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Original Paper

Research on the Impact of Energy Spatial Mismatches on Collaborative Governance of Pollution Reduction and Carbon Reduction in Energy-Rich Areas

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Abstract

Collaborative governance of pollution reduction and carbon reduction is the core path and key starting point to promote green and low-carbon transformation, and helps to achieve two-way empowerment of environmental quality improvement and carbon peak and carbon neutrality. In the face of the prominent contradiction between the current distribution of energy resources and the reverse mismatch of demand, solving the contradiction of energy spatial mismatch and optimizing the geographical layout of energy have become the strategic fulcrum to ensure energy security and efficiency. Based on this, this study uses the panel data of 77 prefecture-level cities in China from 2012 to 2022, and firstly uses the fixed effect model to explore the direct relationship between energy spatial mismatch and collaborative governance of pollution reduction and carbon reduction. Secondly, this paper explores the transmission mechanism of energy spatial mismatch in collaborative governance of pollution reduction and carbon reduction with energy consumption intensity as the constraint variable. The results show that: (1) The energy spatial mismatch has a significant inhibitory effect on the collaborative governance of pollution reduction and carbon reduction. (2) Alleviating energy spatial mismatch can reduce energy consumption intensity and indirectly improve collaborative governance of pollution reduction and carbon reduction. The research conclusions provide theoretical basis and practical path reference for optimizing the collaborative development mechanism of environmental protection industry and clean energy industry in energy rich areas, and promoting the construction of sustainable collaborative governance system of pollution reduction and carbon reduction.

Keywords

Energy spatial mismatches, Collaborative governance of pollution reduction and carbon reduction,

Benchmark regression, System GMM

1. Introduction

The superposition effects of global warming and environmental pollution is reshaping the human environment at an unprecedented rate. According to the *AR6 Synthesis Report: Climate Change 2023* released by the IPCC, the global average temperature in the past decade has exceeded the historical maximum of 122,000 years. According to the World Health Organization (WHO), pollutants closely related to the burning of fossil energy, such as fine particulate matter, ozone, cause about 7 million premature deaths worldwide every year, and the resulting extreme climate events, ecological degradation and health risks exacerbate the complexity of environmental governance (Han et al., 2024). This series of data shows that the necessity and urgency of global environmental governance are self-evident. At the same time, the fossil energy-dependent development model leads to significant homology between air pollutants and greenhouse gas emissions, forming a lock-in effect of a vicious cycle of "high pollution-high carbon emissions" (Wesseh & Lin, 2018). In this context, China has made the collaborative governance of pollution reduction and carbon reduction (hereinafter referred to as) $Integration$ a national strategy. The Ministry of Ecology and Environment and other seven departments jointly issued the *Implementation Plan for Synergistic Efficiency of Pollution Reduction and Carbon Reduction* and other documents, it aims to solve the problem of separation of pollutants and carbon emissions through the systematic integration of environmental regulation and climate policies. breaks through the limitation of the single dimension of traditional environmental governance and promotes the in-depth coordination between environmental quality improvement and climate governance through the systematic coupling of pollutant emission control and greenhouse gas emission reduction.

China's energy-rich areas are mostly located in the central and western regions with fragile ecological environment, while the energy consumption center is concentrated in the eastern coastal urban agglomerations. The reserves of coal, oil and gas and renewable energy in energy-rich areas account for more than 70% of the total in China, but their energy consumption only accounts for about 35% of the total in China, forming the asymmetry of energy "production-consumption" space. The superposition of barriers, such as energy policy bias and market distortion, causes energy allocation to deviate from the general equilibrium state of "Pareto Optimality" in neoclassical economics and finally forms the energy spatial mismatch (hereinafter referred to as $Mismatch$) (Bai & Liu, 2018). Generally, hinders the free flow and "reallocation" of production factors, leading to substantial energy consumption. According to the National Bureau of Statistics, China's total energy consumption reached 5.41 billion tons of standard coal in 2022, a 2.9 percent increase year over year. Greenhouse gas emissions are projected to rise by 16 percent by 2030, with the current forecast indicating a 3% increase. Currently, hampers the optimal allocation and efficiency of energy utilization across industries, leading to a significant rise in pollution and carbon emissions directly (Guo et al., 2024). However, correctly correcting may effectively promote the upgrading of industrial structure and improve energy utilization, thus realizing the effect of (Li et al., 2021; Sun et al., 2023). Therefore, it is urgent to study the impact of on in energy-rich areas, which is the "key" to cracking the multiple constraints of the "energy-environment-economy" system, and also a significant strategic choice to plan regional coordinated development and ecological civilization construction under the background of "dual carbon" goal.

This research is devoted to addressing the following key questions: Does have a significant effect on $Integration$? If there is an impact, what is its specific mechanism? Through systematic theoretical analysis and empirical tests, this research will not only provide a decision-making basis for optimizing in energy-rich areas but also provide Chinese plans and reference value for global high-quality energy development and environmental governance.

The rest of the paper is arranged as follows: Section 2 systematically reviews the existing literature, focusing on $Mismatch$, the relationship between and $Integration$, and the research progress of $Integration$; Section 3 constructs the theoretical framework and puts forward the research hypothesis; Section 4 introduces the setting of measurement model and the calculation of core variables; Section 5 reports the empirical results, including benchmark regression analysis and mechanism analysis; Section 6 summarizes the findings, puts forward policy implications and points out the direction for future research.

2. Literature Review

2.1 Relevant Research on Energy $Mismatch$

There has been a lot of discussion on the actual demand of in the academic circle, and most of the literature focuses on three aspects: measurement research, antecedence research and aftereffect research of $Mismatch$.

(1) Research on the measurement of $Mismatch$. Based on the method of Chen et al. (2011), this paper calculates the energy mismatch by calculating the energy price distortion index and studying the two methods of directly measuring the market distortion degree and allocation efficiency of energy factors (Chen & Zhou, 2022; Kan & Lyu, 2016). Chu (2019) calculated the energy mismatch index and pointed out that energy mismatch hindered the optimal allocation of resources among enterprises, inhibited the effective flow of production factors and the upgrading of industrial structure.

(2) Antecedents and aftereffects of $Mismatch$. The previous research on is mainly carried out along two paths: one is the measurement and optimization of energy factor allocation efficiency; the other is the non-equilibrium analysis of energy price formation mechanism. Although the academia has made preliminary achievements in these two dimensions, it has not yet formed a complete theoretical system and research framework (Choi, 2020). Empirical studies have shown that the manufacturing industry generally has the problem of homogeneous resource allocation distortion (Su et al., 2021), showing

significant common characteristics of the industry. Based on the quantitative analysis results of and price formation mechanism, relevant studies further explore the internal correlation and action mechanism between the above distortion effect and key indicators such as environmental pollution and energy efficiency. Su (2020) evaluated and studied the regional gap, spatial effect and dynamic evolution of energy factor price distortion, and proposed that the market imbalance of energy pricing mechanism not only significantly inhibited the coordinated improvement of export trade competitiveness and energy utilization efficiency (Jiang, 2020; Yu & Yu, 2019), and the distortion of factor allocation caused by the distortion of price signals has a chain transmission effect on carbon emission efficiency (Su et al., 2021). Regarding the after-effect research of many scholars have explained the causes of energy misallocation from the dimensions of administrative monopoly (Leng & Du, 2016), industrial structure level (Li & Zhang, 2022), and government price intervention (Choi, 2020).

To sum up, $Mismatch$, as an important economic phenomenon, has attracted wide attention from all walks of life and policy makers. Existing studies mainly focus on the causes and consequences of and their own measurement. Future studies on should be more in-depth and comprehensive, which is of great significance for achieving the goal of energy transformation and carbon neutrality.

2.2 Related Research on Mismatch on Integration

At present, there are few studies that incorporate and into the same framework in the academic world, and the relevant researches mainly focus on the pollution and carbon emission effect of energy structure, energy intensity and energy price, and the environmental effect of resource mismatch.

(1) Pollution and carbon emission effect of energy. Wang (2019) believed that the improvement of carbon emission reduction efficiency and energy use efficiency mainly depended on the upgrading of energy structure, while to a certain extent and in specific fields, the change of energy structure was not conducive to carbon emission reduction. Cheng et al. (2013) found that the decline in energy intensity was the main reason for the decline in pollution and carbon emission intensity. Some scholars also pointed out that there was a non-linear correlation between energy price and carbon emission intensity, and the ability of energy price to regulate carbon emission intensity was different in different development stages, and the increase of energy price was conducive to carbon emission reduction in general (Chen & Yang, 2019). (2) Environmental effect of resource mismatch. The research of environmental policy and resource allocation is an important part of assessing the economic effect of environmental policy, Tombe et al. (2015) constructed a basic research framework on the impact of environmental policies on resource mismatch, and selected the optimal factor allocation as the reference system, indicating that there is resource mismatch in the absence of environmental policies. In addition, scholars analyzed the impact of resource mismatch on environmental pollution from the perspective of the action mechanisms such as resource mismatch hindering the optimization of industrial structure and inhibiting the improvement of ecological efficiency (Wang et al., 2022), and

resource mismatch leading to overcapacity and environmental pollution (Han et al., 2021).

To sum up, the current research on versus mainly focuses on the impact of energy economic attributes on pollution carbon emissions, and how resource mismatch affects environmental policies, pollution control and eco-efficiency. These researches provide an important reference for promoting the efficient use of energy resources and achieving the goal of "dual carbon". However, the current research on the specific analysis of effect and the deep mechanism of influencing is still insufficient.

2.3 Related Research on

Pollutants and greenhouse gas emissions are the main factors causing environmental degradation, and the two have strong roots and homology. Strengthening is the key measure to achieve the goal of "dual carbon". Therefore, has attracted the attention of scholars at home and abroad, and the existing research mainly focuses on three aspects: co-benefits, antecedent causes, and after-effects.

(1) In terms of co-benefits, the term "co-benefits" was first proposed by Ayres et al. (1991), that is, the emission reduction measures of greenhouse gases such as carbon dioxide can reduce the generation of other pollutants, and the effective treatment of pollutants can also reduce carbon emissions (Wang et al., 2021). On the one hand, the co-benefits of carbon on pollution. Liu et al. (2021) pointed out that reducing carbon emissions can also reduce pollutant emissions from the root, and the two can be promoted in a coordinated way. On the other hand, the co-benefits of pollution on carbon. Scholars have found that switching to low-sulfur or low-carbon fuels can improve air quality at the lowest cost, achieve the goal of reducing CO_2 emissions, and help improve the ecological environment (Chae, 2010; Fang et al., 2019). (2) In terms of antecedent causes, the existing literature has decomposed the total emissions of carbon into three types of drivers: population, economy and energy structure, namely KAYA identity. On this basis, scholars at home and abroad have conducted research based on technological change (Tong et al., 2020), enterprise digital transformation and other micro perspectives (Dai & Yang, 2022), and carbon tax policy (Barrage, 2020), international trade policy (Shaver & Shapiro, 2021), environmental policy (Lu & Yan, 2022) and other macro perspectives. Liu et al. (2019) believed that the effect of carbon emission trading policy was more significant in cities with large scale and high degree of industrialization. And some other scholars focus on low-carbon city pilot policies and find that low-carbon city pilot policies can effectively achieve (Zhang, 2020). (3) In terms of after-effects, coordinated efforts to reduce pollution and carbon emissions can have multi-dimensional effects. From the perspective of public health, significantly enhances residents' health benefits by improving air quality (Gallagher et al., 2019). From the perspective of economic efficiency, can optimize the efficiency of resource allocation and effectively reduce the marginal emission reduction cost of the whole society (Jiang et al., 2021). From the perspective of industrial development, can promote the upgrading of the industrial structure and accelerate the green and low-carbon transformation of the industrial sector through the forced mechanism of environmental regulation (Xiao & Lu, 2019).

To sum up, reducing pollution and carbon emissions is the basic premise and important guarantee of sustainable development, but the existing literature on the problem of in energy-rich areas is not sufficient.

3. Mechanism Analysis and Research Hypothesis

3.1 Theoretical Analysis and Research Hypotheses

The direct transmission mechanism of promoting can be systematically discussed from the three dimensions of cost internalization theory, environmental externality, and Coase theorem, as follows:

Firstly, based on the cost internalization theory, when is low, the environmental cost is internalized through carbon pricing (such as carbon tax and carbon trading), forcing the reconstruction of the energy system, and the internalized cost forms a closed loop of "energy conservation and emission reduction—cost shifting—technology diffusion". The carbon tax makes the environmental cost of the whole life cycle of fossil energy obvious, and the internalized cost forms the pressure of technology upgrading through market transmission (Shu et al., 2023), the cost of emission reduction will be transferred through the industrial chain, which will ultimately promote technology diffusion throughout the industrial chain, improve energy utilization efficiency, and achieve $Integration$. Secondly, according to the environmental externality, the environmental externality caused when are small and have the characteristics of spatial spillover, and the spatial optimal allocation of environmental capacity resources can be realized by establishing the ecological service value evaluation system and pollution right trading market, and the dual-track mechanism of horizontal compensation and market trading (Zhu et al., 2024). In addition, by designing a benefit-sharing mechanism for technology transfer, the transaction cost of green technology diffusion can be reduced, and a positive cycle of "innovation spillover—technology convergence" can be formed, which helps to improve (Yuan et al., 2022). Thirdly, the Coase Theorem shows that when is low, it can force the innovation of property rights system, form exclusive property rights through the initial allocation of carbon emission rights, clarify the development rights through the renewable energy quota system, and finally build the adjustment mechanism of "property rights definition—market transaction—spatial equilibrium". In addition, it can guide the flow of production factors to the clean energy field through price signals, realize the Pareto Optimization of the energy system in the spatial dimension, and then improve the level of (Wang et al., 2023).

To sum up, can form a transmission chain of "efficiency correction—compensation and incentive—allocation optimization", which can promote the transformation of energy system to a clean and low-carbon direction while reducing institutional transaction costs, and finally achieve the goal of $Integration$. Therefore, the research hypothesis of this paper is proposed below.

Hypothesis 1: will directly have a negative impact on $Integration$.

3.2 Indirect Conduction Mechanism and Research Hypothesis

Energy-rich areas are usually rich in traditional energy resources such as coal and oil, but these areas often face the problems of low energy utilization efficiency and high *Intensity*. This mode of high energy consumption not only leads to higher carbon emissions, but also intensifies the emission of air pollutants, thus weakening the effect of *Integration*. Therefore, is a key hub to link and *Integration*, and its transmission mechanism is reflected in the following two aspects. First, in terms of industrial structure, the improvement of the geographical agglomeration degree of the secondary industry will intensify the effect of *Mismatch*, resulting in an increase in the elasticity coefficient of energy intensity (Xia et al., 2018), which will further increase regional carbon emissions. On the contrary, the reduction of similarity coefficient in the process of rationalizing industrial structure can effectively reduce carbon emission intensity (Wang et al., 2022). The carbon emission intensity per unit GDP can be reduced through the triple path of deepening specialization, factor market integration and green technology diffusion in inter-regional industries. Second, at the level of technological innovation, leads to energy price distortion and government intervention jointly inhibiting green technological innovation (Li et al.,2016). On the one hand, price distortions make traditional energy have cost advantages, increase *Intensity*, and weaken the market competitiveness of green technology; On the other hand, government intervention may make the energy market lack sufficient incentives to promote green technology innovation, resulting in the process of technological innovation hindered, energy consumption further increased, and greatly hindered the process of *Integration*.

To sum up, although energy-rich areas are rich in traditional energy sources such as coal and oil, their high energy consumption patterns lead to low efficiency of energy use, aggravated carbon emissions and air pollution, and hinder the *Integration*. The core problem is that plays a role through dual mechanisms, and optimizing industrial structure, correcting price distortion, strengthening market incentives and technology diffusion are the key paths to achieve *Integration*. Therefore, the research hypothesis of this paper is proposed below.

Hypothesis 2: Alleviating is conducive to reducing and indirectly promoting *Integration*.

4. Research Design

4.1 Model Construction

In order to test the two hypotheses proposed in this paper, the system GMM model is used to examine the direct impact and mechanism path of the on the *Integration*. This paper incorporates into the analysis category of regional *Integration*. Considering the dynamic characteristics of *Integration*, this paper refers to the practice of Hou and other scholars, and introduces the variable of lag item $Integration_{it-1}$. The system GMM estimation method is used to construct the following models:

$$\mathrm{Integration}_{it}=\alpha_0+\alpha_1\mathrm{Integration}_{it-1}+\alpha_2\mathrm{Mismatch}_{it}+\alpha_n X_{it}+\lambda_i+\varepsilon_{it} \quad (1)$$

Where represents the city, represents the year, represents the collaborative governance of pollution reduction and carbon reduction in city in the year. is the core variable of this paper, representing the spatial mismatch degree of energy in city in the year *t*, and is the control variable in this model. It includes the level of opening-up (hereinafter referred to as *Open*), environmental regulation (hereinafter referred to as *Environment*), financial development level (hereinafter referred to as *Finance*), and Government preference for innovation (hereinafter referred to as *Government*). In addition, considering that there are some unobservable factors that also affect inclusive green growth in reality, this paper includes the unobservable individual fixed effect in the model. The random error term ε_{it}, α_1, are the coefficients of each variable, and represents the intercept term.

4.2 Variable Measurement

4.2.1 Explained Variable

Considering that air pollutant emissions and carbon dioxide emissions have the characteristics of the same root, same origin and same process, and China's coal-based energy structure, heavy-chemical industry structure and road-based transportation structure determine that there can be a strong synergistic effect between pollution reduction and carbon reduction (Wang et al., 2022). Carbon emission reduction and air pollutant control belong to two different subsystems in the same system, and there is a close dynamic coupling and mutual feed relationship, and the two are interrelated, interactive and mutually affecting (Tang et al., 2022). Referring to Han et al. (2023) and Han et al. (2023), this paper mainly selects carbon dioxide, soot and nitrogen oxide emissions for measurement in terms of pollution reduction. In terms of carbon reduction, carbon dioxide emissions are selected for measurement. The coupling coordination model is used to analyze the coordinated development level of things. The interaction and mutual influence between two or two systems can be expressed by the coupling degree, which can effectively reflect the cooperative development trend between different subsystems and the overall effect between systems. Therefore, the coupling coordination model is used to study the evaluation of the $Integration$, and then the differences in the coordination degree between air pollutant emission control and carbon emission reduction in different regions are analyzed. Referring to the research method of Wang et al. (2021), this paper divides the levels of coupling degree and coupling coordination degree, and corrects the model, and obtains the following model calculation method:

$$C=\frac{2\sqrt{U_1U_2}}{U_1U_2} \tag{3}$$

$$T=aU_1+bU_2 \tag{4}$$

$$Integration=\sqrt{C\times T} \tag{5}$$

Where, is pollutant emissions, is carbon emissions, this paper adopts the range standardization method to carry out dimensionless processing of the index; is the coupling coordination degree, and the value is [0,1]. The greater the value of $Integration$, the better the coordination between pollutant emission control and carbon emission reduction systems, and the stronger the degree of coordination, On the contrary, the degree of coordination is weaker. represents the coupling degree of the two systems; is the comprehensive coordination index of the two systems; This paper refers to the research of Wang et al. (2021), and takes a=b=0.5, that is, the control of air pollutant emission and carbon emission reduction are equally important.

4.2.2 Core Explanatory Variables

Referring to the idea of Bai et al. (2018), we measure the regional energy mismatch index by calculating the energy output elasticity and energy price distortion coefficient. The specific calculation steps are as follows:

(1) Calculation of energy output elasticity:

In order to accurately calculate the energy mismatch index, it is necessary to first estimate the energy output elasticity. Referring to the practice of Zhao (2006), this paper adopts Solow residual value to measure. It is assumed that the production function is C-D production function with constant returns to scale, namely:

$$Y_{it}=AK_{it}^{\beta_1}L_{it}^{\beta_2}E_{it}^{\beta_3} \tag{6}$$

Where $\beta_1+\beta_2+\beta_3=1$. The logarithm of both sides of the function is taken simultaneously, and the individual and the time effect are added to the model in the following form:

$$ln(Y_{it}/L_{it})=lnA+\beta_1 ln(K_{it}/L_{it})+\beta_3 ln(E_{it}/L_{it})+\mu_i+v_t+\varepsilon_{it} \tag{7}$$

Output variable (Y_{it}). It is represented by the GDP of each region, and the GDP of other years is calculated at constant prices using the GDP deflator with 2009 as the base period.

Capital input (K_{it}). It is represented by the fixed capital stock of each region, and the stock is calculated by the perpetual inventory method.

Labor input (L_{it}). It is represented by the number of employees in each region.

Energy input (E_{it}). It is represented by the total energy consumption of each region.

Due to the large differences in the economic strength of each province, the energy output elasticity of each region may be different, so it is more appropriate to adopt the variable coefficient panel model with variable intercept and variable slope. The estimation results show that the provincial dummy variable and the interaction term between the dummy variable and the explanatory variable of the variable coefficient are significant, so it is appropriate to use the variable coefficient model.

(2) Calculation of energy mismatch index:

In competitive equilibrium, we can define the "distortion coefficient" as follows:

$$\gamma_{Eit}=\frac{1}{1+\tau_{Eit}}$$

(8)

Where is the absolute distortion coefficient of factor prices, representing the markups when resources are relatively undistorted. The distortion coefficient reflects the deviation degree of the actual resource allocation from the theoretical effective resource allocation. When determining the allocation of factors among industries, it is the "relative" rather than the "absolute" distortion degree of factor prices that is important. Therefore, in the actual calculation, the relative distortion coefficient is used instead:

$$\hat{\gamma}_{Eit}=\frac{\gamma_{Eit}}{\sum_{i=1}^{n}(\frac{s_{it}\beta_{Eit}}{\beta_{Et}})\tau_{Eit}}$$

(9)

By transforming Formula (9), we can obtain:

$$\hat{\gamma}_{Eit}=\frac{K_{it}}{K_t}\Big/\frac{s_{it}\beta_{Eit}}{\beta_{Et}}$$

(10)

Where represents the actual proportion of energy used in in i; represents the share of regional output in national output in year i; represents the output weighted energy contribution value; respectively said that needs to be put into energy efficient allocation of resources theory. Due to the two situations of under-allocation and over-allocation, in order to make the regression direction consistent, this paper refers to the practice of Ji (2016) to process the absolute value of the threshold variable, the closer the value is to 0, the lower the degree of mismatch is.

4.2.3 Mechanism Variables

Intensity is the core index to measure regional energy utilization efficiency, and its reduction process is an important breakthrough to realize the synergy of pollution reduction and carbon reduction (Tang et al., 2022). By establishing a three-in-one governance framework of "structural optimization-technological innovation-system improvement", the contradiction of "energy efficiency improvement but total expansion" can be effectively solved, and then a collaborative control system covering the dual goals of pollution control and carbon emission reduction can be formed. This multi-dimensional and systematic governance mode can not only improve the efficiency of energy economic output, but also provide scientific decision-making basis for regional green and low-carbon transformation. This paper refers to the existing literature and uses the ratio of total urban energy consumption to GDP to reflect the provincial (Zhang, 2022).

4.2.4 Control Variables

The improvement of the is affected by many other factors in addition to the *Mismatch*. In order to ensure the robustness of the empirical results, this paper adds a series of control variables. ① Level of opening-up (*Open*). The synergistic effect of carbon reduction policies depends on the effect of technological progress, and the technology transfer brought about by opening up may strengthen this path (Zhang et al., 2022). Therefore, the level of opening-up has an important impact on the *Integration*, which is characterized by the proportion of total import and export volume in GDP of each province (Zhang et al., 2022). ② Environmental regulation (*Environment*). Environmental regulation needs to promote pollution reduction and carbon reduction from division and rule to coordination through the path of "difference and coordination-whole process embedded-multiple tool integration", and finally realize the qualitative change leap of ecological environmental governance. In this paper, the completed investment in industrial pollution control per CNY 1000 of industrial added value is used as the indicator to measure environmental regulation, and the calculation formula is the ratio of completed investment in industrial pollution control to industrial added value (He & Luo, 2018). ③ Financial development level (*Finance*). Referring to the existing literature, this paper uses the ratio of the balance of deposits and loans of financial institutions to GDP at the end of the year to represent the level of financial development. (4) Government innovation preference (*Government*). The integration of digital technology and digital intelligence has become an important starting point for the government to promote collaborative governance, and digital technology can achieve synergy in pollution reduction and carbon reduction at the national level by optimizing energy efficiency and production process innovation (Liu & Chen, 2023). Referring to the existing research, this paper uses the ratio of local science and technology investment to the total local fiscal expenditure to represent the government's innovation preference (Shi et al., 2024).

5.Empirical Results and Analysis

5.1 Analysis of Benchmark Regression Results

This research uses the official statistics released by the National Bureau of Statistics as the sample source, which ensures the accuracy and authority of the data. In order to reduce the endogeneity problem caused by measurement errors, this paper introduces four types of control variables: *Open*, *Environment*, and to alleviate the omitted variable bias. It should be pointed out that there may be bidirectional causality between and Integration. In addition, given the complexity and diversity of factors affecting Integration, it is difficult to cover all relevant variables in the process of model construction, which may lead to the problem of omitted variables to a certain extent. Therefore, this research attempts to alleviate the endogeneity problem through the instrumental variable method, selects the data of lagged by one period as the instrumental variable, and uses the system GMM model for estimation, and incorporates the control variables into the model in turn. According to the results of the system GMM model, as shown in Table 1, firstly, the AR test shows that the model is serially correlated in the first order but uncorrelated in the second order, indicating that the original model has no significant serial correlation in the error term. Secondly, the Hansen test value is greater than 0.1, indicating that the overidentifying constraint is valid. At the same time, it can be observed that the influence coefficients of on are significantly negative, that is, it plays an inhibitory role. This conclusion is similar to that of Guo et al. (2024), which further proves the robustness of the research results.

In terms of control variables, the coefficient of on is -0.009, but it is not significant. The reason may be that: In order to attract foreign investment, the threshold of environmental protection may be lowered, especially in the energy-rich areas in the central and western regions, is accompanied by the transfer of pollution-intensive industries, aggravating the pressure of local environmental pollution, and the scale and level of are insufficient to achieve *Integration*, and this conclusion is consistent with the "pollution paradise" hypothesis (Gao, 2025). The coefficient of affecting is 0.439, and it is significant at the level of 10%. The increase of can force enterprises to upgrade green technology, improve energy efficiency, and reduce pollutants and carbon emissions, indicating that stricter policy of helps to promote *Integration*, which is in line with the theoretical expectation of Porter hypothesis (Han et al., 2024). promotes at the significance level of 1%, and when is high, it has more perfect green credit, green bonds, carbon finance and other tools, which can provide financial support for clean technology R&D and low-carbon projects, thus effectively promoting (Hu et al., 2025). The influence coefficient of on is 0.024, and the significance level is 1%. The government regards scientific and technological innovation as the core of environmental governance, and the policy support and resource tilt for scientific and technological innovation bring about iterative upgrading of technology, lead the development of technology to green innovation, improve the efficiency of resource utilization, and thus effectively promote *Integration*.

Table 1. Benchmark Regression Results

	(1) *Integration*	(2) *Integration*	(3) *Integration*	(4) *Integration*	(5) *Integration*
Mismatch	-0.005***	-0.005***	-0.006***	-0.007***	-0.007***
	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)
L.Integration	0.722***	0.726***	0.754***	0.772***	0.786***
	(0.004)	(0.003)	(0.004)	(0.007)	(0.007)
Open		0.018***	-0.005***	-0.011**	-0.009
		(0.000)	(0.002)	(0.005)	(0.008)
Environment			0.835***	0.568***	0.439*
			(0.051)	(0.144)	(0.240)

Finance				0.006***	0.007***
				(0.001)	(0.001)
Government					0.024***
					(0.008)
_cons	0.151***	0.143***	0.121***	0.101***	0.088***
	(0.003)	(0.001)	(0.003)	(0.007)	(0.006)
AR (1)	0.000	0.000	0.000	0.000	0.000
AR (2)	0.366	0.377	0.382	0.341	0.351
Hansen	0.360	0.615	1.000	1.000	1.000
N	770	770	770	770	770

Note. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$. The standard error is given in parentheses (the same as in the table below).

5.2 Analysis of Mechanism

The test results of the mechanism of in energy-rich areas affecting the are shown in Table 2. By analyzing the influence coefficients and significance levels of key variables and mechanism variables in the model, it is concluded that under the influence of *Intensity*, the in energy-rich areas has an indirect effect on the to a certain extent, which provides sufficient evidence for Hypothesis 2 of this paper. Specifically, on the premise that other factors remain unchanged, the will increase by 0.007 units for every 1 unit increase in the level of *Mismatch*. Furthermore, reducing means improving energy utilization efficiency, directly reducing fossil energy consumption, and thus reducing pollutants (such as SO_2 and PM2.5) and CO_2 emissions (Zhang et al., 2022). Similarly, by improving energy efficiency, the energy-use trading system reduced CO2 emissions and PM2.5 concentration by 13.3% and 3.1% respectively in the pilot areas (Wu & Qiu, 2024), which verified the direct synergistic emission reduction effect of energy intensity reduction. In addition, there are certain spatial differences in the *Mismatch*, and most of the energy-rich areas are cities in the central and western regions and resource-based cities. All in all, the factor reorganization effect and structural energy saving effect caused by the optimal allocation of energy space can effectively drive the dual optimization of improving energy utilization efficiency and decreasing *Intensity*, thus providing a continuous impetus for the synergy of pollution and carbon reduction, thus verifying Hypothesis 2.

Table 2. Mechanism Analysis Results

Variables	(6) *Intensity*	(7) *Integration*
Mismatch	0.007***	-0.007***
	(0.002)	(0.002)

L.Integration		0.786***
		(0.007)
L.Inensity	0.730***	
	(0.002)	
Open	-0.009	-0.008
	(0.007)	(0.008)
Environment	2.307**	0.439*
	(0.193)	(0.240)
Finance	-0.006***	0.007***
	(0.001)	(0.001)
Government	-0.314***	0.024**
	(0.022)	(0.008)
_cons	0.213***	0.088***
	(0.004)	(0.006)
AR (1)	0.000	0.000
AR (2)	0.256	0.351
Hansen	1.000	1.000
N	770	770

6. Conclusions and Prospects

6.1 Research Summary

From the perspective of energy mismatch in energy-rich areas, based on the panel data of China's prefecture-level cities from 2012-2022, this paper deeply analyzes the role and influence of in the from two dimensions of basic impact effect and effect transmission mechanism. This paper uses panel fixed effect model and intermediary effect model, and adopts GMM method to explore the complex relationship between and in energy-rich areas (77 cities in the Yellow River Basin), and further reveals the impact mechanism of on through theoretical analysis and empirical test results. The research conclusions are as follows: (1) can play a significant positive role in the *Integration*. This conclusion is still robust after GMM regression. (2) Energy spatial mismatching produces multi-level indirect effects. It optimizes the distribution of production factors, improves energy utilization efficiency, and reduces *Intensity*, thus providing impetus for *Integration*.

6.2 Policy Implications

First, build a dynamic and optimal allocation mechanism for energy space. A dynamic trading platform for energy indicators will be designed to allow energy-rich areas to realize cross-regional energy quota adjustment through market-oriented mechanisms on the premise of achieving pollution reduction and carbon reduction targets. Explore the index management of "mismatch tolerance", incorporate the optimization effect of into the carbon emission trading system, and form a closed-loop mechanism of "mismatch correction - efficiency improvement - value transformation". In addition, a special fund for the circulation of factors in the Yellow River Basin was set up to focus on supporting the inter-regional mobility of skilled labor in energy-intensive industries. For enterprises that take the initiative to optimize energy allocation, policy incentives such as carbon tax reduction and discount interest on green credit will be given, and a positive cycle of "mismatch improvement - factor restructuring - collaborative governance" will be established.

Second, we need to deepen the mechanism for coordinated regional governance. Cities should innovate the accounting standard of "synergistic equivalent of pollution reduction and carbon reduction" and implement the doubling plan of ecological compensation for energy-exporting cities. The co-governance benefits generated by the are quantified as the value of ecological products, and cross-regional value sharing is realized through horizontal transfer payments. For the Yellow River basin, lay out a smart energy corridor and build a clean energy transmission network of version 2.0 of "power transmission from west to east". Establish a consortium for environmental governance in urban agglomerations to realize the coordinated scheduling of joint prevention and control of air pollution and carbon emission reduction.

Third, cultivate new governance bodies. The city focuses on cultivating market players with comprehensive capabilities in energy system optimization, pollution control and carbon asset management, establishing the Green technology Innovation Alliance in the Yellow River Basin, and establishing a collaborative research mechanism of "enterprises producing problems, institutes solving problems, and the government assisting problems". Furthermore, an open technology verification platform should be set up to accelerate the industrial application of innovation achievements, and provide cities with customized services of energy spatial configuration diagnosis and governance schemes.

6.3 Limitations

Although this study makes a quantitative analysis on the mechanism of affecting the *Integration*, and puts forward corresponding suggestions according to the actual situation, there are still some limitations, which are also key areas for future research, including the following: ① In terms of research objects, this study only focuses on 77 prefecture-level cities in the Yellow River Basin, and the conclusions may not be extended to other energy-rich areas in China. In terms of research methods, although the system GMM model and instrumental variable method are adopted, the complex bidirectional causal relationship between and may not be completely eliminated. (2) In the follow-up research, in order to more comprehensively explore the "black box" mechanism of for *Integration*, a series of key variables can be included, such as innovation capacity, policy support, market environment and infrastructure construction, so as to build a multi-dimensional analysis framework and provide theoretical basis for the formulation of more accurate policy measures.

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