.571 units, suggesting that the energy-consuming right trading system has not comprehensively enhanced environmental performance at the individual enterprise level, and its effects may be uncertain. The reasons might include: First, the system is still in the pilot phase in China, where the leading environmental regulatory policies are command-and-control and the marketization level is insufficient, affecting the efficiency of the system. Second, there are significant differences in quota allocation schemes among different pilot regions, such as Henan Province, which issues quotas for free, based on benchmark methods and historical total amounts, possibly leading to unfair initial distribution of quotas [40]. In contrast, Zhejiang Province's allocation method, which combines evaluation of output per mu, is more referential. Third, differences in technological innovation, management level, and geographical location among enterprises lead to varying production efficiencies; these efficiency differences may result in substantial variation in the benefits that the system brings to different enterprises [41].

Through mechanistic analysis, we found that enterprises primarily rely on green technological innovation to enhance environmental performance. This finding aligns with the Porter Hypothesis [42], which posits that market-based environmental regulation policies induce firms to pursue green innovation. Green technology plays a role in reducing the consumption of raw materials, lessening environmental pollution, and improving energy technology within enterprises [43]. The enhancement of innovation capabilities enables firms to implement green and clean production, which is beneficial for improving their environmental performance. Furthermore, technological innovation is the fundamental driver of industrial structure optimization and upgrading [44], which can optimize the allocation of energy resources through the upgrade of industrial structure, thereby reducing energy consumption. In this context, the vigorous development of the digital economy has led to the emergence of digital green innovations, accelerating the digital transformation and quality improvement of traditional manufacturing and benefiting substantial adjustments in regional economic

Table 7
Heterogeneity analysis regression results on the nature of enterprise ownership and asset structures.

Variables	(1)	(2)	(3)	(4)
	SOEs	non-SOEs	Low flexibility enterprises	High flexibility enterprises
ECRTS	0.045	0.088**	0.209	0.763**
	(0.052)	(0.036)	(0.204)	(0.318)
Constant	1.678	−1.153	16.815***	−5.724
	(1.829)	(0.818)	(5.250)	(3.815)
Control variables	Yes	Yes	Yes	Yes
Individual fixed effect	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes
Observations	4,249	5,255	4,149	5,972
R^2	0.817	0.720	0.845	0.808

Note: *P < 0.10, **P < 0.05, ***P < 0.01; robust standard errors are in parentheses.

Table 8
Regression results of regional distribution heterogeneity analysis.

Variables	(1)	(2)	(3)
	Eastern regions	Central regions	Western regions
ECRTS	0.778***	0.305	0.107
	(0.200)	(0.490)	(0.401)
Constant	3.350	2.672	−8.012
	(4.333)	(10.193)	(7.304)
Control variables	Yes	Yes	Yes
Individual fixed effect	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes
Observations	6,496	2,072	1,680
R^2	0.834	0.762	0.841

Note: *P < 0.10, **P < 0.05, ***P < 0.01; robust standard errors are in parentheses.

structures [45,46].

Our heterogeneity analysis indicates that, in comparison, the environmental performance of non-state-owned enterprises is more significantly affected by the energy-consuming right trading system. This phenomenon may relate to the unique institutional environment of China. With the reform towards a market economy, China has established a socialist market economy system which is dominated by the public economy, but coexists with various forms of ownership. Within this framework, Chinese enterprises have a unique ownership structure, where businesses operate independently in the market, but are owned by the state. This leads to different resource constraints faced by state-owned and non-state-owned enterprises [47], resulting in varying levels of response to the energy-consuming right trading system. State-owned enterprises typically have larger scales and more employees, and local governments have to consider factors such as political stability and employment security, in addition to promoting the pilot energy-consuming right trading system [16]; thus, their response to policy incentives tends to be slower. By contrast, non-state-owned enterprises are more flexible in decision-making, can adjust more rapidly to new policies, and are more sensitive to market changes. Driven by a stronger motive for profit, they are more willing to reduce energy consumption and transfer the surplus energy-use rights, which supports environmental goals and brings economic benefits. Additionally, our research finds that the positive impact of the energy-consuming right trading system on environmental performance is mainly evident in enterprises with flexible asset structures. In regions and enterprises with high energy consumption, their operational costs inevitably rise when local governments impose usage restrictions. The pollution haven hypothesis suggests that enterprises facing rising energy costs may relocate to regions with more relaxed environmental regulations [48], a hypothesis confirmed by research from Jin and Wang [49] in China. However, enterprises with flexible asset structures and strong adaptability to changes in environmental policies are able to quickly adjust production processes, invest in clean technologies, and improve environmental performance, thereby avoiding the need for relocation and other forms of regulatory evasion. Such enterprises often use their asset flexibility to comply with the energy-consuming right trading system to enhance environmental performance. The results also reveal that the impact of the energy-consuming right trading system on corporate environmental performance is more prominent in the eastern regions of China. This is because China is vast, with different regions having diverse resource endowments, geographical environments, national policies, and development orientations, leading to uneven development speeds and levels. This imbalance results in significant regional differences in environmental regulatory policies [50]. The eastern region is more economically developed, with stricter government regulation and richer human resources; thus, enterprises there are more likely to proactively reduce energy consumption and emissions, achieving better environmental performance under the energy-consuming right trading system.

Compared to previous studies [16–18], this research utilizes data from listed industrial companies in pilot areas to reveal the link between the energy-consuming right trading system and corporate environmental performance. Moreover, addressing the shortcomings in the literature [24–28], this study has refined the corporate environmental assessment indicator system, covering all aspects of enterprise operations from early prevention, the production process, to end-of-pipe treatment. Therefore, the marginal contributions of this study are mainly reflected in the following aspects: Firstly, it focuses on different aspects of corporate environmental performance, conducting a detailed analysis at the enterprise level, aiming to provide a reference for evaluating the effectiveness of the energy-consuming right trading policy and helping identify critical policy elements for improving environmental performance. Secondly, by exploring the multidimensional effects of the energy rights trading system on corporate environmental performance and its mechanisms, this study deepens the understanding of relevant policies and supports the development of the energy-consuming right trading market. Lastly, building upon previous research, this paper has improved the corporate environmental performance evaluation model, which will promote more accurate effect assessment and enhance the precision of research findings.

7. Conclusion and insights

7.1. Research conclusions

This study uses panel data from 1,281 listed industrial companies across China from 2012 to 2019 and employs a difference-in-differences approach to explore the impact and mechanisms of the pilot energy-consuming right trading system on corporate environmental performance using an improved corporate environmental performance assessment system. The research findings are as follows.

The study discovers that the energy-consuming right trading system can effectively enhance the environmental performance of enterprises in pilot regions, and this result is supported after conducting parallel trend tests, propensity score matching tests, placebo tests, and controls for other policy impacts. Analysis of the mechanisms finds that the promotion of corporate environmental performance by the energy-consuming right trading system is primarily achieved through fostering green technological innovation. Additionally, the heterogeneity analysis indicates that the energy-consuming right trading system has a significant effect on enhancing environmental performance for enterprises with high asset structure flexibility, while the effect is not significant for those with low asset structure flexibility. In terms of the nature of enterprise ownership, the system significantly improves the environmental performance of non-state-owned enterprises but does not show a significant effect on state-owned enterprises. Regarding geographic location, the system has a notable impact on improving the environmental performance of enterprises in the eastern regions, but the effect is not significant in the central and western regions.

7.2. Implications on theory and practice

As the pilot work of the energy-consuming right trading system continues to advance, the national level has successively introduced multiple supportive policies related to the energy-consuming right trading system, clarifying the importance of the energy-consuming right trading system in promoting high-quality development of social energy conservation and low carbon during the "14th Five-Year" period. The research work of this article has certain theoretical reference and practical application significance for the establishment and perfection of the national energy-consuming right trading system market in the future.

In terms of theoretical significance, compared with the previous single environmental performance evaluation of enterprises, this study has optimized the evaluation system for corporate environmental performance, making it more comprehensively reflect the environmental performance of enterprises. Then, based on this, it analyzed the impact of the energy-consuming right trading system on enterprise environment, thoroughly dissected the internal mechanism by which the energy-consuming right trading system enhances corporate environmental performance, and deepened the research on the policy effects of the energy-consuming right trading system. While assessing the impact of the energy-consuming right trading system on corporate environmental performance, it further examined the influence mechanisms and heterogeneity of the system.

In terms of practical significance, this study has examined the policy effects of the energy-consuming right trading system from the perspective of corporate environmental performance, providing a new angle for the study of the policy outcomes of environmental regulation policies, and offering experiential support for China to perfect the energy-consuming right trading system, further expand the scope of the energy-consuming right trading pilots, or even establish a nationwide unified energy-consuming right trading market. Additionally, this study has brought forth some enlightenments, detailed in the following three points.

(1) Based on the construction experience accumulated in the pilot areas of the energy-consuming right trading system, this study proposes suggestions for perfecting the mechanism design of the energy use rights trading. Results indicate that pilot areas have significantly improved the environmental performance of enterprises through energy-consuming right trading, demonstrating the great potential of market-oriented energy conservation and emission reduction policies in enhancing environmental performance. Therefore, it is imperative to rapidly absorb these experiences and insights, expand the scope of the pilot, cover more industries and areas, and realize comprehensive benefit enhancement for regions with high energy-saving potential. For the long-term effectiveness and successful implementation of the system, it is necessary to refine the allocation of indicators, trading scales, types, and methods, and to continuously optimize regulatory mechanisms to enhance regulatory efficacy, legalize the processes to increase the authority of transactions. Furthermore, we should respect the basic laws of the market economy, play the leading role of the market in energy conservation and emission reduction, strive to build a unified national energy-consuming right trading market to promote market vitality and liquidity, and drive enterprises towards sustainable green practices.

(2) Formulate differentiated pilot policies for energy-consuming right trading to enhance the effectiveness of policy implementation. The study finds that the effectiveness of the energy-consuming right trading system varies among different enterprises and regions. For enterprises with relatively fixed asset structures, the government could offer R&D subsidies or tax incentives to stimulate market activity, and consider more flexible regulatory frameworks to help these companies gradually adapt to energy-consuming right trading. For state-owned enterprises, they could be encouraged to actively participate by incorporating environmental performance into the performance assessment system or increasing the weight of energy conservation and consumption reduction in evaluations, promoting their transformation and upgrading. At the same time, the government should encourage enterprises in the central and western regions, especially those with considerable potential for energy saving, to develop in conjunction with new energy, cutting-edge technology, new business models, and to utilize digital economy, integrating big data and artificial intelligence to revamp production methods and optimize energy consumption. In general, the government should continuously adjust the design of the market trading mechanism based on a comprehensive assessment of regional industrial structure, project layout, and energy use situation, and propose characteristic energy-consuming right trading policies according to local actual conditions, resource endowments, and industrial characteristics.

(3) While promoting the energy-consuming right trading system, it is also necessary to guide enterprises in green technological innovation. Compared with traditional energy sources, investing in the R&D of clean energy technologies, infrastructure construction efforts, and promotion and popularization require substantial financial support and a longer return period, which might cause some companies and investors to hesitate or feel higher risk at the initial stage. Moreover, updating technology and

equipment means a transformation of the entire industrial chain, even corporate culture and business philosophy, requiring time to adapt and stabilize. Therefore, the government and relevant departments need to provide more guidance and support, such as financial subsidies, tax incentives, low-interest loans, and technical R&D funding assistance, etc. They could also enhance publicity and education to improve public understanding and acceptance of environmentally friendly products, thus creating a better social and market environment for green transformation.

7.3. Deficiencies and future prospects

Due to limitations in data availability and calculation methods, this study has the following deficiencies: (1) In terms of data selection, the study is limited by the fact that the most recent information from the "China Enterprise Database" is only updated to before the implementation of the pilot policy, compelling reliance on data from listed industrial companies. This leads to a sample that cannot fully represent the overall situation of China's industrial enterprises, especially the numerous non-listed companies. (2) The research mainly explored the internal pathways of corporate green technology innovation as an intermediary factor affecting corporate environmental performance, but it did not cover other potential influencing factors, such as government support and the policy implementation environment. This may affect the comprehensiveness of the analytical results, and future studies could consider these factors to enrich the current conclusions. (3) As the energy-consuming right trading market is still in its early stages of development, relevant indicators are extremely scarce. The degree of marketization significantly affects the effectiveness of the energy-consuming right trading system. Future research needs to explore how marketization affects corporate environmental performance and examine how the scale of the energy-consuming right trading market impacts corporate environmental performance.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Hongyuan Shen: Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **Panyu Xiong:** Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization, Writing – review & editing. **Ling Zhou:** Resources, Formal analysis, Data curation, Investigation.

Declaration of competing interest

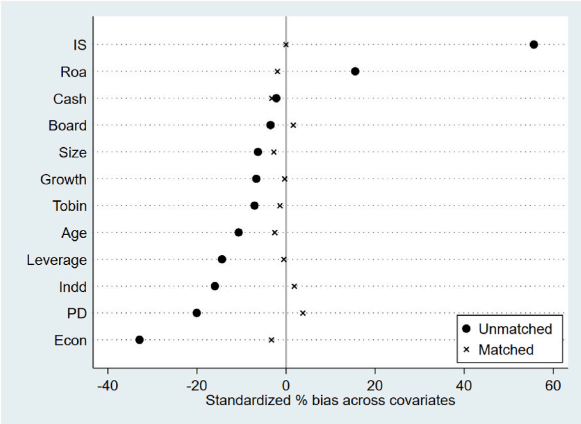
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendices.

Appendix 1
Parallel trend test

Variables	CEP
2013	−0.054
	(0.101)
2014	−0.044
	(0.088)
2015	0.032
	(0.101)
2016	−0.049
	(0.193)
2017	0.479***
	(0.155)
2018	0.570***
	(0.181)
2019	0.600***
	(0.171)
Constant	2.804
	(3.418)
Control variables	Yes
Individual fixed effect	Yes
Time fixed effect	Yes
Observations	10,248
R^2	0.818

Note: *P < 0.10, **P < 0.05, ***P < 0.01; robust t-statistics in parentheses.



Appendix 2. Standardized bias of matching variables.

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