Does Renewable Energy Consumption Successfully Promote the Green Transformation of China's Industry?

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Abstract: The trade-off between economic growth and ecological improvement has always become an important and difficult issue for many countries, especially for developing countries. Due to a long-term extensive economic growth pattern, the regional resource allocation deviates from the optimal, especially the existence of energy misallocation, which hinders the maximization of economic output. Therefore, considering the characteristics and heterogeneity of resource endowments in different regions and increasing renewable energy consumption, that is, promoting energy transition, is it capable of sustainable development under China's actual conditions? The exploration of the issue is a core step in the research of the impact of renewable energy on industrial green transformation. Based on the panel data of 30 regions in China from 2009 to 2016, this paper constructs a threshold model from the perspective of regional energy misallocation and empirically tests the nonlinear mechanism of renewable energy consumption to promote industrial green transformation. The results show that China's energy allocation efficiency is low, there is a certain misallocation phenomenon, and the improvement effect in recent years is not satisfactory. Further, the relationship between renewable energy consumption and industrial green transformation is not a simple linear relationship, but a double threshold effect due to regional energy misallocation. In areas with severe energy misallocation, renewable energy consumption does not have a significant boost to industrial green transformation. Finally, this paper proposes the policy enlightenment of promoting industrial green transformation from the aspects of performance evaluation, market reform, and factor flow.

Keywords: renewable energy consumption; industrial green transformation; energy misallocation; China

1. Introduction

With the continuous advancement of industrialization, the global environmental crisis has also emerged. At present, the contradiction between environmental protection and economic growth in various countries is becoming increasingly acute, and the promotion of green development has gradually become a global consensus. China's economy has grown rapidly over the past four decades. However, the extensive industrial growth model with high input and low output has also come at a serious environmental cost. A mass of resource consumption and ecological destruction have approached the environmental carrying limit, forcing China's industry to achieve green transformation and upgrading [1]. For the first time, at China's 19th National Congress, green development has been raised to the height of the national development strategy, and it proposed to promote the energy production and consumption revolution and effectively guide the industrial transformation and upgrading. At the same time, General Secretary Xi Jinping also pointed out that clean energy development is an important task to ensure energy security, and promote the construction of an

ecological civilization, which has become an essential path for solving the main contradictions in our society in the new era. Therefore, the development of renewable energy and the promotion of industrial green transformation have become the key to achieving a "win-win" strategy for economic growth and environmental protection. Meanwhile, due to the wide geographical distribution of China, according to the China Statistical Yearbook, the per capita GDP of the eastern region in 2017 was 82,970.05 yuan, and the average carbon emission intensity was 1.294 tons/10,000 yuan. However, the per capita GDP in the central and western areas is only 47,312.27 yuan, and the average carbon emission intensity is as high as 3.522 tons/10,000 yuan. Areas in China differ in terms of ecological resource structure, environmental quality, and economic growth patterns, especially, the difference between China's three major economic zones is more prominent. Therefore, in the process of promoting renewable energy consumption and an industrial green transition, regional heterogeneity should be fully considered, which has not been entirely reflected in previous studies.

Due to a large number of distortions in the operation of China's market [2,3], the prices of energy and other factors of production are distorted, hindering the free flow of energy and resulting in excess energy supply in some regions, but insufficient energy supply in other regions, which deviated from the Pareto optimality, causing a certain degree of "energy misallocation" [4]. In the process of promoting renewable energy consumption, if energy is mismatched in the region, the increase in renewable energy consumption may exacerbate the distortion of factor markets and hinder economic output. If the regional energy allocation structure is reasonable, a clean energy transition may promote the optimization of the industrial structure, help to coordinate the contradiction between environmental pollution and economic growth, and generate positive externalities. Therefore, when exploring the promotion of industrial green transformation through renewable energy consumption, the degree of regional energy misallocation should be fully considered. However, existing research focuses more on the allocation of capital and labor and fails to pay sufficient attention to the importance of energy allocation. Resource allocation is rarely mentioned in the literature on the impact of renewable energy consumption. In addition, there are few studies that involve differences in the impact of renewable energy development on industrial green transformation under heterogeneous conditions; that is, different degrees of energy misallocation.

Therefore, from a regional perspective, this paper studies the mechanism of the development of renewable energy consumption on industrial green transformation based on the energy misallocation situation in various regions. First, we measured the level of industrial green transformation in 30 regions in China. Second, we calculated the degree of energy misallocation in each region based on the least squares dummy variable (LSDV) method. Third, we built a research model that includes three variables: renewable energy consumption, energy misallocation, and industrial green transformation. Finally, based on the threshold effect of energy misallocation, we explored whether a non-linear relationship exists between renewable energy consumption and industrial green transition. In theory, this research can expand the study on energy transition, resource allocation, and sustainable development issues. In practice, this research can provide experience and reference for policy making and industrial adjustment of high-quality development in China and other developing countries.

2. Literature Review

Promoting renewable energy consumption and development has become a vital energy strategy for countries [5]. However, the current level of renewable energy technology is generally poor, especially new energy, such as ocean and solar energies. Relevant studies on renewable energy have been carried out by scholars from the technical routes [6], case studies [7,8], or support policies [9]. In addition, some scholars have analyzed the possible impact of renewable energy consumption. For example, through causal testing, Dogan and Seker [10] found a two-way causal relationship between renewable energy consumption and carbon dioxide emissions, Moreover, they proposed that the active development of renewable energy is conducive to reducing carbon dioxide emissions [11]. Using the logarithmic mean Divisia index (LMDI) decomposition model and China's panel data

from 1994 to 2008, Lu et al. [12] suggested that renewable energy, as an environmentally friendly energy source, can replace non-renewable energy, which can optimize an energy structure and help control carbon dioxide emissions. Other domestic scholars have similar conclusions [13]; they also suggested that regional governments should take advantage of natural resources, such as wind, solar, and hydropower, to reduce dependence on high-pollution coal and promote carbon dioxide emission reduction. Moreover, using the panel data model studies, Inglesi-Lotz [14] found that renewable energy consumption can significantly help national economic development, which was confirmed by the results of Bhattacharya et al. [15]. Through long-term observations of the economic development of the Black Sea and the Balkan countries, Kocak and Sarkgunesi [16] conducted a detailed study of the relationship between energy structure and economic growth and found a cointegration relationship between them. However, using the same model to simulate the relationship between renewable energy development and economic growth, Kahia et al. [17] showed that long-term and short-term two-way causality between them may exist. This suggests that when studying the relationship between energy structure and economic development in different countries, even with the same research methods and models, the results are significantly different [18,19]. The main reason is that economic phenomena are complex and variable, leading to nonlinear relationships between economic variables. Granger [20] pointed out that "the world is almost composed of nonlinear relationships." Ignoring the strong nonlinear relationship between economic variables, and using traditional linear methods to study the relationship between renewable energy and energy structure, economic growth, and other factors, will inevitably lead to significant errors in the estimation results. Moreover, the conclusions may not fully explain the economic reality, and the recommendations may not be of practical significance [21]. China has a vast territory, but due to historical development, geographical location, natural conditions, population, policies, and other factors, vast differences occur in the level of national economic growth in various regions [22]. Ignoring these objective regional differences, the conclusions obtained from research at the national level are difficult to apply to the needs of the development of renewable energy in different regions.

In addition, some scholars have recently explored the effects of renewable energy consumption based on the factor allocation structure. For example, Zhang [23] proposed that the rational adjustment of the energy factor structure is the primary prerequisite for industrial restructuring to promote carbon emission reduction. By introducing the production function of energy and human capital factors to explore its relationship with carbon productivity, Li [4] proposed that the decline of China's labor energy ratio in recent years is an essential reason for the low carbon productivity. Further, he offered to adjust the factor structure at a deeper level, improve the efficiency of factor allocation, and achieve sustainable economic development. Although scholars have recognized the impact of factor allocation on economic low-carbon transformation, related literature on energy misallocation is scarce. Based on the resource allocation structure of each region, the research on quantifying the degree of energy misallocation is even insufficient.

The available literature has a precious theoretical reference value for this paper. However, there is still room for improvement in the study on whether renewable energy consumption can promote industrial green transformation.

First, the existing literature on renewable energy consumption is more concerned with its relationship with economic benefits and carbon emission. The significance of sustainable development lies in coordinating the sharp contradiction between economy and ecology, rather than merely promoting or inhibiting either of them. The question that arises is whether renewable energy consumption can reduce pollution while ensuring economic development; that is, can it sustainably promote China's industrial green transformation? Research on this issue is insufficient.

Second, capital, labor, and energy are the three essential elements of the transformation of production mode. The adjustment of factor structure is the most fundamental and important characteristic of industrial transformation. Therefore, the importance and urgency of improving the efficiency of factor allocation to meet the requirements of low-carbon development should be given full

attention, especially energy factors. However, the existing literature pays less attention to this issue, which will undoubtedly affect energy transformation and low-carbon development in China and other developing countries.

Third, the previous literature mainly studied the effects of renewable energy consumption on its contributing factors and regional differences based on linear methods and grouping methods. However, relying solely on traditional linear methods may not be accurate enough because of the multiple mechanisms of action between renewable energy consumption and industrial green transformation. At the same time, the biggest problem with the grouping method is that the determination of the grouping criteria is arbitrary and not inferred from the mathematical statistics. It is also impossible to test the difference in the regression results of different samples [24]. This may result in invalid or unreliable parameter estimates.

To make up for the shortcomings of the above three aspects, this study supplements the following three points: First, we construct a more reasonable evaluation index system, scientifically assess the industrial green transformation performance of 30 regions in China, and then explore whether renewable energy consumption has promoted industrial green transformation. Second, based on the LSDV model, we measure the energy allocation efficiency of various regions in China, and analyze whether a misallocation occurs and its extent. Third, we put renewable energy consumption, energy misallocation, and industrial green transformation under the same framework, and explore whether a nonlinear relationship exists between the three.

3. Research Design

3.1. Threshold Model Construction

As aforementioned, the impact of renewable energy consumption on industrial green transformation is not necessarily a simple linear relationship, but a non-linear relationship due to the difference in regional energy allocation efficiency. In order to further explore whether renewable energy consumption has different mechanisms of action for industrial green transformation under varying levels of energy misallocation, this paper uses the panel threshold model for empirical research.

Assume that the balance panel dataset is $\{y_{it}, q_{it}, x_{it}, 1 \leq i \leq I, 1 \leq t \leq T\}$, then a single threshold model can be expressed as

$$y_{it} = \mu_i + \beta_1 x_{it} \times I(q_{it} \leq \gamma) + \beta_2 x_{it} \times I(q_{it} > \gamma) + \varepsilon_{it}, \tag{1}$$

where y_{it} and x_{it} are the explained variable and explanatory variables, respectively; $I(\bullet)$ is an indicator function whose value is 1 or 0, depending on the authenticity of the expression; u_i is the individual fixed effect, $\varepsilon_{it} \sim idd(0, \delta^2)$ is the random interference term; and β_1 and β_2 are variable coefficients, in which $\beta_1 \neq \beta_2$ indicates the existence of the threshold effect.

When using the group test method to examine the nonlinear effects between variables, the grouping criteria are given exogenously. However, in the threshold model, the threshold γ is unknown and is determined entirely by the data characteristics of the sample. The grid search method is typically used to ensure the optimal threshold value $\hat{\gamma}$. When γ is $\hat{\gamma}$, the residual sum of squares $S(\gamma)$ of the threshold model is the smallest; that is, $\hat{\gamma} = argminS(\gamma)$ [25]. After the optimal threshold value is determined, it is necessary to further check whether the threshold effect is significant and real.

The above model assumes only a single threshold, but in reality a double threshold or multiple thresholds may exist. Taking the double threshold as an example, we set the model to

$$y_{it} = \mu_i + \beta_1 x_{it} \times I(q_{it} \leq \gamma_1) + \beta_2 x_{it} \times I(\gamma_1 < q_{it} \leq \gamma_2) + \beta_3 x_{it} \times I(q_{it} > \gamma_2) + \varepsilon_{it}, \tag{2}$$

where $\gamma_1 < \gamma_2$ and the other indicators have the same meaning as in Equation (1). The steps for the double threshold estimation according to the optimized search method are as follows [26]: First, assume that the model has a single threshold, and after searching for the first threshold value $\hat{\gamma}_1$,

assume that $\hat{\gamma}_1$ is a known variable. Second, continue to search for the second threshold value $\hat{\gamma}_2$. If $\hat{\gamma}_2$ exists, it is necessary to assume that $\hat{\gamma}_2$ is a known variable, and then we search for the first threshold value again. The above steps were repeated to obtain a consistent estimate of the two threshold values.

Taking the double threshold model as an example, this paper establishes a dual-threshold model with industrial green transformation as the explained variable, renewable energy consumption as the core explanatory variable, and energy misallocation degree as the threshold variable. Then, we explored the difference in the impact of renewable energy consumption on industrial green transformation when the degree of energy misallocation is greater or less than the threshold. The model is set explicitly as follows:

$$
\begin{aligned}
Upgrade_{it} = {} & \theta + \alpha_1 R\&D_{it} + \alpha_2 Regulation_{it} + \alpha_3 OPEN_{it} + \alpha_4 Human_{it} \\
& + \beta_1 Renewable_{it} I(\tau_{it} \leq \gamma_1) + \beta_2 Renewable_{it} I(\gamma_1 < \tau_{it} \leq \gamma_2) \\
& + \beta_3 Renewable_{it} I(\tau_{it} > \gamma_3) + u_i + \varepsilon_{it},
\end{aligned} \tag{3}
$$

where $Upgrade_{it}$ indicates the degree of industrial green transformation; $Renewable_{it}$ denotes the renewable energy consumption; τ_{it} denotes the degree of energy misallocation; and γ is the threshold value. The control variables mainly include $R\&D_{it}$ denoting the regional R&D level, $Regulation_{it}$ denoting the environmental regulation intensity, $OPEN_{it}$ denoting the degree of openness, and $Human_{it}$ denoting human capital.

3.2. Variable Description and Data Processing

(1). Interpreted variable: Industrial Green Transformation (*Upgrade*). This paper draws on the Industrial Green Development Plan released by the Ministry of Industry and Information Technology in 2016, and the research results of Deng et al. [1]. Moreover, this study uses the entropy method of objective weighting to calculate China's industrial green transformation index. Specific indicator evaluation systems and calculation steps are provided in the Appendices A and B.

(2). Explanatory variable: Renewable energy consumption (*Renewable*). This paper uses the ratio of renewable energy consumption to the total regional energy consumption, reflecting the level of cleanliness of regional energy. Among them, renewable energy consumption is converted using standard coal. Limited by the availability of data, the scope of renewable energy in this paper is narrowly defined, referring only to non-fossil energy sources.

(3). Threshold variable: Energy misallocation(τ). This paper measures the regional energy misallocation index by calculating energy output elasticity and energy price distortion coefficient [27–29]. The specific calculation steps are provided in the Abbreviations.

(4). Control variables: This paper selects the following four variables to control the regional trait effects that cannot be observed: Regional R&D level (*R&D*), expressed by the unit's R&D investment in the technical market turnover; environmental regulation strength (*Regulation*), expressed by the amount of investment in environmental pollution control per unit of GDP; degree of openness (*OPEN*), expressed by the proportion of total import and export volume and GDP; and human capital (*Human*), expressed by average years of schooling.

All data were from the China National Bureau of Statistics, and the National Energy Model Integration Platform of the Beijing Institute of Technology. To reduce possible heteroscedasticity and dispersion in the data, this paper performs logarithmic and subtraction processing on related variables. The descriptive statistical analysis of the samples is shown in Table 1.

Table 1. Descriptive statistics of variables.

Variable	Mean	SD	Variance	Min	Max
Upgrade	0.333333	0.028740	0.001	0.400356	0.248822
Renewable	0.126633	0.164297	0.027	1.175026	0.001711
τ	0.621777	0.547796	0.300	2.262257	0.001402
R&D	4.428229	0.715301	0.512	6.336892	2.839786
Regulation	1.387302	1.190319	1.417	9.936815	0.067043
OPEN	0.273221	0.303401	0.092	1.457920	0.013364
Human	2.183610	0.100052	0.010	2.509904	1.911606

4. Panel Regression Results

4.1. Variable Multicollinearity Test

The test results of this study reveal that the correlation coefficient between the variables is not significant, and all are less than 0.6. Among them, the correlation coefficient between the industrial green transformation of the explanatory variable and the region R&D level of the control variable is the highest, which is 0.5709.

For the variables in the text, the variance inflation factor (VIF) test results are shown in Table 2. The maximum VIF value of all variables is 1.79, which is much smaller than 10.

Table 2. Variance inflation factor (VIF) of each variable.

	Upgrade	Renewable	τ	R&D	Regulation	OPEN	Human	Mean
VIF	1.79	1.56	1.41	1.15	1.14	1.04	1.348333	1.56
1/VIF	0.559525	0.639533	0.709933	0.872749	0.874453	0.961118	0.769552	0.559525

Therefore, combining the correlation coefficient and the analysis result of the VIF, we determined that no multicollinearity exists between variables [5].

### 4.2. Panel Threshold Model Results and Analysis

Based on the energy misallocation level in each region, this paper uses the panel threshold measurement method to empirically explore the complex mechanism between renewable energy consumption and industrial green transformation. The F-value and *p*-value obtained after 300 repeated samplings are presented in Table 3. The result shows that both the single and the double threshold effects of the model pass the test; that is, a significant double threshold effect of energy misallocation exists, with the single and double threshold values of 0.1789 and 0.8936, respectively. Therefore, this paper makes a detailed analysis of the double threshold effect.

Table 3. Test results of threshold significance.

Threshold	F-Value	*p*-Value	Critical Value		
			1%	5%	10%
Single threshold	48.56 ***	0.0000	300	29.4830	22.0200
Double threshold	23.42 *	0.0633	300	46.5905	24.6869

*, **, and *** denote statistical significance levels at 10%, 5%, and 1%, respectively.

To better observe the estimation and confidence interval of the threshold value, the threshold value *LR* of the least squares is used to identify the threshold value. The threshold estimate is the value of *γ* when *LR* is zero. Next, the likelihood ratio function graphs of the two threshold values are plotted, as shown in Figure 1.
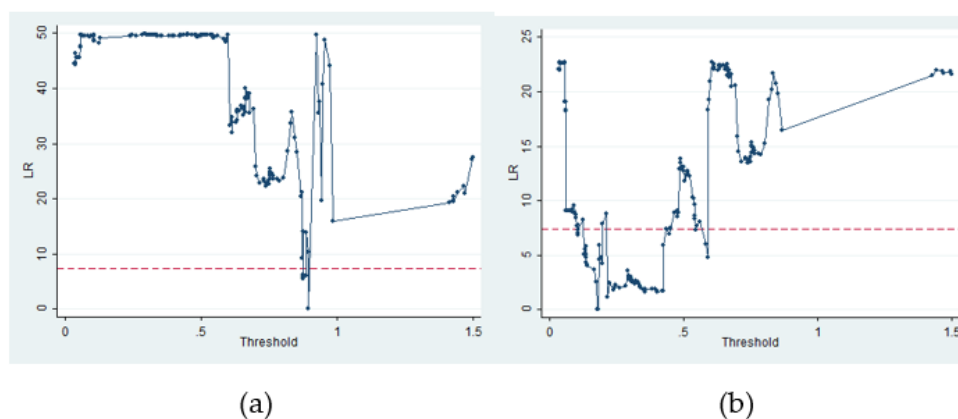
Figure 1. Estimation and confidence interval for the first threshold (**a**) and the second threshold (**b**) of energy misallocation.

Table 4 reports two threshold estimates and a 95% confidence interval. In conjunction with Figure 1, the 95% confidence intervals for the two threshold values γ_1 and γ_2 are 0.1496 and 0.1818 and 0.8841 and 0.9225, respectively. All *LR* values are less than 7.35, which is the critical value at 5% significant level (denoted by the dashed line in the figure).

Table 4. Threshold values and confidence intervals.

Model	Threshold Values	95% Confidence Intervals
Single threshold	0.1789	(0.1496, 0.1818)
Double threshold	0.8936	(0.8841, 0.9225)

The above analysis shows that the impact of renewable energy consumption on industrial green transformation presents a nonlinear relationship. According to the threshold effect test, two threshold variables can be obtained, and the estimated values are 0.1789 and 0.8936. Further, we analyzed the relative threshold distribution of energy misallocation levels in 30 provinces in China from 2009 to 2016 and then divided the samples into three groups, namely "low misallocation", "medium misallocation", and "high misallocation." The grouping results are shown in Table 5. The number of samples in the relatively optimal low misallocation interval is small. In recent years, although the gap of energy misallocation in China has a certain convergence trend, the number of samples in the low misallocation interval is slowly increasing, but the improvement effect is not very obvious. There is still room for improvement. China's current large-scale promotion of renewable energy consumption can only achieve green growth effects in some areas, and so improving energy misallocation is imperative, which is an integral part of the transition from extensive to intensive in the context of the "new normal".

According to the threshold regression consequences, the driving force of renewable energy consumption on industrial green transformation is not monotonously increasing (decreasing). The influence coefficient of renewable energy consumption varies significantly in different provinces; that is, with the increase of energy misallocation, the effect of promoting and suppressing industrial green transformation will be more apparent. When the energy misallocation level is higher than 0.8936, every 1% increase in renewable energy consumption will lead to a decline in industrial green transformation of 0.38209%. When the degree of energy misallocation exceeds a threshold, that is, the degree of energy misallocation is between 0.1789 and 0.8936, the direction of the role of renewable energy consumption in the industrial green transformation will be a structural mutation. Moreover, the influence coefficient will change from negative to positive, but the estimated value of the parameter has not passed the significance test. As the degree of energy misallocation becomes lighter, the coefficient continues to increase. When the energy misallocation exceeds another threshold of 0.1789, the elastic coefficient of renewable energy consumption is 0.040981 at a significant level of 0.01. This shows that 0 and 0.1789 is

the optimal range of energy misallocation, and renewable energy consumption can effectively promote industrial green transformation.

Table 5. Distribution of relative thresholds of energy misallocation levels in 30 provinces of China in 2009 and 2016.

Threshold Interval	Province Distribution (2009)	Province Distribution (2016)
$\tau \leq 0.1789$	Hebei, Jilin, Henan, Sichuan, Yunnan, Gansu	Hebei, Shanxi, Jilin, Henan, Hainan, Sichuan, Yunnan, Gansu
$0.1789 < \tau \leq 0.8936$	Inner Mongolia, Liaoning, Tianjin, Heilongjiang, Shanghai, Jiangsu, Fujian, Shandong, Hubei, Xinjiang, Guangdong, Hainan, Chongqing, Guizhou, Shaanxi, Qinghai, Ningxia, Shanxi, Hunan	Inner Mongolia, Guizhou, Liaoning, Heilongjiang, Chongqing, Ningxia, Tianjin, Shanghai, Jiangsu, Fujian, Shandong, Hubei, Hunan, Guangdong, Shaanxi, Qinghai, Xinjiang
$\tau > 0.8936$	Beijing, Zhejiang, Jiangxi, Anhui, Guangxi	Beijing, Zhejiang, Jiangxi, Anhui, Guangxi

Note: Due to space limitations, only the provinces in 2009 and 2016 are listed.

4.3. Analysis

The above analysis results (as shown in Table 6) show that it is necessary to fully consider energy misallocation when exploring the relationship between renewable energy consumption and industrial green transformation. In general, we find that the effect of renewable energy consumption on industrial green transformation is not linear, but a nonlinear and complex mechanism with energy misallocation as the threshold. In other words, under different levels of energy allocation, the role of renewable energy consumption in promoting regional green development levels is quite different.

Table 6. Estimation results of model parameters.

Upgrade	Coef.	Std. Err	t	$p > |t|$	95%	Conf. Interval
R&D	0.022944 ***	0.002616	8.77	0.000	0.017785	0.028102
Regulation	0.001394 **	0.000588	2.37	0.019	0.000235	0.002552
OPEN	−0.00119	0.007848	−0.15	0.879	−0.01667	0.014281
Human	−0.07613 ***	0.013379	−5.69	0.000	−0.10251	−0.04975
Renewable($\tau \leq 0.1789$)	0.040981 ***	0.00636	6.44	0.000	0.02844	0.053522
Renewable($0.1789 < \tau \leq 0.8936$)	0.007699	0.005022	1.53	0.127	−0.0022	0.017602
Renewable($\tau > 0.8936$)	−0.38209 ***	0.058183	−6.57	0.000	−0.49681	−0.26737
cons	0.401079 ***	0.025412	15.78	0.000	0.350975	0.451183

*, **, and *** denote statistical significance levels at 10%, 5%, and 1%, respectively.

In the low energy misallocation interval ($\tau \leq 0.1789$), renewable energy consumption can effectively promote industrial green transformation. This is because, on the one hand, the reasonable allocation of renewable energy can fully meet the energy needs of enterprises, provide favorable guarantees for enterprises to carry out technological changes and infrastructure updates, and improve their green technology innovation capabilities. On the other hand, increasing the consumption of renewable energy can fundamentally promote a clean and low-carbon energy transition, improve energy efficiency, change the traditional growth pattern of relying on factor inputs, and promote the industrial green transition.

However, in the medium and high energy misallocation range, the resource allocation between enterprises is unreasonable. Since natural resources are state-owned, the government has absolute power to determine the initial allocation of energy. In general, energy is preferentially allocated to local state-owned monopolies that can create more state-owned output, whereas other non-state-owned

enterprises do not have access to obtain similar energy resources. Nie et al. [30] discovered that resource misallocation is the primary cause of lower total factor productivity in state-owned enterprises compared with non-state-owned enterprises. For one thing, local state-owned monopolies generally do not choose green transformation after obtaining low-cost energy elements; only by increasing the input of factors can they gain considerable profits, which leads to excessive use of energy and ineffective promotion of the industrial green transformation. For another, the development of renewable energy for other companies not only requires a large investment of funds and scientific research of human resources, but also needs to update the relevant supporting infrastructure, which many companies cannot afford. Therefore, some enterprises, especially small and medium-sized enterprises, may have short-sighted behavior and pursue profits unilaterally. Meanwhile, production technology innovation and industrial structure upgrading will be neglected, and industrial green transformation will not be effectively promoted.

In terms of control variables, the coefficients of environmental regulation and technological innovation are significantly positive at 1%, indicating that the two influencing factors are important in promoting industrial green transformation, and have substantial positive effects on high-quality economic development and environmental protection. However, the promotion of human capital has not been verified.

5. Conclusions

Reducing resource misallocation is a crucial part of China's process of achieving high-quality development. Moreover, improving renewable energy consumption is the fundamental driving force for industrial green transformation. Following the theory of low-carbon economy development, this paper constructs a nonlinear threshold model for renewable energy consumption, energy misallocation, and industrial green transformation. Based on the calculation of the degree of energy misallocation in different regions, and combined with its spatial and temporal heterogeneity factors, the complex mechanism of renewable energy consumption to promote industrial green transformation is clarified. Through theoretical and empirical analysis, the paper draws the following conclusions:

In general, the impact of renewable energy consumption on industrial green transformation is non-linear. Taking into account the significant differences in various regions of China and the energy misallocation caused by the long-term extensive economic growth pattern, we find that there is significant energy misallocation threshold characteristic in the relationship between renewable energy consumption and industrial green transition.

Energy allocations across China are not ideal with some degrees of misallocation. According to the threshold levels, the areas are divided into three types: low ($\tau \leq 0.1789$), medium ($0.1789 < \tau \leq 0.8936$), and high misallocation interval ($\tau > 0.8936$).

As energy misallocation continues to cross the threshold, the direction of renewable energy consumption in the industrial green transformation also continues to change. In the low misallocation interval, renewable energy consumption can significantly promote industrial green transformation. Nevertheless, in the high misallocation interval ($\tau > 0.8936$), the effect of renewable energy consumption cannot be seen. This shows that the low misallocation interval ($\tau \leq 0.1789$) is the optimal period, and in this case, the role of renewable energy in promoting industrial green transformation is the most obvious.

In addition, we found that during the sample period, although the number of regions in the low misallocation interval has increased, the change is very slow, and the provinces with medium and high misallocation still account for the majority, indicating that the improvement effect of energy misallocation is only modest and more effort need to be made to change this situation.

According to the above research conclusions, we believe that it is imperative to optimize the allocation of energy elements. China should vigorously promote clean energy transformation and thus enhance the positive effect of renewable energy consumption to promote industrial green transformation. Specifically, this paper proposes the following suggestions:

First, China's energy misallocation and resource allocation efficiency should be improved. The government should fully respect the fundamental role of the market in resource allocation, reduce direct intervention, deepen market reforms, and promote effective allocation of energy elements. At the same time, we should also break the long-standing "discrimination of ownership" and eliminate all kinds of hidden institutional barriers, so that non-public enterprises can freely enter competitive industries. In addition, the government needs to timely correct the discrimination of non-state-owned economies in financial services, such as credit and listing.

Second, renewable energy must be developed and clean energy transformation must be promoted. The central and local governments should adopt various measures such as fiscal and taxation to share the pressure on enterprises to use renewable energy and develop clean technologies and promote the rapid development of the renewable energy industry. For example, the government should provide a certain percentage of financial subsidies and tax breaks for new energy vehicle consumption, photovoltaic enterprise production, and clean energy access.

Third, the process of regional market integration should be further promoted and the barriers of resource misallocation caused by local protectionism in the process of industrial green transformation should be reduced. Environmental protection has robust spatial transmission and negative externalities, which requires cross-regional "joint prevention and control" to share the responsibility of low-carbon transformation and to promote the coordinated development of the economy and environment. By eliminating trade barriers, we can optimize resource allocation and provide an effective long-term mechanism to promote industrial green transformation.

Fourth, the performance appraisal should emphasize more environment indicators. By establishing a performance appraisal system combining "top-down" and "bottom-up", local governments are encouraged to rely on technological innovation to promote environmental governance and industrial green transformation. The local governments should pay more attention to the current and long-term unity, which will help to fundamentally resolve the contradiction between economic development and environmental protection.

Abbreviations

Upgrade	Industrial green transformation
Renewable	Renewable energy consumption
τ	Energy misallocation
R&D	Regional research and development level
Regulation	Environmental regulation intensity
Open	Degree of openness
Human	Human capital
DEA	Data Envelopment Analysis
SFA	Stochastic Frontier Analysis
LSDV	Least squares dummy variable method
LMDI	Log-average Ditch index

Appendix A

Appendix A.1. The Index System of Industrial Green Transformation

Table A1. Industrial Green Transformation Index System.

Index	Sub Indicator	Calculation Method
Energy resource-intensive use	Energy consumption	Energy consumption accounts for the proportion of industrial added value
	Water consumption	Industrial water consumption accounts for the proportion of industrial added value
Degree of pollution reduction	CO_2 emissions	CO_2 emissions account for the proportion of industrial added value
	SO_2 emissions	Industrial SO_2 emissions account for the proportion of industrial added value
	Wastewater discharge	Wastewater discharge accounts for the proportion of industrial added value
Industrial structure upgrading	The proportion of high-energy-consuming industries	The sum of the total industrial output value of the six high-energy-consuming sectors accounts for the proportion of industrial added value
Productivity improvement	Total factor productivity	Calculating total factor productivity by SFA
Sustainable development	Comprehensive utilization rate of industrial solid waste	The comprehensive utilization of solid waste accounts for the proportion of production

Appendix A.2. Entropy Evaluation Method

First, the index data are standardized according to the forward index and the reverse index. The specific formula is as follows:

$$x'_{ik} = (x_{ik} - \bar{x}_j)/sd_k, \tag{A1}$$

$$x'_{ik} = (\bar{x}_j - x_{ik})/sd_k, \tag{A2}$$

where x'_{ik} is the data after standardization, of the province i for indicator k. x_{ik} is the truth of the index. $\bar{x}_j$ and sd_k are the mean and standard deviation of the k indicator, respectively. Equation (A1) is a standardized formula for the forward index, and Equation (A2) is the standardized formula for the inverse index.

Second, calculate the weight of the province i for k indicator,

$$r_{ik} = X_{ik}/\sum_{i=1}^{n} X_{ik}. \tag{A3}$$

Third, calculate the entropy of k indicator,

$$e_{ik} = -\frac{1}{\ln(n)} \sum_{i=1}^{n} r_{ik} \ln(r_{ik}). \tag{A4}$$

Four, calculate the weight of k indicator,

$$w_{ik} = \frac{1 - e_{ik}}{\sum_{k=1}^{m}(1 - e_{ik})}. \tag{A5}$$

Finally, calculation industrial green transformation,

$$UPGRADE_i = \sum_{k=1}^{m} w_{ik} r_{ik}. \tag{A6}$$

Appendix B. The Specific Calculation Steps of Energy Misallocation

Suppose province *i* has a C-D production function with the constant returns to scale, i.e.,

$$Y_i = AK_i^{\beta_1} L_i^{\beta_2} E_i^{\beta_3}, \tag{A7}$$

where Y_i, A, K_i, L_i and E_i represents the total output, total factor productivity, capital investment, labor input, and energy input of province *i*, respectively. β represents the factor output elasticity of province *i*. Because the driving forces of economic development in different regions are quite different, this paper uses the LSDV method to estimate the energy output elasticity of each area.

In the case where the factor price is distorted [2], it is assumed that the actual energy price of the province *i* is $(1 + \tau_i)P_E$, if $\tau_i \neq 0$, it means there is energy misallocation, and absolute distortion coefficient (γ_{Eit}) is expressed as follows:

$$\gamma_{Eit} = \frac{1}{1 + \tau_{Eit}}. \tag{A8}$$

The absolute distortion coefficient refers to the addition of energy prices to regions without distortion, and it reflects information on the absolute value of energy use costs. For example, when regional energy prices are completely free of distortion, facing the energy distortion $\tau_{Eit} = 0$, then $\gamma_{Eit} = 1$. When energy prices are above normal, that is, $\tau_{Eit} > 0$, then $0 < \gamma_{Eit} < 1$. And when energy prices are below normal, that is, $\tau_{Eit} < 0$, then $\gamma_{Eit} > 1$.

The relative distortion coefficient reflects the relative situation of regional energy price distortion compared with the average level, and it reflects the relative information of energy use cost. Take region *i* as an example, when $\hat{\gamma}_{Eit} > 1$, it means that compared with the entire economy, the cost of energy use in the region is low; when $\hat{\gamma}_{Eit} < 1$, it means that compared with the entire economy, the cost of energy use in the region is high.

Generally, in the calculation, it can be replaced by the relative distortion coefficient ($\hat{\gamma}_{Eit}$) of province *i*, which is expressed as follows:

$$\hat{\gamma}_{Eit} = \frac{E_{it}}{E_t} \bigg/ \frac{s_{it}\beta_{Eit}}{\beta_{Et}} \tag{A9}$$

where E_{it}/E_t represent the actual proportion of energy used in the $t - year$ of the $i - region$ in the national energy use, $s_{it} = p_{it}y_{it}/Y$ represents the share of output, $\beta_{Et} = \sum_{i=1}^{n} s_{it}\beta_{Eit}$ indicates the output weighted energy contribution value, $s_{it}\beta_{it}/\beta_{Et}$ indicates the theoretical proportion of energy that needs to be invested in the effective allocation of resources. It should be noted that, because the energy misallocation includes insufficient configuration ($\tau_{Eit} < 0$) and over configuration ($\tau_{Eit} > 0$), in order to ensure the consistency of the regression direction, this paper draws on the idea of Ji, S.H. [27], and performs absolute value processing on τ_{Eit} in the empirical case.

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