Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 28 February 2023
DOI 10.3389/fenvs.2023.1123608

The improvement of energy-consuming right trading policy on the efficiency of urban green development

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

RECEIVED 15 December 2022
ACCEPTED 15 February 2023
PUBLISHED 28 February 2023

CITATION
Guo B, Hu P, Zhang H, Weng X and Hu F (2023), The improvement of energy-consuming right trading policy on the efficiency of urban green development. *Front. Environ. Sci.* 11:1123608.
doi: 10.3389/fenvs.2023.1123608

As a measure to promote the reform of China's ecological civilization system, the energy-consuming right trading policy has great potential to reduce pollutant emissions and achieve green development in China. Based on the panel data of 254 cities in China from 2005 to 2019, this paper uses difference-in-differences (DID) model and super-efficiency slacks-based measure (Super-SBM) to investigate the impact of energy-consuming right trading policy on the efficiency of urban green development. The findings are as follows. i) The energy-consuming right trading policy can significantly promote the efficiency of urban green development. The conclusion still holds after a series of robustness tests. ii) The energy-consuming right trading policy can improve the efficiency of urban green development by promoting green technology innovation. This finding supports the Porter Hypothesis. iii) Heterogeneity analysis shows that the energy-consuming right trading policy can significantly improve the green development efficiency of cities in the eastern region. On the contrary, there is no significant effect on the green development efficiency of cities in the central and western regions. The government should expand the scope of energy-consuming right trading policy implementation according to local conditions. At the same time, the government should also stimulate enterprises to innovate green technologies and maximize the effect of the energyconsuming right trading policy on the efficiency of green development.

KEYWORDS

energy-consuming right trading policy, green development efficiency, DID, green technology innovation, China

1 Introduction

Since the reform and opening up, China's economy has developed rapidly and made great achievements. However, the early crude economic development model with high energy consumption, high emissions, and high pollution has caused severe environmental and ecological damage. The deterioration of the ecological environment has exacerbated the conflict between economic development and environmental protection, which constrained the sustainable development of China's economy. At present, China's economy has entered the stage of high-quality development. So, the economic growth model with high energy consumption needs to be changed. It is urgent to explore a high-quality development way that balances economic and environmental benefits (Cheng et al., 2017). The 19th National

Congress of the Communist Party of China proposed to adhere to green development, which is significant in solving development problems. The 20th Party Congress indicated the necessity of promoting green development and accelerating the transformation of the development mode. In this context, appropriate and effective environmental policy tools are one of the most effective ways to promote green development.

The current environmental regulatory policy in China can be broadly divided into command-and-control and market-incentive environmental policies (Xiong et al., 2020). Command-and-control environmental policies have long dominated environmental regulatory policy in China. The command-and-control environmental policy mainly uses legal and administrative means to set environmental standards and punish violators for protecting the environment. In recent years, market-incentivized environmental policies have gradually emerged to accelerate the green transformation of the development approach, such as the emissions trading system, carbon emissions trading policy, and energy-consuming right trading policy. The energy-consuming right trading policy strengthens pollution source control by limiting energy consumption, which is an institutional innovation in the practice of green development (Xue and Zhou., 2022). However, the policy has been implemented for a short period and the role of the energy-consuming right trading policy on green development still needs to be clarified. The research on the energy-consuming right trading policy still needs to be improved. Therefore, it is of great theoretical and practical significance to investigate the impact of the energy-consuming right trading policy on the efficiency of green development. This paper fills the gap of related studies and can provide references for the development and improvement of the policy.

2 Literature review

Two main types of literature are closely related to this paper. The first category of literature focuses on the efficiency of green development. Green development is characterized by three dimensions: Status, speed, and efficiency (Che et al., 2018). The critical point to achieving green development lies in improving the efficiency of green development (Liu et al., 2019). The available literature on green development efficiency has focused on two main aspects. One focuses on the regional differences in green development efficiency (Yang et al., 2015; Li et al., 2021). The second focuses on the relationship between social or economic variables and green development efficiency, including the relationship between variables such as industrial agglomeration (Chen M. et al., 2022), technological innovation (Zhu et al., 2022), capital mismatch (Yang et al., 2022), and land price distortion (Lyu et al., 2022) and green development efficiency. Environmental regulation policy, as the main means of government environmental governance, has attracted more and more attention from scholars. Research on the relationship between environmental policies and green development efficiency has become increasingly abundant. Huang and Wu (2020) argue that the impact of environmental regulatory policies on the efficiency of green development is in a "U" shape that inhibits and then promotes. Wu et al. (2020) argue that different environmental regulatory policies affect the efficiency of green development differently. With the introduction of many environmental regulatory policies, scholars have begun to analyze the impact of specific environmental policies on green development. Fan et al. (2019) used a four-dimension dynamical system to find a robust beneficial role of environmental tax on green development. Lan (2021) used the DID model to assess the impact of the low-carbon city pilot policy on green development efficiency. The study found that the policy significantly improved the green development efficiency of cities. Zhu et al. (2020) believed that the carbon emissions trading policy has significantly improved the efficiency of green development. As a major initiative to promote the reform of China's ecological civilization system, the energy-consuming right trading policy plays a vital role in promoting green development. The policy has been implemented for a short period, so there has been no literature to investigate the impact of the energy-consuming right trading policy on green development efficiency.

The second category of literature is the studies on the energy-consuming right trading policy. The energy-consuming right trading policy is currently only implemented in some regions of China. Although there is no energy-consuming right trading policy in other countries, the white certificate scheme in European countries is similar. Transue and Felder. (2010), Stede (2017), Franzò et al. (2019), and Meran and Wittmann. (2012) demonstrate the vital role of the white certificate scheme in promoting environmental protection and energy utilization from the cost, energy efficiency, and environmental perspectives, respectively. China's social and economic conditions are different from those of European countries. So, the policy effects of the energy-consuming right trading policy still need to be tested empirically. The effects of energy-consuming right trading policy have been empirically analyzed in the literature at macro, meso, and micro levels. At the macro level, Wang et al. (2021) analyzed the impact of the energy-consuming right trading policy on energy consumption with provincial data. Liu and Wang (2019) used the non-parametric Data Envelopment Analysis (DEA) approach to analyze the economic dividends of the energy-consuming right trading policy at the provincial level. At the meso level, Wang et al. (2019) analyzed the economic and energy-saving potential of different industries under the effect of energy-consuming right trading policy. At the micro level, Zhang and Chen (2023) demonstrated the role of the energy-consuming right trading policy in promoting green innovation at the firm level. Luo and Zhang (2021) compared the Porter Effect of command-and-control policies and the energy-consuming right trading policy from a firm perspective.

A review of the existing literature shows that there is still room for improvement in research on the energy-consuming right trading policy. 1) The existing literature has fragmented the relationship between economic development and environmental protection. Studies have yet to consider the economic and environmental impacts of the energy-consuming right trading policy in an integrated manner. Based on this, this paper investigates the impact of the energy-consuming right trading policy on the efficiency of urban green development from a green development perspective. This paper also explores its transmission mechanism. On the one hand, the paper enriches the empirical evidence on whether market-incentivized environmental policies can balance economic and environmental effects. On the other hand, this paper expands the focus point of the energy-consuming right trading policy to deliver policy dividends. 2) Most studies have analyzed the effects of the energy-consuming right trading policy at the province, industry, or enterprise level. These studies ignored the important role of cities in policy implementation. This paper extends the research horizon and fills in the gaps in existing studies by focusing the research sample at the city level.

This paper analyzes the impact of the energy-consuming right trading policy on green development efficiency and its impact mechanism. Moreover, the paper investigates the regional heterogeneity of the policy effects. Finally, targeted suggestions are made for implementing and improving the policy.

3 Policy background and research hypothesis

3.1 Policy background

Since the 1990s, the global economic situation has undergone profound and dramatic changes. With global warming, severe environmental pollution, and the intensifying conflict between the supply and demand of resources and energy, countries are facing new challenges in development. Resources and the environment are increasingly becoming important constraints on the development of countries. China has begun to gradually use market mechanisms to solve environmental problems in order to promote the reform of the ecological civilization system and accelerate green development. The Chinese government issued the General Plan for the Reform of the Ecological Civilization System in 2015, which proposed implementing the energy-consuming right trading policy for the first time. In 2015, China's 13th Five-Year Plan proposed to establish a sound system for the initial allocation of energy consumption rights, water use rights, and carbon emission rights.

In 2016, the National Development and Reform Commission (NDRC) released the Pilot Program of the Paid Use and Trading Policy of Energy-consuming Rights. It officially proposed to carry out the pilot work of the energy-consuming right trading policy in four provinces, namely, Zhejiang, Fujian, Henan, and Sichuan. Specifically, The pilot areas determine the total energy consumption of each city according to the total energy consumption issued by the state and the local development status. The initial energy consumption quotas, or the energy-consuming right, are allocated to energy-consuming units by industry according to the city's total energy consumption target. The energy-consuming right within the quotas is free of charge, and the energy consumption beyond the quotas is paid for. Energy-consuming units can trade the energy rights they had in the trading market. The government of the pilot region determines the initial trading price of energy-consuming rights. Then it gradually transitioned to the transaction price formation by the trading parties' pooled bidding. The government will impose administrative penalties on units that consume more energy than they have energy consumption quotas and include them in the list of defaulting enterprises. The policy was implemented in these four provinces in 2017. Henan Provincial Government clearly pointed out that the pilot will only be launched in four cities or areas, namely, Zhengzhou, Hebi, Pingdingshan, and Jiyuan. Except for Henan Province, the other three pilot provinces have carried out pilot programs across the whole province. By 2019, the cumulative transaction volume of the environmental rights category, including energy-consuming rights transactions, exceeded 26 billion yuan. The pilot of the energy-consuming rights trading policy has achieved some achievements. Therefore, it is necessary to evaluate the policy effects of the energy-consuming rights trading policy.

3.2 Research hypothesis

According to the theory of Coase (1960), if property rights are clear, the market will internalize the externality to achieve the optimal allocation of resources. Compared with the low energy-consuming enterprises, the high energy-consuming enterprises will produce more emissions, which is not conducive to the efficiency of green development (Chen and Zhu, 2022). The energy-consuming right trading policy can endogenize the externalities generated by energy consumption to increase the production cost of high energy-consuming enterprises. Ultimately, energy saving and emission reduction are achieved through the market mechanism to improve the efficiency of green development. If a company's energy consumption exceeds the limit, the company needs to buy more energy-consuming rights. That can result in additional corporate costs for companies. Conversely, if energy consumption is below the limit, companies can sell their excess energy-consuming rights in the market to increase their profits. On the one hand, enterprises will reduce energy consumption by adjusting the scale of production or improving energy efficiency to reduce additional costs (Wang et al., 2019). On the other hand, the enterprise will reallocate investment capital to introduce high-efficiency production equipment under the profit incentive (Li and Bin, 2022). Thus, the efficiency of green development will be improved. Based on the above analysis, this paper proposes the Hypothesis 1.

Hypothesis 1: The energy-consuming right trading policy can improve the efficiency of green development through market mechanisms.

According to the Porter Hypothesis (Porter, 1996), The energy-consuming right trading policy can stimulate firms to innovate or introduce new technologies. The emergence of new technologies can offset the additional costs of the policy and promote economic growth. With the implementation of the energy-consuming right trading policy, excessive energy consumption will increase costs and reduced energy consumption will increase profits. With the double incentive of cost and profit, enterprises will get more benefits from green technology innovation. The additional benefits will induce them to make green technology innovations and increase their investment in green technology innovation (Shen and Chen, 2020). On the one hand, the increased investment can direct resources to shift from highly polluting industries to green industries. On the other hand, the results of green technology innovation can change production processes and reduce governance costs (Guo et al., 2023). Companies can use new technologies to save energy and reduce emissions (Chen and Li, 2023), thus promoting green development efficiency. Based on this, this paper proposes Hypothesis 2.

Hypothesis 2: The energy-consuming right trading policy can improve the efficiency of green development by promoting green technology innovation.

For many reasons, the different location conditions and natural endowments of different regions in China have led to large differences in economic and social development (Han and Zhou, 2022). On the one hand, compared with the central and western regions, the eastern region is more market-oriented. Therefore, energy-consuming rights trading in the eastern region is more efficient, and the market incentive effect of the energy-consuming trading policy is more significant. On the other hand, the eastern regions tend to pay more attention to technological innovation and hold a better foundation for green innovation (Hu et al., 2023). Therefore, the eastern region has more advantages in technological innovation. This policy can significantly improve the efficiency of green development through technological innovation. Based on this, this paper proposes Hypothesis 3.

Hypothesis 3: Compared with the central and western regions, the energy-consuming trading policy can more significantly improve the efficiency of urban green development in the eastern region.

4 Data sources, variables, and models

4.1 Data sources

Our study sample contains 254 prefecture-level and above cities in China from 2005 to 2019. The data are mainly acquired from China City Statistical Yearbook, China Energy Statistical Yearbook, China Statistical Yearbook, and EPS database. The number of green patent applications is based on the International Patent Classification (IPC) green list codes issued by the World Intellectual Property Organization (WIPO) and compiled from the patent application information provided by the State Intellectual Property Office of China.

4.2 Model selection

4.2.1 Super-SBM model

Because of the superiority of the Data Envelopment Analysis (DEA) method in avoiding subjective factors and reducing errors, this paper uses this method to construct green development measurement indicators. However, the traditional DEA model ignores the undesired output, which may lead to a large error in the measured results. This paper refers to the super-SBM model based on slack variables proposed by Tone (2002). After adding the undesirable output, this paper builds the following model.

$$min\,\rho = \frac{1 - \frac{1}{N}\sum_{n=1}^{M}\frac{{s_n}^{x-}}{x_{nk}}}{1 + \frac{1}{D+I}\left(\sum_{d-1}^{D}\frac{y_d}{y_{dk}} + \sum_{i=1}^{I}\frac{b_i}{b_{ik}}\right)} \quad (1)$$

$$s.t.\begin{cases} X\lambda + s^{x-} = x_k \\ Y\lambda - s^{y+} = y_k \\ B\lambda + s^{b-} = b_k \\ \lambda \geq 0.s^{x-}, s^{y+}, s^{b-} \geq 0 \end{cases}$$

Where N represents the number of observations. s^{x-} represents the slack value of inputs. s^{y+}, and s^{b-} represent the slack values of desired and undesired outputs, respectively. x_{nk} denotes the input n of city k. y_{dk} represents the desired output d of city k and b_{ik} represents the undesired output i of city k. ρ represents the efficiency of green development.

4.2.2 DID model

By comparing the net effects of the treatment and control groups, the DID method can effectively identify the causal effects of external policy shocks. This paper regards the energy-consuming trading right policy as a quasi-natural experiment. The first pilot cities of the energy-consuming trading right policy will be the treatment group, and the rest of the cities will be the control group. The DID model is set as follows.

$$gde_{it} = \beta_0 + \beta_1 treat_i \times post_t + \gamma X_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (2)$$

i and t represent city and year, respectively. gde_{it} represents the green development efficiency of city i in year t. $treat_i$ is the policy dummy variable, and the value is 1 for the pilot city of energy-consuming right trading policy; otherwise, it is 0. $post_t$ is the time dummy variable. It is assigned to 1 in the year after the implementation of the energy-consuming right trading policy; otherwise, it is assigned to 0. $treat_i \times post_t$ is the interaction item of $treat_i$ and $post_t$. X_{it} is the control variable. μ_i represents the city fixed effect. δ_t represents the year fixed effects. ε_{it} is the random error term.

4.2.3 Parallel trend test model

A critical prerequisite for using the DID method is that the parallel trend assumption is satisfied. The following model is constructed to test whether the sample selected in this paper satisfies this assumption.

$$gde_{it} = \theta_0 + \theta_j \sum_{j=-5, j\neq -1}^{2} treat_i \times year_j + \alpha X_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (3)$$

θ_j represents the estimated coefficient of energy-consuming right trading policy before and after the policy implementation. If the difference between the sample year and the policy occurrence year is j, $year_j$ takes the value of 1; otherwise, it takes 0. In addition, this paper takes the year before the policy implementation as the base year to avoid the effect of cointegration. The remaining variables are the same as described in the DID model.

4.2.4 Mechanism test model

Referring to Baron and Kenny. (1986), this paper constructs the following model to explore the intrinsic influence mechanism.

$$M_{it} = \varphi_0 + \varphi_1 treat_{it} \times post_{it} + \tau X_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (4)$$

$$gde_{it} = \vartheta_0 + \vartheta_1 treat_i \times post_t + \beta_3 M_{it} + \omega X_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (5)$$

Where M_{it} is the intermediary variable, and the rest variables are defined in the same Eq. 2.

4.3 Variable's selection

4.3.1 Explained variable

This paper constructs the indicators of urban green development efficiency in three dimensions: input indicators, desired output indicators, and undesired output indicators, referring to the study of Lan (2021).

(1) Input indicators. Labor, energy and capital are taken as input indicators. Labor input is measured by the number of urban units employed at the end of the year. Referring to Sui and Zhang (2022), the energy input can be measured by multiplying the total energy consumption of the whole province by the proportion of enterprises above the designated size in the city and enterprises above the designated size in the whole province. Capital input is measured by the urban capital stock calculated by the perpetual inventory method. Referring to the research of Zhang et al. (2004), the calculated value of 9.6% is taken as the depreciation rate of fixed capital.
(2) Desired output indicators. Desired output is measured by GDP *per capita* and deflated by the GDP deflator to remove the effect of price changes.
(3) Undesired output indicators. Industrial waste gas, industrial wastewater, and industrial dust emissions are taken as undesired outputs.

In this paper, the above variable indicators are taken into the super-SBM model with the help of MaxDEA software to calculate the urban green development efficiency index.

4.3.2 Explanatory variable

The core explanatory variable is the energy-consuming right trading policy ($treat_i \times post_t$). The value is 1 for cities that have already implemented the energy-consuming right trading policy; otherwise, it is 0.

4.3.3 Mechanism variable

The mechanism variable is green technology innovation (*gti*). Referring to the study of Zhang and Chen (2023), green technology innovation is measured by the number of green patent applications plus one and taking the natural logarithm.

4.3.4 Control variables

This paper selects the following control variables to control the influence of other factors on the efficiency of green development, referring to the existing literature. 1) Population size (*pop*) is measured by the logarithm of the city's total population at the end of the year. Increased demand for transportation and housing due to population agglomeration usually increases environmental pollution (Chen Y. et al., 2022). Therefore, the increase in population size is not conducive to the improvement of urban green development efficiency. 2) The level of urbanization (*urban*) is measured by the proportion of the urban population to the total population. Urbanization can lead to industrial agglomeration and population aggregation, which ultimately affects the efficiency of urban green development (Yang, 2022). 3) Referring to the research of Huang and Wu (2019), the degree of openness to the outside world (*rofe*) is measured by the share of actual foreign capital used in fixed assets. Foreign investment can improve green production efficiency through technology spillover and may introduce highly polluting enterprises into the local area. The degree of foreign development has an unknown impact on the efficiency of urban green development. 4) The rate of economic development (*ggdp*) is measured by the GDP growth rate of each city. The economic development level of a region is relevant to local environmental pollution, which in turn affects the efficiency of urban green development (Shi et al., 2019). 5) Industrial structure (*idst*) is measured by the ratio of industrial output to GDP. Industrial restructuring is a key factor affecting green development, which will change production methods (Li and Su, 2016). The impact of industrial structure on the efficiency of urban green development is unknown. 6) Referring to the research of Tian et al. (2022), the degree of urban economic prosperity (*depc*) is measured by the logarithm of total social retail sales. Higher urban economic prosperity areas are more economically developed, and people have better environmental protection awareness, so urban green development is more efficient. The descriptive statistics of the variables involved in this paper are shown in Table 1.

TABLE 1 Descriptive statistics of variables.

VAR	Obs	Mean	Std.Dev.	Min	Max
gde	3,810	0.1661	0.1785	0.0023	3.3000
treat × *post*	3,810	0.0315	0.1747	0.0000	1.0000
izs	3,810	1.3729	0.7036	0.2435	10.6026
gti	3,810	3.6142	1.8487	0.0000	9.1145
idst	3,810	48.0465	10.4121	10.6800	90.9700
urban	3,810	49.6786	16.4691	3.8247	100.0000
pop	3,810	5.9287	0.6148	3.3925	7.3132
rofe	3,810	0.0293	0.0335	0.0000	0.2574
depc	3,810	5.992	1.087	−3.738	9.165
ggdp	3,810	10.9433	4.9261	−12.3000	109.0000

5 Empirical results and analysis

5.1 Main results

This paper uses the DID model for regression to explore the impact of the energy-consuming right trading policy on the efficiency of urban green development. The regression results are shown in Table 2. Column (1) shows the regression results without control variables. Column (2) shows the regression results after adding the control variables. The regression coefficients of the energy-consuming right trading policy are significantly positive at the 1% level regardless of whether the control variables are added or not. The results show that the energy-consuming right trading policy significantly improves the efficiency of urban green development. Hypothesis 1 of this paper is verified.

TABLE 2 Effects of the energy-consuming right trading policy on the efficiency of urban green development.

VAR	*gde*	
	(1)	(2)
treat × *post*	0.0314*** (2.8750)	0.0325*** (2.9817)
idst		0.0001 (0.1295)
urban		−0.0014*** (−4.3242)
pop		−0.1165*** (−3.6535)
rofe		0.0810 (0.9432)
depc		−0.0070 (−0.8683)
ggdp		−0.0002 (−0.5158)
Constant	0.1475*** (23.9419)	0.9097*** (4.8531)
year	YES	YES
city	YES	YES
Observations	3,810	3,810
R^2	0.088	0.097

Note: 1) ***, **, * represent significance at 1%, 5% and 10% confidence level, respectively; 2) *T*-values are in parentheses. The following table is the same.

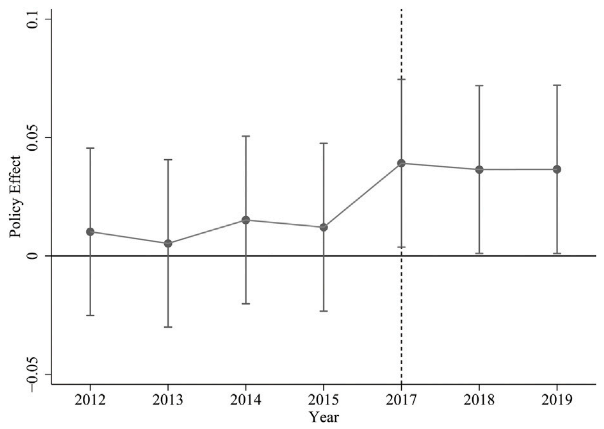

FIGURE 1
Parallel trend test graph.

In terms of control variables, the estimated coefficients of industrial structure, the degree of urban economic prosperity, and the rate of economic development are not significant. The results show that the above variables have no significant effect on the efficiency of urban green development. The estimated coefficient of urbanization level is significantly negative, which indicates that urbanization inhibits the efficiency of urban green development. This paper argues that the reason is that urbanization in China is mainly population urbanization (Zheng et al., 2018). Population agglomeration increases the pressure on urban resources and environment, which inhibits the efficiency of green urban development. The estimated coefficient of population size is significantly negative at the 1% level. This paper suggests that the excessive population size increases the pressure on urban ecology and inhibits the efficiency of urban green development.

5.2 Robustness tests

5.2.1 Parallel trend test

Figure 1 shows the results of the parallel trend test. The coefficients of the energy-consuming right trading policy were insignificant in any of the 4 years before the policy was implemented. The results indicate no significant difference in green development efficiency between the pilot and non-pilot cities before the policy implementation. The parallel trend hypothesis is satisfied. After implementing the energy-consuming right trading policy, the coefficient of the energy-consuming right trading policy is significantly positive. The results indicate that the energy-consuming right trading policy significantly improves the efficiency of urban green development.

5.2.2 Placebo test

This paper conducted a placebo test to ensure the accuracy of the policy effect assessment. Referring to Li et al. (2015) and Lu et al. (2021), this paper randomly selects pilot cities and randomly generates pilot time of the energy-consuming right trading policy to construct a sham experimental group. Then this paper regresses the sham treatment group according to the DID model. After repeating the above process 1,000 times, the reliability of the main regression results was determined based on the distribution of the regression coefficients. The main regression results are reliable if the estimated coefficients are distributed around 0. Otherwise, it indicates that other omitted variables severely confound the main regression results. The regression results of the sham experiment are shown in Figure 2. The results show that the estimated coefficients of the energy-consuming right trading policy are concentrated around 0 and follow a normal distribution. The above results indicate that there are no serious omitted variables in the model setup. The analysis passed the placebo test, and the main finding is robust.

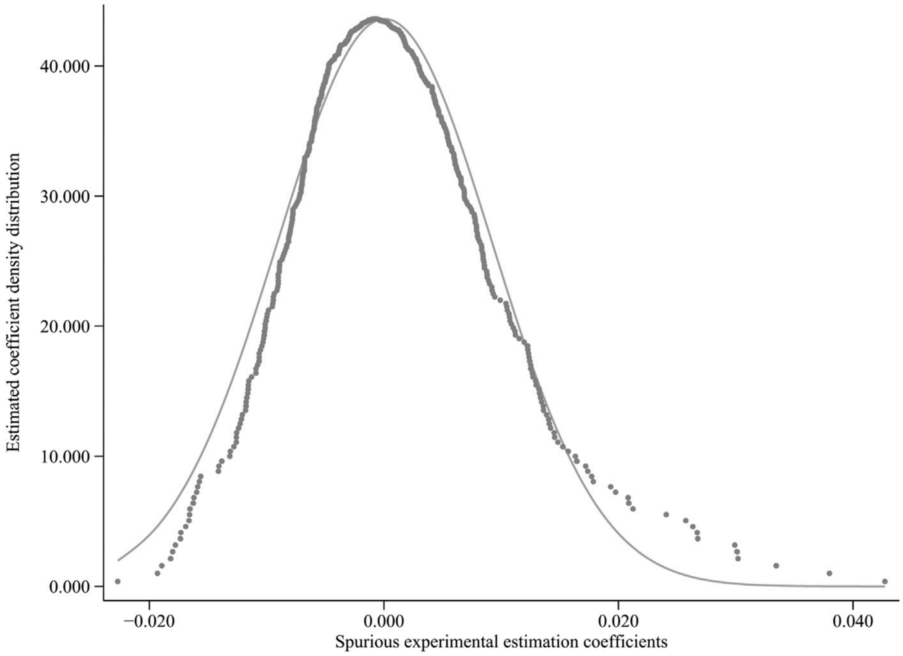

FIGURE 2
Placebo test graph.

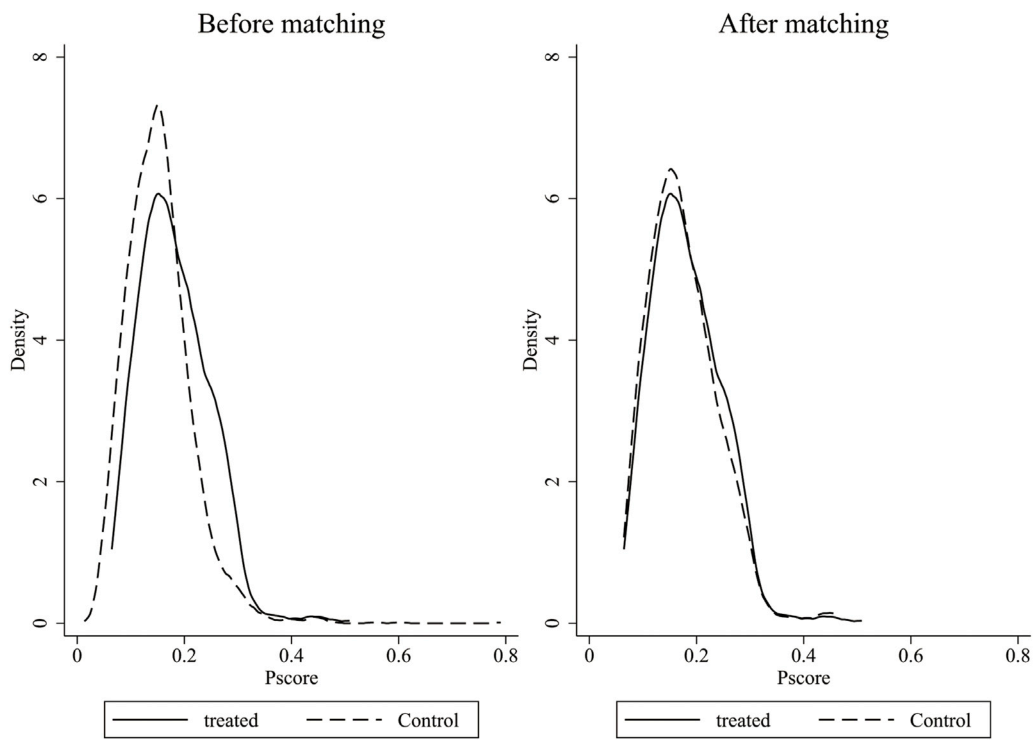

FIGURE 3
Density distribution graph of PSM.

5.2.3 PSM-DID test

The choice of the pilot and non-pilot cities for the energy-consuming right trading policy may not be random. This paper uses the PSM-DID method to match the control and experimental group cities to avoid selectivity bias. Specifically, this paper constructs a logit model with urban green development efficiency as the outcome

TABLE 3 Robustness tests.

VAR	*gde*			
	(1)	(2)	(3)	(4)
treat × post	0.0303*** (3.0454)	0.0304** (2.1912)	0.0397*** (4.12278)	0.0373*** (3.9981)
idst	0.0002 (0.5142)	0.0007 (1.3332)	0.0011** (2.8224)	0.0004 (1.3146)
urban	−0.0013*** (−3.9110)	−0.0013*** (−2.7727)	−0.0000 (0.0308)	−0.0009*** (−3.1426)
pop	−0.1059*** (−3.4695)	−0.1697*** (−4.5466)	−0.1687*** (−5.3473)	−0.0968*** (−3.4156)
rofe	0.1062 (1.3218)	−0.0303 (−0.2001)	0.1444 (1.6172)	0.0544 (0.6970)
depc	−0.0244 (−1.6400)	−0.0252 (−1.5190)	−0.0101 (−1.4642)	−0.0061 (−0.5902)
ggdp	0.0002 (0.4427)	0.0008 (1.3039)	−0.0013*** (−2.9521)	−0.0018*** (−3.2313)
Constant	0.9037*** (5.1247)	1.1084*** (3.7622)	1.1840*** (6.2527)	0.7687*** (4.6581)
year	YES	YES	YES	YES
city	YES	YES	YES	YES
Observations	3,714	2055	3,810	3,810
R^2	0.113	0.128	0.794	0.128

Note: 1) ***, **, * represent significance at 1%, 5% and 10% confidence level, respectively; 2) *T*-values are in parentheses. The following table is the same.

variable and control variables as covariates. Furthermore, the one-to-one nearest neighbor matching method with put-back is used for matching. Finally, the matched samples are regressed again according to the DID model. This paper plots the propensity score density function to clearly describe the matching effect (Figure 3). The graph shows that the propensity score probability densities of the control and experimental groups are closer after matching. It indicates that the matching effect is good. The regression results are shown in column (1) of Table 3. After the Propensity Score Matching (PSM), the estimated coefficient of the energy-consuming right trading policy is significantly positive at the 1% level. The regression results again indicate that the energy-consuming right trading policy significantly improves the efficiency of urban green development. It shows that the main conclusion of this paper is robust.

5.2.4 Removal of competitive policies

The Chinese government implemented the low-carbon city pilot and carbon emissions trading policy in 2010 and 2011. It has been demonstrated that low-carbon city pilots and carbon trading policies can significantly improve the efficiency of green development (Zhu et al., 2020). This paper excluded the sample of cities with the above policies and regressed again to avoid the findings being influenced by the above policies. The regression results are shown in column (2) of Table 3. The estimated coefficient of the energy-consuming right trading policy is significantly positive at the 5% level after excluding the sample of pilot cities mentioned above. The results show that the energy-consuming right trading policy still significantly improves the efficiency of urban green development after excluding the effects of the above policies. The main conclusion of this paper is robust.

5.2.5 Interaction fixed effects test

Although this paper passes the parallel trend test, other omitted factors may still influence the green development efficiency of different cities. This paper adds the interaction fixed effects of city and year based on the DID model and regresses again to reduce the interference of omitted factors. The regression results are shown in column (3) of Table 3. The estimated coefficient of the energy-consuming right trading policy is still significantly positive at the 1% level after adding the interaction fixed effects. The regression results again indicate the robustness of the main analysis results that the energy-consuming right trading policy can improve the efficiency of urban green development.

5.2.6 Shrinkage processing

Extreme values in the sample data may lead to biased regression results. This paper applies Winsorize shrinkage to continuous variables at the 1% and 99% levels to remove the effect of extreme values. The regression results are shown in column (4) of Table 3. After excluding the extreme values of the sample, the estimated coefficient of the energy-consuming right trading policy is significantly positive at the 1% level. The results show that the energy-consuming right trading policy can improve the efficiency of urban green development. The main conclusion of this paper is robust.

5.3 Mechanism analysis

The previous analysis and a series of robustness tests have shown that the energy-consuming right trading policy has significantly positive effects on green development efficiency. This paper regresses green technology innovation (*gti*) as a mediating variable according to the mechanism test model to explore its effect mechanism. The regression results are shown in Table 4. Column (1) reports the regression results of model (1). Columns (2) and (3) report the regression results of model (4)

TABLE 4 Mechanism test.

VAR	gde	gti	gde
	(1)	(2)	(3)
treat × post	0.0325*** (2.9817)	0.1468** (2.4342)	0.0314*** (2.8777)
gti			0.0077** (2.5373)
idst	0.0001 (0.1295)	0.0165*** (7.7662)	−0.0001 (−0.2001)
urban	−0.0014*** (−4.3242)	0.0084*** (4.6635)	−0.0015*** (−4.5127)
pop	−0.1165*** (−3.6535)	1.6147*** (9.1522)	−0.1290*** (−3.9998)
rofe	0.0810 (0.9432)	−2.2206*** (−4.6740)	0.0981 (1.1399)
depc	−0.0070 (−0.8683)	0.0751* (1.6720)	−0.0076 (−0.9399)
ggdp	−0.0002 (−0.5158)	0.0047* (1.8816)	−0.0003 (−0.5962)
Constant	0.9097*** (4.8531)	−9.2114*** (−8.8842)	0.9807*** (5.1785)
year	YES	YES	YES
city	YES	YES	YES
Observations	3,810	3,810	3,810
R^2	0.097	0.820	0.099

Note: 1) ***, **, * represent significance at 1%, 5% and 10% confidence level, respectively; 2) *T*-values are in parentheses. The following table is the same.

TABLE 5 Heterogeneity analysis.

VAR	Midwest cities		Eastern cities	
	(1)	(2)	(3)	(4)
treat × post	0.0211 (1.5521)	0.0166 (1.2185)	0.0394** (2.1068)	0.0550*** (2.8862)
idst		0.0004 (0.9608)		−0.0029*** (−3.1411)
urban		−0.0006* (−1.6836)		−0.0026*** (−4.2758)
pop		−0.1515*** (−4.9175)		0.1616 (1.4552)
rofe		−0.1156 (−0.8916)		0.1530 (1.1338)
depc		−0.0105 (−1.3239)		0.0109 (0.4287)
ggdp		0.0004 (0.7804)		−0.0013 (−1.4951)
Constant	0.1655*** (24.0641)	1.0896*** (6.0675)		−0.6841 (−1.0466)
year	YES	YES	YES	YES
city	YES	YES	YES	YES
Observations	2,475	2,475	1,335	1,335
R^2	0.117	0.129	0.064	0.092

Note: 1) ***, **, * represent significance at 1%, 5% and 10% confidence level, respectively; 2) *T*-values are in parentheses. The following table is the same.

and model (5), respectively. Referring to the mediating effect test by Wen and Ye (2014), this paper conducts the mediating effect test step by step. In the first step, the regression coefficient of the energy-consuming right trading policy in the DID model is tested. The coefficient is significantly positive from column (1) in Table 4. In the second step, test the coefficient φ_1 in the model (4) and the coefficient β_3 in the model (5). As shown by columns (2) and (3) in Table 4, both are significantly positive. In the third step, the coefficient ϑ_1 in the model (5) is tested. Column (3) in Table 4 shows that ϑ_1 is also significantly positive. Finally, the positive and negative signs of $\varphi_1\beta_3$ and ϑ_1 are compared. It can be concluded from Table 4 that the positive and negative signs are the same for both. The above stepwise tests indicate that green technology innovation has a partial mediating effect. The energy-consuming right trading policy can improve the efficiency of urban green development by promoting green technology innovation. The results of this paper support the "Porter Hypothesis" and verify Hypothesis 2 of this paper.

5.4 Heterogeneity analysis

China is a vast country, so the geographical environment, resource endowment, economic base, and other factors vary significantly between regions. The effect of the energy-consuming right trading policy cannot be generalized. This paper divides the sample into midwestern cities and eastern cities for regression to study the differences in policy effects among different regions. The regression results are shown in Table 5. Columns (1) and (2) indicate the regression results for midwestern cities, while columns (3) and (4) indicate the regression results for eastern cities. From columns (1) and (2) in Table 5, the estimated coefficients of the energy-consuming right trading policy are insignificant with or without control variables. From column (3) in Table 5, the estimated coefficients of the energy-consuming right trading policy in eastern cities are significantly positive at the 5% level without control variables. Column (4) shows that the estimated coefficient of the policy in eastern cities is significantly positive at the 1% level with control variables. The results show that the energy-consuming right trading policy has no significant effect on the green development efficiency of cities in the central and western regions. On the contrary, it significantly promotes urban green development efficiency in the eastern region.

6 Conclusion and implications

This paper investigates the impact of the energy-consuming right trading policy on urban green development efficiency based on data from 254 cities in China from 2005 to 2019. The conclusion of this paper are as follows. 1) The energy-consuming right trading policy has significantly improved the efficiency of urban green development. The conclusion still holds after a series of robustness tests such as parallel trend test, placebo test, PSM-DID test, removal of competitive policies, interaction fixed effects test, and shrinkage processing. The conclusion is robust. 2) The energy-consuming right trading policy has significantly improved the efficiency of urban green development by promoting green technology innovation. The conclusion supports the "Porter hypothesis." 3) Compared with the central and western regions, the energy-consuming right trading policy has more significantly improved the efficiency of urban green development in the eastern region.

Based on the above conclusion and the actual situation in China, this paper draws the following implications and makes recommendations. First, the government should actively summarize the implementation experience in the location and gradually expand the scope of the pilot. Meanwhile, the government should also follow the trend of market-oriented reform and use market-incentivized policy tools. The relevant departments should establish and improve a unified trading platform for the energy-consuming right. Second, the government should encourage enterprises to actively innovate green technology through taxes and subsidies while implementing the energy-consuming right policy. The conclusion suggests that green technology innovation has a partial mediating effect. Therefore, green technology innovation should be included in the inspection index of energy-consuming rights allocation to stimulate enterprises to innovate green technology. Third, the implementation of the energy-consuming right trading policy needs to be adapted to local conditions. Because the policy effects of the energy-consuming right trading policy vary in different regions, the government should reduce the allocation of energy-consuming rights for cities in the central and western regions. In this way, the energy-consuming right trading policy can be fully utilized in midwestern cities to improve the efficiency of urban green development.

There are still some limitations that could be explored in further research. On the one hand, the sample of this paper is updated only to 2019 because of data limitations. The sustainability of the effect of energy-consuming right trading policy on urban green development is yet to be tested. On the other hand, our results are more applicable to the Chinese city. However, as micro-entities of the energy-consuming right trading policy, the enterprises play an important role. The impact of the policy on the production methods of enterprises should be noticed. We believe that future work will provide valuable supplements in these aspects.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: EPS database (https://www.epsnet.com.cn).

Author contributions

BG and PH designed the study, performed the research, analyzed data, and wrote the paper. HZ collected most of the data. FH provided suggestions response on revising the paper.

Funding

This research is supported by (The National Social Science Foundation of China) [Grant numbers (20BJL040)].

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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