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Original Research

The Impact of Environmental Regulations on Energy-Environmental Efficiency: Evidence from China

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Abstract

Within the context of Carbon Peaking and Carbon Neutrality objectives, reducing carbon emissions and improving energy-environmental efficiency have emerged as the primary concerns of China's environmental governance. It will become increasingly important to study how environmental regulation can improve the environmental efficiency of energy. First of all, this study uses the non-radial distance function method to measure the energy-environmental efficiency of 30 provinces in China from 2011 to 2020. Secondly, this study uses the generalized moment estimation model to test the relationship between the two. Furthermore, in order to better clarify the transmission mechanism between environmental regulation and energy environmental efficiency, this study uses the intermediary effect model to conduct an empirical test. Finally, in order to explore the spatial distribution relationship of energy-environmental efficiency, this study conducts an exploration based on the spatial regression model. It has been observed that: (1) The average energy-environmental efficiency in China exhibits "high in the east and low in the west" distribution characteristics, and the energy-environmental efficiency fluctuates steadily all the time. (2) Environmental regulation can effectively enhance regional energy-environmental efficiency. (3) Industrial upgrading and technological innovation are essential mediating mechanisms of environmental regulation for energy-environmental efficiency. (4) The energy-environmental efficiency of each province has a significant positive spillover effect. Environmental regulation not only plays a significant role in promoting regional energy and environmental efficiency, but also plays a positive role in promoting energy and environmental efficiency in neighboring areas. Consequently, this study puts forward specific suggestions to improve China's energy-environmental efficiency through environmental regulations.

Keywords: environmental regulation, energy-environmental efficiency, mediation mechanism, spatial spillover, industrial upgrade, technological innovation

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Introduction

As it gradually modifies its economic development philosophy, China is shifting from high-speed growth to high-quality growth. Adjusting the industrial structure and actively promoting Supply-Side Reform has become the core factor in China's current high-quality development. Building a "wild China" has become the main aim of China's ecological progress in the new era. China's previous rapid economic growth came at the expense of the environment. Since the 18th National Congress of the CPC, environmental protection has been emphasized, and the idea that "Clear waters and green mountains are as good as mountains of gold and silver" has spread throughout society. The "carbon peaking and carbon neutrality" goal has accelerated China's environmental governance. Moreover, the current situation calls for China to adjust its energy structure by lowering carbon emissions and increasing the supply of green energy. In 2021, China's total energy consumption reached 5.24 billion tons of standard coal, 5.2 percentage points lower than that in 2020. Besides, China's carbon dioxide emissions reached 36.3 billion tons in 2021. Under the "carbon peaking and carbon neutrality" target, breaking through environmental constraints and promoting the high-quality evolution of the Chinese economy to become the essential point of development, as well as improving energy-environmental efficiency, are the predominant parts to alleviate this problem.

Nonetheless, how to react to improve China's energy-environmental efficiency remains the question. Cao et al. [1] found that digital finance substantially improved China's energy-environmental efficiency performance. Cheng et al. [2] found that R&D investment and governance transformation can promote the growth of energy-environmental efficiency in the manufacturing industry. It is evident that despite there being a variety of tools that exist with the aim to enhance energy-environmental efficiency, the enhancement of energy-environmental efficiency should be done by the subjective initiative of the government, strengthen the ability to control environmental pollution, decrease environmental toxicity at its source, and actively adjust the economic operation of enterprises to reduce the negative impact of environmental pollution on the whole society. Some scholars have found that environmental regulation significantly improves total factor energy efficiency through the backforcing mechanism. For example, in 2024, China achieved significant carbon reduction through its "two new" policies (equipment renewal and recycling actions), reducing CO_2 emissions by about 73 million tons. Hence, environmental regulation is a powerful device to improve energy-environmental efficiency [3].

Alongside the expansion of our economy and environmental regulations. The concept of environmental regulation has shifted from a "pollution-prevention view" to an "ecological-civilization view", and the policy category has shifted from government involvement to market stimulation, and then to public participation and joint supervision of the entire society. China has prioritized environmental protection since the CPC's 18th National Congress, and the "Five-Sphere Integrated Plan" includes the development of ecological civilization. At the same time, China has issued the Opinions of the State Council on Accelerating the Construction of Ecological Civilization and the Overall Plan for the Reform of the System for Ecological Civilization and other relevant documents, which provide fundamental guidelines on how to promote the construction of ecological civilization. Moreover, numerous ministries and regions have issued relevant ecological construction documents, which indicate that China's environmental regulation policy and, consequently, the system are being enriched.

To more thoroughly investigate how environmental regulation and energy-environmental efficiency relate, this study first measured the energy-environmental efficiency of 30 provinces in China from 2011 to 2020 with the help of the non-radial distance function (NDDF). Through theoretical derivation, the relationship between environmental regulation and energy-environmental efficiency is clarified, and the transmission mechanism between them is clearly stated. With the assistance of systematic generalized moment estimation (SYS-GMM), the data of 30 provinces from 2011 to 2020 are used to empirically test the above theoretical derivation hypothesis. To comprehend the spatial correlation of energy-environmental efficiency, the Moran index was applied to describe the above relationship.

The following are the areas where this study may contribute most significantly: (1) Since the 18th National Congress of the CPC, the energy-environmental efficiency of each province in China has been measured more precisely and scientifically with the assistance of NDDF and the addition of unintended output-carbon emission to the model. (2) Environmental regulation and energy environment efficiency are condensed into a unified theoretical framework, and their association is explored in depth with the help of the SYS-GMM model. (3) The mediating effect model is employed to clarify the transmission mechanism of industrial upgrading and technological innovation between environmental regulation and energy-environmental efficiency, to put forth more targeted suggestions for enhancing environmental regulation and energy-environmental efficiency. (4) A more thorough discussion of the spatial correlation between energy-environmental efficiency is provided by the spatial Moran model, in the situation where the improvement of environmental and energy efficiency of each region is on its own.

Literature Review

Previous literature mainly focused on how to reduce the number of carbon emissions, and there were relatively few studies on how to improve energy-environmental efficiency. In the study of energy-environmental efficiency measurement, previous scholars often used the DEA model to measure energy-environmental efficiency. Royo et al. [4] analyzed some of the most relevant issues to be faced by energy-intensive industries based on DEA models to improve their energy and environmental performance according to innovative transformation strategies. Nonetheless, the above models are not comparable across periods, and some scholars have improved them. Mavi [5] used the Malmquist Productivity Index (MPI) to measure energy-environmental efficiency in OECD countries from 2012 to 2015. Sun and Kporsu [6] used the Malmquist-Luenberger Productivity Index to measure the environmental performance of 104 countries from 1980 to 2016. In the context of carbon emission reduction, more scholars have incorporated carbon emission data into their output. Iram et al. [7] adopted the DEA to assess the energy use efficiency and its role in carbon dioxide emissions (CI) and economic environmental efficiency (EEE) of national OECD economies between 2013 and 2017. Zhang [8] adopted DEA window evaluation technology to measure cross-sectional efficiency by using two kinds of inputs (energy consumption and labor), expected output (GDP), and non-expected output CO_2 emission.

In the literature on the relationship between environmental regulation and environmental efficiency, there has been much debate on whether strict environmental regulations can simultaneously promote environmental performance. According to Ren et al. [9], the impact of various types of environmental regulations on eco-efficiency varies significantly across China's regions. Liu et al. [10] argue that the relationship between environmental regulation (ER), green technology innovation (GTI), and energy efficiency varies in different regions and periods in China. While GTI effectively improves efficiency, inappropriate ER undermines the marginal benefit of GTI. Moderate ER levels were found to help reduce the harmful effects of GTI when the "energy rebound effect" occurred. In terms of the research on the relationship between environmental regulation and carbon emissions, Pei et al. [11] found that for the whole energy-intensive industry group, environmental regulation can not only potentially directly reduce carbon emissions, but also indirectly reduce carbon emissions through technical efficiency. According to Zhang et al. [12], there is a significant inverted U-shaped relationship between environmental regulation and carbon emissions. With the improvement of environmental regulation, the positive role of environmental regulation in reducing the total amount and intensity of carbon emissions becomes more obvious.

To sum up, on the one hand, in terms of energy-environmental efficiency measurement, the existing efficiency measurement methods cannot accurately and objectively measure energy-environmental efficiency based on carbon emission data. Specifically, the problem that the radial distance function tends to overestimate the efficiency value cannot be solved, and the impact of carbon emissions on energy-environmental efficiency cannot be effectively reflected. On the other hand, the existing research results on the relationship between environmental regulation and energy environmental efficiency have not been unified, so it is necessary to understand the impact of environmental regulation on energy environmental efficiency more scientifically. Furthermore, it is not clear through what mechanism environmental regulation affects energy-environmental efficiency, and the transmission mechanism between the two cannot be effectively blocked.

Research Hypothesis

Environmental pollution is an economic activity with unfavorable externalities, and society as a whole is responsible for bearing these externalities. Besides, this negative externality will lead to the aggravation of environmental pollution across all of society. Although environmental regulation can eliminate the negative impact of economic activities on the environment, it drives up production costs and impedes industrial growth. There is disagreement among scholars regarding how environmental regulation might generate profitability that improves innovation offsetting capacity. Under a certain degree of strict environmental regulation, the environmental regulation policy has favorable effects on green productivity growth. Notwithstanding, when environmental regulation policies are strict to some extent, environmental regulation is detrimental to green productivity growth because the cost of compliance outweighs the benefits of innovation [13]. According to Porter's hypothesis, appropriate environmental regulation can stimulate the "innovation compensation" effect, which can not only cover the "compliance cost" of enterprises but also boost their productivity. The background that the Chinese government attaches great significance to environmental protection, relevant laws such as the Environmental Protection Tax Law of the People's Republic of China has been formally promulgated and implemented, which partially resolves the issue of enterprise production's detrimental environmental externalities, the clarity of property rights and the innovation of regulatory means such as tax tools [14], which can make the revenue brought by enterprise innovation better compensate the compliance cost of enterprises and can improve pollution reduction while expanding enterprise innovation, concerning continuously enhance the energy-environmental efficiency of the whole society. Prior to 2018, China's environmental regulation policies were mainly implemented in the form of pollution charges. Research shows that environmental regulation policies significantly improve the cost markup rate of manufacturing enterprises, but this improvement is mainly achieved through an innovation compensation mechanism, that is, enterprises offset part of the compliance cost through technological innovation.

However, compliance with the cost mechanism (that is, the costs that firms directly add to compliance) has a negative impact on the cost-plus rate. This shows that although enterprises face increased compliance costs, some enterprises can obtain certain compensation through technology upgrading and innovation. Consequently, this study proposes the following hypothesis:

H1: Environmental regulation can effectively improve regional energy-environmental efficiency.

In the past period, the contradiction between China's rapid economic development, resource mismatch, and environmental damage has become more prevalent. As a bridge between economic activities and the ecological environment, upgrading industrial structures has become an essential strategy for solving ecological and environmental problems [15]. Due to the constraints of production technology risks, institutional inertia, and other factors, enterprises alone are responsible for industrial upgrading, which will require a great deal of time and money and make it difficult for the entire society to achieve industrial transformation and upgrading. Serving as the "visible hand" in the market economy, the government can eliminate negative externalities in the economy and society through institutional arrangements, re-optimize the allocation of resources, restructure the production system, guide enterprises to develop specialized, refined and new upstream high-end industries, and promote the upgrading of regional industrial structure [16]. The upgrading of industrial structures can encourage the industrialization of regional industrial structures, reduce carbon emissions, and promote the enhancement of energy efficiency [17]. Therefore, this study proposes the following hypothesis:

H2: Through environmental regulation, industrial upgrading is a crucial transmission mechanism for energy-environmental efficiency.

Conforming to the Porter hypothesis, the strengthening of environmental regulation can lead to a rise in enterprises' R&D investment, primarily because enterprises try to strengthen their ability to control pollution and the technological content of products through R&D investment, to continuously increase their market share, to offset the adverse effects of environmental regulation on business performance. In most cases, environmental regulation can play a "booster" role in stimulating regional innovation [18]. Continuously improving the level of innovation reduces the long-term energy consumption and emission levels of businesses, thereby enhancing their energy-environmental efficiency [19]. To put it in another way, environmental regulation affects industrial energy-environmental performance through technological innovation [20]. Consequently, this study proposes the following hypothesis:

H3: Technological innovation is another transmission mechanism of energy-environmental efficiency through environmental regulation.

In terms of energy efficiency, there are technical variables. There is a free flow of technology between regions, and technological progress in one region can be transferred to another region, a phenomenon known as spatial spillover [21]. Especially in the process of industrial development, industrial integration can largely boost the energy efficiency of the industry through cross-industry and cross-region imitation and learning [22]. Simultaneously, industrial transfer plays an essential role in affecting the spatial effect. Specifically, with the change in industrial distribution, industrial transfer can optimize the spatial configuration of production [23]. Such a transfer will inevitably affect China's regional energy-environmental efficiency, resulting in convergence of energy efficiency and a decrease in regional energy efficiency disparities. Therefore, this study proposes the following hypothesis:

H4: There is a significant spatial spillover effect among the energy-environmental efficiencies of different provinces.

Materials and Methods

Model

Non-Radial Distance Function

To scientifically and accurately measure China's energy-environmental efficiency, in a combination with existing research methods, this study selects the NDDF (non-radial distance function) model. Compared with other efficiency measurement models, this model can structurally solve the problem that the radial distance function can easily overestimate the efficiency value and ensure the accuracy of measurement results. In contrast, the model takes into account the distinction between expected output and non-expected output, and adds carbon emission data to the non-expected output in order to ensure the accuracy of the scientific measurement results. Moreover, the model measure yields comparable results.

$$\overrightarrow{ND}(x,y,b;g) = sup\{W^T\beta: ((x,y,b) + g * diag(\beta)) \in T(x)\} \quad (1)$$

The above definition, $w = (w_m^x, w_s^y, w_j^b)^T$ said associated with the input and output of the standardized weight collection, $g = (-g_x, g_y, -g_b)$ as the direction of the collection, $\beta = (\beta_m^x, \beta_s^y, \beta_j^b)^T \geq 0$ is the set of factors that affect individual inefficiency for each input (output). *diag* is a diagonal matrix, and T is the environmental production technology. In combination with the environmental production technology and the definition of the NDDF model, the subsequent model can be solved to compute $\overrightarrow{ND}(x,y,b;g)$.

$$\overrightarrow{ND}(x,y,b;g) = max\ \ w_m^x\beta_m^x + w_s^y\beta_s^y + w_j^b,\beta_j^b$$

$$s.t.\ \sum_{i=1}^{N}\lambda_n x_{mn} \leq x_m - \beta_m^x g_{xm}, m = 1, \ldots M$$

$$\sum_{i=1}^{N}\lambda_n y_{sn} \geq y_s - \beta_s^y g_{ys}, s = 1, \ldots S$$

$$\sum_{i=1}^{N}\lambda_n b_{jn} = b_j - \beta_j^b g_{bj}, j = 1, \ldots J$$

$$\lambda_n \geq 0, n = 1, \ldots N$$

$$\beta_m^x, \beta_s^y, \beta_j^b \geq 0 \tag{2}$$

To objectively and precisely measure China's energy-environmental efficiency, this study chooses capital, labor, and energy as input indicators, regional GDP and carbon emission as output indicators, with carbon emission being the undesirable output. Set the specific direction as $g = (-g_x, g_y, -g_b)$ $(-L, -K, -E, Y, -C)$. Given that neither capital nor labor directly produces carbon dioxide, the weighting set is (0, 0, 1/3, 1/3, 1/3) and the direction set g is (0, 0, -F, E, -C). To the research needs of this study, energy-environmental efficiency (EEPI) is defined as:

$$EEPI = \frac{1/2[(1-\beta_E^*)+(1-\beta_C^*)]}{1+\beta_Y^*} =. \frac{1-1/2[\beta_E^*+\beta_C^*]}{1+\beta_Y^*} \tag{3}$$

The System-Generalized Moment Model

To explore China's dynamic relationship between energy-environmental efficiency and environmental regulation, this study adopts the System Generalized Moment estimation (System-GMM) model to explore the dynamic relationship between them. The primary reasons for this are the potential dynamic relationship between environmental regulation, energy-environmental efficiency, and the potential endogeneity issue. Accordingly, this study adopts System-GMM for testing, because SYSTEM-GMM can well deal with the problems of equation identification and explanatory variable endogeneity in the estimation. In particular, System-GMM estimation of the environmental regulation of the endogenous explanatory variables will be performed, and the first-order lag term of energy-environmental efficiency will be included in the explanatory variables.

$$eepi_{i,t} = \alpha_0 + \alpha_1 eepi_{i,t-1} + \alpha_2 envi_{i,t} + \alpha_3 x_{i,t} + \varepsilon \tag{4}$$

In the above model, *eepi* represents energy-environmental efficiency, *envi* represents environmental regulation, and x stands for other control variables. i represents the region, t represents the year, α_0 signifies the constant term, and ε represents the random error term.

Mediating Effect Model

Formulated on the mediating effect model, this study explores the transmission mechanism of environmental regulation and energy-environmental efficiency in China.

$$mid_{i,t} = \alpha_4 + \alpha_5 mid_{i,t-1} + \alpha_6 envi_{i,t} + \alpha_7 x_{i,t} + \varepsilon \tag{5}$$

$$eepi_{i,t} = \alpha_8 + \alpha_9 eepi_{i,t-1} + \alpha_{10} mid_{i,t} + \alpha_{11} envi_{i,t} + \alpha_{12} x_{i,t} + \varepsilon \tag{6}$$

In the above model, *mid* is the mediating variable. In this study, industrial upgrading (*upgrade*) and innovation level (*tech*) are correspondingly selected for exploration. On condition that environmental regulation can remarkably act on mediating variables, and the mediating variables can substantially increase energy-environmental efficiency, and α_2, α_{11} are notably distinctive, then the above mediating mechanism exists, and the reverse is untrue.

Spatial Moran Model

Since the spatial econometric model is built on regional interaction, typically, it is required to determine whether the research objects have a spatial correlation. In this study, the global Moran's index is applied to test the spatial autocorrelation of energy-environmental efficiency. The calculation formula is as follows:

$$Moran's\ I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}(Y_i-\bar{Y})}{S^2\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}} \tag{7}$$

In the formula, $S^2 = \sum_{i=1}^{n}(Y_i - \bar{Y})^2$; Y_i, Y_j represent the observed values of region i and j, n is the total number of cities, and W_{ij} is the element of the spatial weight matrix (i, j) (the distance between region i and region j is measured). $\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}(Y_i - \bar{Y})$ shows the total space weights. The Moran index is generally between -1 and 1. A positive Moran index indicates a positive spatial correlation, that is, high values are adjacent to high values. Negative values indicate negative spatial correlation; in other words, high values are adjacent to low values. The Moran index is equal to zero, indicating that no spatial correlation exists.

The existing spatial weight matrix includes an adjacent weight matrix, a geographical distance weight matrix, and an economic distance weight matrix. By the needs of this study's research, the reciprocal of regional distance is used as the spatial weight matrix, which is specifically expressed as:

$$w_{ij} = \frac{1}{d_{ij}} \tag{8}$$

where, d_{ij} represents the geographical distance between regions i and j, and this matrix can indicate that non-adjacent regions in geographic space also have interaction.

On the basis of the existence of spatial correlation, this paper uses the practice of Atikah et al. (2021) [24] for reference and adopts the spatial Durbin model to explore the impact of environmental regulations on environmental energy efficiency:

$$eepi_{i,t} = \gamma_1 + \rho Weepi_{i,t} + \gamma_2 envi_{i,t} + \gamma_3 x_{i,t} + \beta_1 Wenvi_{i,t} + \beta_2 Wx_{i,t} + v_i + \mu_t + \varepsilon_{it} \quad (9)$$

In the above model, W is the geographical distance matrix, $Weepi_{i,t}$ is the spatial lag term of energy and environmental efficiency, $Wenvi_{i,t}$ is the spatial lag term of environmental regulation, $Wx_{i,t}$ is the spatial lag term of control variables, v_i is the individual fixed effect, μ_t is the time fixed effect, and ε_{it} is the error term.

Variable Selection and Data Sources

Input-output Variables of Energy-Environmental Efficiency Measurement

Labor force (L): Labor is one of the core factors of production activities. The quantity and quality of the labor force not only affect production efficiency but are also closely related to the technical level of energy utilization and management efficiency. Rational labor input can optimize the process of energy utilization and improve energy efficiency. Following Li's (2021) [25] approach, select the number of employed individuals in the region for representation.

Capital (K): Capital is an important basis for productive activities, including fixed assets (such as plant and equipment) and working capital. Capital input directly affects energy efficiency and production scale. By measuring capital investment, it can reflect the hardware level and financial support capacity of a region or enterprise in the process of energy utilization. According to Pokki (2018) [26], we adopt the perpetual inventory method to represent regional capital stock, with a depreciation rate of 9.6%.

Energy (E): Energy is the core factor of energy environmental efficiency measurement, which directly reflects the energy consumption level of production activities. By measuring energy input, the efficiency and structure of energy utilization can be analyzed, and the basis for energy conservation, emission reduction, and energy optimization can be provided. According to Huterski (2021) [27], regional power generation is used to represent energy levels.

Output (Y): GDP is an important measure of economic activity and reflects the level of output in the economic system. Using GDP as the expected output can reflect the economic efficiency of energy use, that is, the economic value created per unit of energy input. Such indicators can help analyze the economic benefits of energy use and provide support for economic decision-making. According to Huang et al. (2021) [28], we use regional gross domestic product to represent output.

Carbon Emissions (C): Carbon emissions are the main negative environmental externalities arising from energy use and are a key measure of environmental efficiency. Taking carbon emissions as an undesirable output can fully reflect the environmental cost of energy utilization and reflect the sustainability of energy utilization. By analyzing the relationship between carbon emissions and economic output, the environmental efficiency of energy utilization can be evaluated, and the basis for the formulation of low-carbon policies can be provided. Calculate carbon dioxide emissions according to the method provided in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).

Given that the preceding values are relatively large, the logarithms of the preceding variables are taken uniformly.

Explained Variables

Energy-environmental efficiency (*eepi*): This study selects the energy-environmental efficiency measured based on the above NDDF model.

Explanatory Variables

Environmental regulation (*envi*): Industrial SO_2 emissions and industrial soot emissions are the core indicators to measure industrial pollution emissions, which can fully reflect the negative impact of industrial activities on the environment. These index data are highly available and widely used in environmental regulation research, and scholars use this method in their research. According to the approach of Li and Du (2021) [29], the comprehensive index of environmental regulation is calculated using the entropy method based on the industrial wastewater emissions, industrial SO_2 emissions, and industrial smoke emissions of each province.

Mediating Variables

Industrial upgrade (*upgrade*): According to Dong et al. (2022) [30], this article selects the ratio of the added value of the tertiary industry to that of the secondary industry to characterize the level of industrial upgrading.

Technological innovation (*tech*): According to Svensson (2022) [31], this study represents the number of granted patents using its logarithm.

Control Variables

Urbanization rate (*urban*): According to Zhang (2022) [32], it is expressed as the ratio of the permanent resident population to the total population.

Level of foreign investment (*fdi*): According to Zhao et al. (2024) [33], the logarithm of foreign direct investment is used to represent the level of foreign investment (FDI), mainly presenting the level of regional openness.

Energy consumption structure (*enstru*): By the practice of Tang et al. [34], the proportion of coal consumption to total energy consumption was computed and expressed.

Human capital (*hum*): This article adopts the practice of China's population and employment yearbook, human capital = (illiterate * 1 + primary school education * 6 + middle school education * 9 + high school and technical secondary education * 12 + college education * 16) / total population over 6 years old.

Industrial agglomeration intensity (*agg*): In consonance with the practice of Liu et al. [35], industrial agglomeration intensity = the number of employed persons (ten thousand) / administrative area (square kilometers).

Data Sources and Descriptive Statistics

The variable data employed in this study are all from the China Statistical Yearbook, the Statistical Yearbook of each Province, the China Environmental Statistical Yearbook, and other literature. Due to the serious lack of data in Tibet, this study excluded Tibet and studied the remaining 30 regions. All variables related to value are deflated based on 2011, and all variables related to the US dollar are converted into RMB according to the exchange rate. The specific statistical values of each variable are demonstrated in Table 1.

Results and Discussion

Analysis of Efficiency Value Results

According to Table 2, the top three provinces in terms of energy-environmental efficiency are Beijing, Tianjin, and Shandong, whose average energy-environmental efficiency is 0.879, 0.831, and 0.821, respectively. These three provinces are all developed areas in the east. The western provinces of Qinghai, Xinjiang, and Gansu scored the lowest in terms of energy-environmental efficiency. It displayed a relatively obvious pattern of "high in the east and low in the west". As evidenced by Table 3, the overall change in national average energy-environmental yearly effectiveness is relatively constant, reaching the lowest value of 0.662 in 2018; it peaked at 0.687 in 2014.

Panel Data Model Empirical Results

Benchmark Model

This study empirically analyzes the relationship between environmental regulation and energy-environmental efficiency based on the SYSTEM-GMM model. Before System-GMM regression, OLS regression analysis was first conducted in this study. Before System-GMM regression, OLS regression analysis was performed in this study. Aiming to solve the endogeneity and characterize the dynamic relationship between environmental regulation and energy-environmental efficiency, System-GMM regression is conducted in this study. To ensure the reliability of the results, the benchmark regression was conducted first (2), in which no control variables were added. Observably, the lag phase of energy-environmental efficiency is significantly positive, meaning that the energy-environmental efficiency of the previous period has a positive effect on the energy-environmental efficiency of the current period. Observably, the lag phase of energy-environmental efficiency is significantly positive, meaning that the energy-environmental efficiency of the previous period has a positive effect on the energy-environmental efficiency of the current period. In System-GMM regression, the regression results require that the disturbance terms all have first-order autocorrelation, and no second-order autocorrelation

Table 1. Descriptive statistics of variables.

Variable	Obs	Mean	Std. Dev.	Min	Max
eepi	300	0.678	0.086	0.554	1.000
envi	300	0.189	0.202	0.000	1.000
urban	300	0.576	0.118	0.350	0.896
lnfdi	300	5.139	1.388	1.450	7.818
enstru	300	0.939	0.463	0.015	2.518
hum	300	9.253	0.917	7.474	12.782
agg	300	0.120	0.177	0.001	1.000
upgrade	300	1.219	0.696	0.518	5.297
tech	300	0.021	0.015	0.004	0.068

Table 2. Energy-environmental efficiency of each province.

Province	Obs	Mean	Std. Dev.	Min	Max
Beijing	10	0.879	0.068	0.813	1.000
Tianjin	10	0.831	0.044	0.784	0.943
Hebei	10	0.680	0.010	0.665	0.693
Shanxi	10	0.640	0.011	0.630	0.665
Neimenggu	10	0.672	0.006	0.665	0.681
Liaoning	10	0.663	0.010	0.649	0.683
Jilin	10	0.649	0.012	0.628	0.663
Heilongjiang	10	0.654	0.007	0.643	0.663
Shanghai	10	0.724	0.152	0.617	1.000
Jiangsu	10	0.814	0.026	0.771	0.857
Zhejiang	10	0.671	0.018	0.647	0.699
Anhui	10	0.661	0.019	0.638	0.694
Fujian	10	0.648	0.020	0.619	0.677
Jiangxi	10	0.644	0.017	0.622	0.669
Shandong	10	0.821	0.091	0.735	1.000
Henan	10	0.700	0.023	0.667	0.735
Hubei	10	0.658	0.021	0.622	0.689
Hunan	10	0.650	0.018	0.622	0.675
Guangdong	10	0.677	0.017	0.654	0.705
Guangxi	10	0.632	0.013	0.612	0.648
Hainan	10	0.624	0.022	0.589	0.656
Chongqing	10	0.657	0.024	0.618	0.687
Sichuan	10	0.642	0.021	0.612	0.671
Guizhou	10	0.763	0.140	0.613	1.000
Yunnan	10	0.604	0.021	0.573	0.638
Shaanxi	10	0.630	0.014	0.609	0.646
Gansu	10	0.586	0.013	0.563	0.602
Qinghai	10	0.579	0.016	0.554	0.599
Ningxia	10	0.704	0.036	0.649	0.741
Xinjiang	10	0.584	0.007	0.577	0.594

exists, i.e., there is no autocorrelation in the disturbance terms, and the P-value of the Hansen test should be greater than 10%, that is, there is no over-identification of instrumental variables. Regression (2) demonstrates that the regression has passed the AR test and the Hansen test, indicating that the results are reliable. In regression (3), control variables are added in this study. It can be seen from regression (2) that the regression has passed both the AR and Hansen tests, indicating that the results are reliable. The AR and Hansen's tests show that the results are robust, which verifies the rationality of hypothesis 1. Among the specific control variables, urbanization rate and human capital remarkably improve regional energy-environmental efficiency, whereas the effects of foreign direct investment, energy consumption structure, and industrial agglomeration on energy-environmental efficiency are not crucial.

Mediation Effect Model

Aiming to better investigate the mediatory effect of environmental regulation on energy-environmental

Table 3. National average energy-environmental efficiency each year.

Year	Obs	Mean	Std. Dev.	Min	Max
2011	30	0.669	0.069	0.554	0.876
2012	30	0.680	0.079	0.581	0.867
2013	30	0.677	0.090	0.577	1.000
2014	30	0.687	0.094	0.557	1.000
2015	30	0.684	0.102	0.563	1.000
2016	30	0.681	0.092	0.565	1.000
2017	30	0.685	0.105	0.592	1.000
2018	30	0.662	0.065	0.575	0.838
2019	30	0.681	0.089	0.580	1.000
2020	30	0.673	0.077	0.571	0.866

Table 4. Analysis of System-GMM regression results.

-	(1)	(2)	(3)
Variables	OLS	SYSGMM	SYSGMM1
L.eepi	-	0.382***	0.403***
-	-	(0.003)	(0.041)
envi	0.107***	0.049***	0.063***
-	(0.029)	(0.003)	(0.013)
urban	0.139*	-	0.109***
-	(0.076)	-	(0.038)
lnfdi	0.002	-	0.001
-	(0.004)	-	(0.003)
enstru	0.001	-	-0.004
-	(0.010)	-	(0.009)
hum	0.024**	-	0.007**
-	(0.010)	-	(0.003)
agg	0.071	-	0.059
-	(0.066)	-	(0.067)
Constant	0.338***	0.409***	0.256***
-	(0.071)	(0.002)	(0.027)
Observations	300	270	270
R-squared	0.343	-	-
Number of id	-	30	30
AR(1)	-	0.091	0.088
AR(2)	-	0.110	0.129
Hansen test	-	0.467	1.000

Note: ***, **, and * indicate significance at 1%, 5%, and 10% levels, respectively.
AR is to test whether there is first-order and second-order autocorrelation between the difference of perturbation terms. The Sargan test is used to test whether there is excessive identification of instrumental variables.

performance, this study conducts an empirical analysis based on the above model. According to regression (1), environmental regulation can remarkably improve the level of industrial upgrading. In regression (2), it is obvious that industrial structure upgrading and environmental regulation have a substantial impact on energy-environmental efficiency. As indicated by the regression coefficient for environmental regulation (3) of Table 4, it is significantly different from that in regression (1) of Table 5, indicating that industrial upgrading is an important transmission mechanism between environmental regulation and energy-environmental efficiency, which further demonstrates the soundness of hypothesis 2. Similarly, we discussed the transmission mechanism of technological innovation based on the mediation model. As can be seen from Table 5, technological innovation is also an essential mediating mechanism between environmental regulation and energy-environmental efficiency, which also exemplifies the logic of hypothesis 3. All the above tests pass the AR test and the Hansen test.

Robustness Test

This study employs the method of substituting the core explanatory variables to test the accuracy of the benchmark results and ensure their reliability. In this study, the actual amount of investment in the treatment of industrial pollution sources is adopted to represent the level of environmental regulation and replace the core explanatory variable. In the regression without controlling variables, Table 6 demonstrates that environmental regulation significantly improves regional energy-environmental efficiency. The results were also crucial when control variables were included. All the above regressions passed the AR test and the Hansen test, which further ensured the robustness of the results.

Table 5. Analysis of mediating effect results.

-	(1)	(2)	(3)	(4)
Variable	upgrade	eepi	tech	eepi
L.eepi	-	0.399***	-	0.429***
-	-	(0.018)	-	(0.035)
upgrade	-	0.012***	-	-
-	-	(0.001)	-	-
envi	0.179***	0.074***	0.003***	0.069***
-	(0.012)	(0.008)	(0.001)	(0.009)
L.upgrade	1.062***	-	-	-
-	(0.003)	-	-	-
L.tech	-	-	0.936***	-
-	-	-	(0.033)	-
urban	-	-	0.006**	0.148***
-	-	-	(0.003)	(0.023)
hum	-	-	-0.000	0.005*
-	-	-	(0.000)	(0.003)
tech	-	-	-	0.608**
-	-	-	-	(0.270)
Constant	-0.022***	0.378***	-0.000	0.226***
-	(0.006)	(0.011)	(0.003)	(0.027)
Observations	270	270	270	270
Number of id	30	30	30	30
AR(1)	0.003	0.088	0.027	0.071
AR(2)	0.201	0.107	0.194	0.102
Hansen test	0.254	0.980	1.000	1.000

Note: ***, **, and * indicate significance at 1%, 5%, and 10% levels, respectively. AR is to test whether there is first-order and second-order autocorrelation between the difference of perturbation terms. The Sargan test is used to test whether there is excessive identification of instrumental variables.

Heterogeneity Test

Due to China's expansive territory, there are significant regional differences in resource endowments and economic foundation. To explore the regional heterogeneity of environmental regulation and energy-environmental efficiency, this study conducts an analysis of heterogeneity in the eastern, central, and western regions of China, and the specific regression results are demonstrated in Table 7. It is evident that the eastern region's environmental regulation has a sizable impact on the improvement of energy-environmental efficiency and has passed relevant tests. Although the central and western regions have also shown a certain positive promoting effect, it is not significant. This may be related to differences in economic and technological development levels, as well as industrial transfer. On the one hand, the economy in the eastern region is more developed, and enterprises are more likely to convert environmental regulation costs into efficiency improvements through technological innovation. As Li et al. (2023) [36] pointed out, the pilot policy of carbon emissions trading in the eastern region has significantly promoted green total factor energy efficiency (GTFEE), which is highly dependent on clean technology research and industrial upgrading. On the other hand, the eastern region has optimized its local industrial structure through industrial transfer (such as the relocation of high-energy-consuming industries to the central and western regions), shifting towards service and high-tech manufacturing industries. For example, Chen et al. (2020) [37] empirically found that the eastern region has formed a "pollution paradise avoidance effect" under environmental regulations,

Table 6. Robustness test.

-	(1)	(2)
Variable	SYSGMM	SYSGMM1
L.eepi	0.346***	0.369***
-	(0.005)	(0.025)
envi1	0.001***	0.001***
-	(0.000)	(0.000)
urban	-	0.141***
-	-	(0.022)
fdi	-	0.007**
-	-	(0.003)
enstru	-	0.006
-	-	(0.022)
hum	-	0.000
-	-	(0.002)
agg	-	0.069
-	-	(0.083)
Constant	0.417***	0.287***
-	(0.004)	(0.034)
Observations	270	270
Number of id	30	30
AR(1)	0.090	0.089
AR(2)	0.107	0.109
Hansen test	0.387	1.000

Note: ***, **, and * indicate significance at 1%, 5%, and 10% levels, respectively. AR is to test whether there is first-order and second-order autocorrelation between the difference of perturbation terms. The Sargan test is used to test whether there is excessive identification of instrumental variables.

Table 7. Eastern, Central, and Western region inspection.

-	(1)	(2)	(3)
Variable	east	middle	west
L.eepi	0.455***	0.665**	0.634***
-	(0.088)	(0.258)	(0.075)
envi	0.052***	-0.005	0.016
-	(0.012)	(0.022)	(0.068)
Constant	0.380***	0.222	0.223***
-	(0.063)	(0.167)	(0.056)
Observations	108	81	81
Number of id	12	9	9
AR(1)	0.083	0.064	0.069
AR(2)	0.216	0.908	0.225
Hansen test	1.000	1.000	1.000

Note: ***, **, and * indicate significance at 1%, 5%, and 10% levels, respectively. AR is to test whether there is first-order and second-order autocorrelation between the distinction of perturbation terms. The Sargan test is used to test whether there is excessive identification of instrumental variables.

Table 8. Moran index statistics.

Year	Moran's I	p-values
2011	0.122	0.000
2012	0.040	0.018
2013	0.002	0.163
2014	0.039	0.016
2015	0.039	0.016
2016	0.108	0.000
2017	0.185	0.000
2018	0.171	0.000
2019	0.077	0.000
2020	0.096	0.000

which means reducing local pollution through industrial upgrading.

Spatial Effect Test

As a means to better clarify the spatial effect of energy-environmental efficiency in each province, this study adopts the Moran index to conduct global and local analyses of its spatial correlation.

Moran's Global Autocorrelation Test

In this study, the Moran index is used to test the global autocorrelation of energy-environmental efficiency. It can be seen from Table 8 that the original hypothesis (null hypothesis: no spatial autocorrelation) of energy-environmental efficiency of all provinces is rejected in all years except 2013. This illustrates that each province's energy-environmental efficiency has a sizable spatial autocorrelation and a favorable spatial spillover. According to the changes in each year, the spatial spillover effect was the largest in 2017 and the smallest in 2013. Additionally, this demonstrates the validity of theory 4.

Moran's Local Spatial Autocorrelation Test

To further explore the spatial characteristics of each province, local Moran scatter plots in 2011 and 2020 were drawn, as shown in Fig. 1. It can be seen that most regions are located in the first or third quadrant, that is, they show a "high-high" correlation (high-value aggregation) and a "low-low" correlation (low-value aggregation). According to Fig. 1 and Fig. 2, in 2011 and 2020, regions numbered 1, 2, and 15 are always in the first quadrant, corresponding to Beijing, Tianjin, and Shandong, respectively. This shows that the energy-environmental efficiency of this region and neighboring regions is high. Regions 28, 27, and 30 are always in the third quadrant, corresponding to Qinghai, Gansu, and Xinjiang, respectively, which indicates that the energy-environmental efficiency of the above regions and neighboring regions is low. Some regions are always

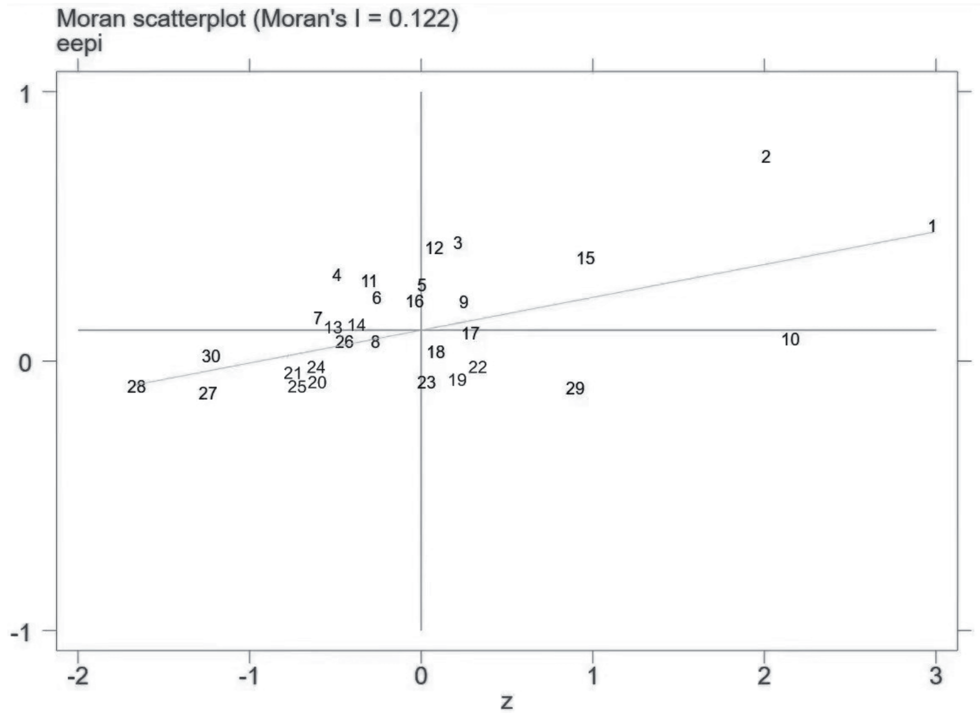

Fig. 1. Moran's correlation chart of energy-environmental efficiency in 2011.

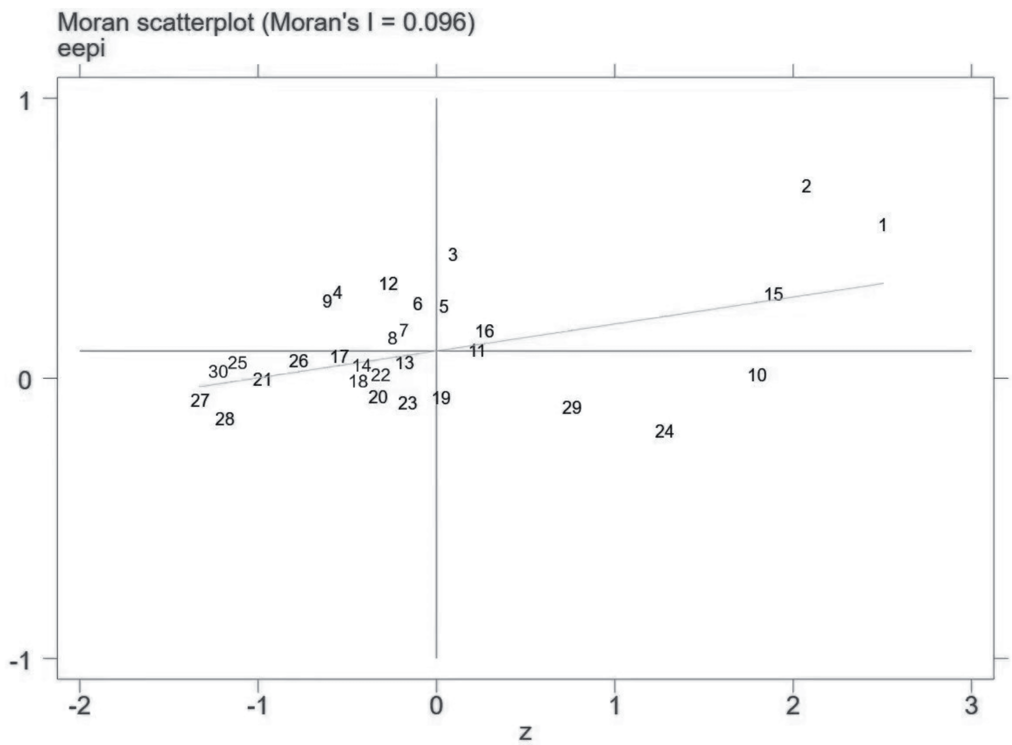

Fig. 2. Moran's correlation chart of energy-environmental efficiency in 2020.

located in the second and fourth quadrants, indicating that their energy environment efficiency is high, while neighboring regions, such as Shanxi, have a low energy environment efficiency. Alternatively, the energy environment efficiency of the local region may be low, but the energy environment efficiency of neighboring regions is high, which is the case for Ningxia. The specific correspondence between the numbers and the names of the provinces can be found in Table 9.

Table 9. The numbers correspond to the names of the provinces.

ID	Province
1	Beijing
2	Tianjin
3	Hebei
4	Shanxi
5	Inner Mongolia
6	Liaoning
7	Jilin
8	Heilongjiang
9	Shanghai
10	Jiangsu
11	Zhejiang
12	Anhui
13	Fujian
14	Jiangxi
15	Shandong
16	Henan
17	Hubei
18	Hunan
19	Guangdong
20	Guangxi
21	Hainan
22	Chongqing
23	Sichuan
24	Guizhou
25	Yunnan
26	Shaanxi
27	Gansu
28	Qinghai
29	Ningxia
30	Xinjiang

Spatial Result Analysis

Through the above Moran test, we find that there is a spatial correlation, so this paper conducts a spatial regression test on the relationship between environmental regulation and energy environmental efficiency. In order to improve the robustness of the model, this paper reports the SDM model, SEM model, and SAR model, respectively, as shown in Table 10. Through regression, it can be seen that the coefficients of the four spatial metrological models are all significantly positive, indicating that energy and environmental efficiency will be affected by energy activities in neighboring areas. In terms of fitting effect, SDM has the most significant numbers compared with SEM, SAR, and SAC. Further, the LR test on the SDM model shows that the P-value corresponding to the λ^2 statistic is less than 0.1. That is, the original hypothesis that spatial SAR, SEM, and SAC models replace SDM models is rejected. Based on the above analysis, the correctness

Table 10. Spatial measurement results and analysis.

-	(1)	(2)	(3)	(4)
Variable	sdm	sem	sar	sac
envi	0.002***	0.007*	0.005**	0.007***
-	(0.014)	(0.013)	(0.014)	(0.013)
urban	0.081**	0.040*	0.064***	0.030*
-	(0.084)	(0.064)	(0.079)	(0.064)
lnfdi	0.001*	0.003	0.001**	0.003*
-	(0.009)	(0.009)	(0.009)	(0.009)
enstru	0.022*	0.014**	0.010*	0.016**
-	(0.031)	(0.029)	(0.030)	(0.030)
hum	0.023*	-0.003	0.019**	-0.003
-	(0.019)	(0.010)	(0.018)	(0.009)
agg	0.497***	0.436***	0.412**	0.440***
-	(0.180)	(0.167)	(0.173)	(0.165)
rho	-0.368	-	0.295	0.196
-	(0.232)	-	(0.224)	(0.430)
sigma2_e	0.002***	0.002***	0.002***	0.002***
	(0.000)	(0.000)	(0.000)	(0.000)
lambda	-	0.038	-0.295	-0.181
-	-	(0.181)	(0.328)	(0.570)
Observations	300	300	300	300
R-squared	0.257	0.184	0.202	0.190
Number of id	30	30	30	30

Note: ***, **, and * indicate significance at 1%, 5%, and 10% levels, respectively.

Table 11. Spatial measurement results and analysis.

Variable	(1)	(2)	(3)
	LR_Direct	LR_Indirect	LR_Total
envi	0.045***	0.057*	0.102**
-	0.015	0.077	0.075
urban	0.090**	-0.558**	-0.468
-	0.083	0.362	0.342
lnfdi	0.002*	0.027***	0.029***
-	0.009	0.051	0.050
enstru	0.016**	0.283**	0.300***
-	0.030	0.188	0.189
hum	0.023***	0.011**	0.033***
-	0.018	0.091	0.094
agg	0.490***	0.718***	1.208**
-	0.175	0.899	0.940

Note: ***, **, and * indicate significance at 1%, 5%, and 10% levels, respectively.

of selecting the SDM model for analysis in this paper is demonstrated.

Since the coefficient in the SDM model cannot directly explain the economic significance of variables, it is necessary to decompose the influence effect, which can be divided into direct effect, indirect effect, and total effect. The specific decomposition is shown in Table 11. It can be seen that the direct effect, indirect effect, and total effect are all significantly positive, indicating that environmental regulation not only has a significant promoting effect on energy and environmental efficiency in the local area, but also has a positive promoting effect on energy and environmental efficiency in neighboring areas. In terms of coefficient size, the total coefficient of spatial effect 0.102 is significantly greater than the coefficient of the benchmark regression model 0.063. The results show that the fixed effect model of the main regression underestimates the impact of environmental regulation on energy environmental efficiency because it ignores the significant spatial spillover effect.

Conclusions

Firstly, this study takes advantage of NDDF to measure the energy-environmental efficiency of 30 regions in China. Secondly, based on relevant theories and calculated data, with the help of SYS-GMM and the mediating effect model, the relationship between environmental regulation and energy-environmental efficiency is explored, and the testing is conducted on the transmission mechanism of industrial upgrading and technological innovation. Finally, with the help of the spatial effect model, this study explores the spatial relationship between energy-environmental efficiency in different regions. The predominant conclusions of this study are as follows:

1) Each province's energy-environmental efficiency displayed distinct regional distribution characteristics. Based on the NDDF model, this study measures the energy-environmental efficiency of various provinces in China from 2011 to 2020. Beijing, Tianjin, and Shandong are the top three provinces in terms of energy-environmental efficiency. These provinces are all relatively developed eastern regions. Qinghai, Xinjiang, and Gansu, all in the western region, ranked lowest in terms of energy-environmental efficiency. From the perspective of time trends, the overall change in energy-environmental efficiency in China is relatively stable. It reached its lowest value in 2018 and its highest value in 2014.

2) Regional energy-environmental efficiency can be effectively enhanced by environmental regulation. Based on SYS-GMM regression, it can be seen that environmental regulation can positively promote the improvement of regional energy-environmental efficiency. Enterprises will be compelled to innovate by the clarity of property rights and the innovation of environmental regulation tools, such as environmental taxes. Business innovation will enhance production technology, reduce pollution emissions, and enhance regional energy-environmental performance. For other control variables, urbanization rate and human capital dramatically improve regional energy-environmental utilization. In the heterogeneity analysis, environmental regulation in the eastern region plays a core role in improving energy-environmental efficiency; however, the effect in the central and western regions is not significant.

3) Industrial upgrading and technological innovation are essential mediating mechanisms for environmental regulation to promote energy-environmental efficiency. The mediating effect model demonstrates that, on the one hand, environmental regulation can force the upgrading of industrial structures, and the upgrading of industrial structures can promote the deindustrialization of regional industrial structures. This will reduce greenhouse gas emissions and increase energy efficiency. On the other hand, environmental regulation can "boost" the improvement of regional innovation, which will reduce the long-term energy consumption and emission level of enterprises, and thus continuously improve energy-environmental efficiency.

4) The energy-environmental efficiency of each province has consequential spatial spillover. Industrial integration improves the spatial correlation between regions through cross-industry and cross-region imitation learning and industrial transfer. In compliance with the global Moran value of energy-environmental efficiency, the spatial spillover effect was the largest in 2017 and the smallest in 2013. In 2011 and 2020, Beijing, Tianjin, and Shandong investigated significant clustering of high energy-environmental efficiency values.

Qinghai, Gansu, and Xinjiang proved essential for the aggregation of low energy-environmental efficiency. At the same time, through the regression of the spatial econometric model, it is found that environmental regulation not only has a significant promoting effect on the energy and environmental efficiency of the local area, but also has a positive promoting effect on the energy and environmental efficiency of the neighboring area.

Policy Implications

Based on the above conclusions, this study puts forward specific suggestions for enhancing energy-environmental efficiency, which are as follows:

1) Strengthen the leading role of environmental regulation in maximizing energy-environmental efficiency. We will accelerate the improvement of the environmental regulation and policy system, continue to promote the establishment of a market for ecological factors, clarify the property rights of relevant ecological factors, and lessen the societal impact of negative environmental externalities. Various ministries and regions continue to improve relevant areas and regional environmental legislation better to regulate the green development of various regions and industries. The central government should enhance the evaluation system for the construction of an ecological civilization, particularly the green development performance evaluation system, to ensure the strict implementation of environmental regulations. It is essential to formulate a more scientific and effective division of labor and cooperation mechanism between the central government and local governments, thereby multiple factors, namely, finance, taxation, law enforcement, and policy, can form a joint force in environmental regulation. We will innovate and investigate the environmental regulation and supervision mode of mass participation, and construct a new three-party environmental regulation and supervision system of "government + market + public". Consequently, the Chinese government should optimize and complement the whole process system in terms of laws and regulations, institutional systems, implementation methods, and regulatory measures, to better play the role of environmental regulation in promoting energy-environmental efficiency.

2) Establish environmental regulations to force industrial structure upgrading mechanisms. Local governments should pay attention to the promoting effect of environmental regulation on the upgrading of industrial structure, and vigorously develop environment-friendly industries, such as high-tech industries, by leveraging the advantages of local resource endowment. The government should adopt stricter environmental regulations for enterprises with high energy consumption and high pollution to expedite their transformation into industries with low energy consumption and low pollution. In this process, environmental protection departments should give green development guidance to enterprises, establish an effective communication platform between local environmental protection agencies and transitioning businesses, and guide the upgrading of regional industrial structures.

3) To build a list management mode of technological innovation under the guidance of environmental regulation. Local governments can launch an incentive model for fundamental pollution control technologies in a variety of industries, thereby incentivizing more businesses to invest capital and talent in pollution control through material rewards. Accelerate the mode of cooperation between universities and businesses, combine the endowment of university research with the actual needs of enterprise development, and encourage the transformation of innovative pollution control technological achievements in universities. To create a market for the transformation of pollution control technology accomplishments, use the power of the market, and rationally allocate the flow of fundamental factors such as innovative technology.

4) We will expedite the establishment of a linkage mechanism between new energy development and environmental protection, and facilitate the implementation of environmental regulations according to local circumstances. Consider the spatial correlation of energy-environmental efficiency and create a linkage mechanism between the development of new energy and environmental protection in adjacent regions. To be more specific, the western region ought to take into account the spillover effect of energy-environmental efficiency in the eastern region and expedite cooperation with the eastern region in the areas of energy conservation and emission reduction, methods of pollution control, and the development of new forms of energy. We will accelerate the establishment of an "East-West" regional development support model and the transfer of innovative technology and human resources from the eastern region to the western region. To expedite the transfer of industries from the eastern region to the central and western regions, enterprises in the central and western regions must accelerate cross-regional and cross-industry technology learning and the improvement of regional energy-environmental efficiency by applying environmental regulations.

Due to the limitation of our research ability, our future research can be carried out from the following aspects: First of all, the research object can be extended to the global level for research, to have a new understanding of the relationship between current global environmental regulations and energy environmental efficiency. Secondly, due to our limited research knowledge, our research on the intermediary mechanism should be expanded to more levels, such as the social dimension, to smooth the transmission mechanism between environmental regulation and energy environmental efficiency.

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Conflict of Interest

The authors declared that there is no conflict of interest.

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