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Research on the Impact of Energy Efficiency on Green Development: A Case Study of the Yellow River Basin in China

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Abstract: In order to achieve China's carbon peaking and carbon neutrality (double carbon) targets and to advance ecological conservation and high-quality development in the Yellow River Basin, it is essential that China reduces its energy intensity and increases its energy efficiency. This research developed an evaluation index system for energy efficiency and green development in the Yellow River Basin based on panel data collected from 64 of its prefecture-level cities and covering the period from 2011 to 2020. Each city's energy efficiency and green development level index was calculated, and was analyzed together with the characteristics of its spatial pattern progression. The STIRPAT model was then used to investigate the influence mechanism of energy efficiency on green development. The final step in the analysis was to assess the process by which technical innovation influences the rise in energy efficiency from a green development point of view. The findings of this study indicate that: (1) There was a marked improvement in energy efficiency and green development levels across the Yellow River Basin over the study period of 2011 to 2020, but there are notable disparities among prefecture-level cities, with higher levels found in capital cities and cities in the lower reaches of the basin. (2) The improvement in energy efficiency has had a positive impact on the transition to green development, with factors such as human capital, urbanization levels, and the upgrading of industrial structures contributing significantly, while the level of foreign direct investment has had a limited impact. (3) Technological innovation plays a partial role in mediating the relationship between energy efficiency and green development in the Yellow River Basin, and passes the single-threshold test. When technological innovation surpasses the threshold value, the effect of energy efficiency on green development is significantly strengthened. This study indicates that improving energy efficiency, stimulating emerging industries, and enhancing technological innovation capabilities can significantly promote transformative green and high quality development in the Yellow River Basin of China.

Keywords: energy efficiency; green development; Yellow River Basin; sustainable development; green economy

Citation: Liu, J.; Zhang, Y.; Pu, L.; Huang, L.; Wang, H.; Sarfraz, M. Research on the Impact of Energy Efficiency on Green Development: A Case Study of the Yellow River Basin in China. *Energies* **2023**, *16*, 3660. https://doi.org/10.3390/en16093660

Academic Editor: Sergey Zhironkin

Received: 24 March 2023
Revised: 23 April 2023
Accepted: 23 April 2023
Published: 24 April 2023

1. Introduction

Climate change poses a significant threat to people's livelihoods and the sustainable development of human society, and to the environment in which we live. To curb the continuous deterioration of the ecological environment, a consensus has been reached by most of the world's countries and regions to advance global climate governance through the establishment of "dual carbon" targets [1–3]. China, as the world's largest energy-consuming country and carbon-emitting nation, faces severe resource-related and environmental problems. Promoting low-carbon energy transformation and improving energy efficiency in

China are crucial measures in achieving its "dual carbon" goals and promoting green development. The Yellow River Basin is an important ecological barrier and economic belt in China, and is also a significant energy basin. For a long time, problems such as the over-exploitation of energy and mineral resources, deterioration of the ecological environment, and low economic efficiency have become increasingly prominent in the basin [4]. On 7 October 2021, the Central Committee of the Communist Party of China and the State Council jointly issued the Outline for the Ecological Protection and High-Quality Development of the Yellow River Basin, which emphasized the need to strengthen environmental pollution control and promote the green transformation of resource-based industries. Against this backdrop, analyzing the energy efficiency and green development of cities in the Yellow River Basin and exploring the relationship of energy efficiency and green development are of great significance in promoting green transformation and ecological protection and high quality development of the Yellow River Basin.

Many studies have been conducted on the relationship between energy efficiency and green development. First, existing research on energy efficiency mainly focuses on measuring it and identifying its influencing factors. Some scholars have measured energy efficiency based on a single index [5] or data envelopment analysis (DEA) and its derived models [6–8]. Energy efficiency is primarily influenced by a combination of factors, such as industrial structure [9], technological progress [10,11], and openness to the world [12,13]. Second, research on green development focuses on the measurement of green development efficiency and its impact factors. Most scholars divide the measurement of green development into two aspects: first, building a comprehensive regional green development index system from economic, social, and environmental aspects [14,15] and measuring the efficiency of green development [16,17], and second, exploring the impacts of factors such as technological innovation [18,19], industrial structure [20], and urbanization [21] on green development. Regarding research on energy and green development, scholars are more focused on energy efficiency and sustainable development, and some scholars believe that sustainable development is equivalent to green development. Zakari et al. [22] studied the relationship between sustainable development and energy efficiency in Asian countries, and found that sustainable economic development has a positive impact on energy efficiency.

In conclusion, current research on measuring levels of green development and energy efficiency focuses mostly on resource city clusters and the Yangtze River Basin. The Yangtze River Basin is rich in resources, has a superior ecological environment, and provides fruitful research results. However, the Yellow River Basin has a fragile ecological environment and slow economic development. As an important strategic area for China's economic and social development, it is of great significance for China's green development transformation. Existing research on cities in the Yellow River Basin is relatively limited and lacks in-depth analysis. Scholars are more limited to provincial-level regions of the Yellow River Basin, and carry out less research on the energy efficiency and the spatial and temporal patterns of green development and its influencing factors in the whole basin. Therefore, in order to provide reference and guidance for the ecological protection and high-quality development of the Yellow River Basin, this paper first builds a system of indicators for evaluating energy efficiency and green development levels, measures the energy efficiency and green development levels of 64 prefecture-level cities in the Yellow River Basin from 2011 to 2020, and examines the characteristics of their spatial pattern evolution. Secondly, the STIRPAT model is used to explore the impact of energy efficiency on green development in the Yellow River Basin. Finally, the mediating role and threshold effect of technological innovation are tested.

The main contributions of this study to the existing literature are as follows: firstly, based on its geographical location and resource endowment, a system of energy efficiency and green development indicators for the Yellow River Basin is constructed to enable us to conduct a more comprehensive and in-depth analysis of its development status and spatiotemporal evolution. Secondly, incorporating technological innovation, energy efficiency, and green development into the same framework of analysis helps us to gain a more comprehensive understanding of the underlying mechanisms by which energy efficiency affects green development. Finally, a threshold effect model is used to test whether energy efficiency and technological innovation have a threshold effect on green development, and its impact mechanism is verified through interaction terms.

2. Theoretical Analysis

Energy efficiency adheres to the principles of green and sustainable development, with efficient energy utilization, pollution control, and advanced resource allocation management methods as the main components, reflecting the comprehensive indicators of regional energy utilization. In China, as the largest energy-consuming country, improving energy efficiency is of great significance for promoting energy conservation and emission reduction, and optimizing environmental issues, and is in line with China's new green development concept. In energy production and processing, improving energy efficiency can reduce the exploitation and use of high-carbon energy while ensuring high-speed economic growth, thus promoting the cyclical pattern of energy production and the green model [23]. Implementing "clean production" in the process of fossil fuel exploration can reduce the emission of pollutants from the source to the maximum extent, promoting the growth of the regional green economy. Improving energy efficiency has a positive effect on resource allocation and clustering of low-carbon industries. In the process of upgrading industrial structure, enterprises are adjusting to a system of low energy consumption and low emission production, gradually exerting energy-saving and efficiency-enhancing effects and allowing for more scientific, reasonable, and recycled resource allocation (Figure 1).

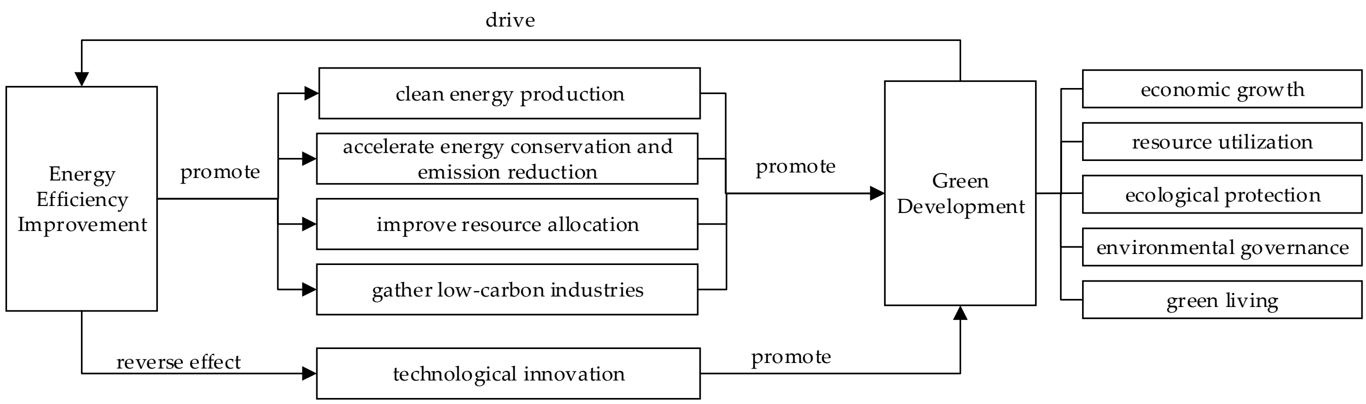

Figure 1. The mechanism of the effects of energy efficiency on green development.

The improvement of energy efficiency has a conducive effect on green development. Improving regional energy efficiency means reducing emissions of pollutants, such as carbon dioxide and sulfur dioxide; this initially raises energy costs and pollution control costs for enterprises, forcing them to engage in independent innovation and increase investment in research and development toward clean and low-carbon energy technologies. At the same time, it can also drive the transformation of the industrial structure towards rationalization and upgrading, thus improving levels of regional technological innovation. Progress in green technology can reduce the production cost and market price of clean energy, optimize the supply of the energy factor market, and reduce the market share of enterprises with high pollution and energy consumption. This will help promote the green transformation of the energy consumption structure and drive the transformation of regional green development (Figure 1).

Regional green development promotes the improvement of energy efficiency. Research has shown that sustainable economic development significantly promotes energy efficiency in the Asia-Pacific region [22]. The growth of an economy increases energy demand, and more developed regions often have the economic ability to adopt advanced energy-saving technologies to improve energy utilization efficiency. With the improvement of regional economic development levels, public demand for a green environment is gradually increasing. The government's energy-saving and emission reduction policies promote the improvement of environmental governance levels, thereby improving energy utilization efficiency (Figure 1).

3. Research Design

3.1. Variable Settings

Based on the aforementioned theoretical analysis and the research purpose of this article, our main focus is on the impact of energy efficiency on green development, and on the mediating role of technological innovation. The variable settings of this study were as follows:

3.1.1. Explained Variable: Green Development

Green development has become a common descriptor of high-quality development in China. Since the concept of green development was proposed, the academic community has conducted research from multiple perspectives on the definition and measurement of green development level, and the factors that influence green development [16].

Referencing the "Green Development Indicator System" and "Ecological Civilization Construction Assessment Goal System" released by the National Development and Reform Commission and other departments, a green development level evaluation indicator system was constructed by selecting 25 indicators from five aspects: economic growth, resource utilization, ecological protection, environmental governance, and green living [24] (Table 1).

① Economic growth represents the foundation of green development, and is reflected by the contribution rate of tertiary industry, the number of people employed in tertiary industry, the per capita GDP, the disposable income of urban residents, and the proportion of R&D expenditure in GDP.

② Resource utilization represents the process of green development, and is reflected by energy consumption per unit of GDP, carbon dioxide emissions per unit of GDP, total water consumption, the per capita cultivated land area, and the comprehensive utilization rate of industrial solid waste.

③ Ecological protection represents the guarantee of green development, and is reflected by per the capita park green space area, the forest coverage rate, the newly added area for soil and water conservation, the proportion of days with good air quality in cities, and the proportion of surface water that is better than Class III.

④ Environmental governance represents the support for green development, and is reflected by the total SO_2 emissions from industry, industrial wastewater discharge, the rate of treatment of household waste to make it harmless, the urban sewage treatment rate, and the proportion of energy-saving and environmental protection expenditure in GDP.

⑤ Green living represents the goal of green development, and is reflected by the regional rate of access to tap water, the gas coverage rate, the number of public transportation vehicles per 10,000 people, the number of hospital beds per 10,000 people, and the green coverage rate in urban built-up areas.

Table 1. Indicator system for green development levels.

Target Level	Criteria Level	Indicator Level	Unit	Indicator Attribute
Green Development Level	Economic growth	Contribution rate of the tertiary industry	%	+
		Number of people employed in the tertiary industry	Per 10,000 people	+
		Per capita GDP	CNY	+
		Disposable income of urban residents	CNY	+
		Proportion of R&D expenditure in GDP	%	+
	Resource utilization	Energy consumption per unit of GDP	Tons of standard coal per 10,000 yuan	−
		Carbon dioxide emissions per unit of GDP	Tons of standard coal per 10,000 yuan	−
		Total water consumption	m^3	−
		Per capita cultivated land area	Hectares	+
		Comprehensive utilization rate of industrial solid waste	%	+
	Ecological protection	Per capita park green space area	m^2	+
		Forest coverage rate	%	+
		Newly added area for soil and water conservation	km^2	+
		Proportion of days with good air quality in cities	%	+
		Proportion of surface water better than Class III	%	+
	Environmental governance	Total SO_2 emissions from industry	Ten thousand tons	-
		Industrial wastewater discharge	Ten thousand tons	-
		Rate of harmless treatment of household waste	%	+
		Urban sewage treatment rate	%	+
		Proportion of energy-saving and environmental protection expenditure in GDP	%	+
	Green living	Regional rate of access to tap water	%	+
		Gas coverage rate	%	+
		Number of public transportation vehicles per 10,000 people	Vehicles	+
		Number of hospital beds per 10,000 people	Beds	+
		Green coverage rate in urban built-up areas	%	+

Note: '+' indicates a positive indicator and '−' indicates a negative indicator.

3.1.2. Core Explanatory Variable: Energy Efficiency

Energy efficiency can reflect the mutual cooperation among energy, capital, labor, and other factors, which is more consistent with the connotation of Pareto efficiency in economics. It is measured using frontier analysis methods, data envelopment analysis, and other methods [5]. The multi-input–multi-output method [4] was adopted to measure energy efficiency indicators in this paper. ① The input indicators included three aspects: labor, capital, and resources. Taking data availability into account, the number of employees at the end of the year was selected to represent labor input; the capital stock was estimated using the perpetual inventory method, and the capital stock index represented capital input; total energy consumption was selected to represent resource input. ② The output indicators included expected and unexpected outputs. The actual GDP of each city was used as the expected output, while the unexpected output, due to environmental problems caused by energy consumption, mainly manifested as air pollution. The entropy method was used to combine several indicators, such as industrial wastewater discharge, industrial smoke and dust emission, industrial SO_2 emission, and CO_2 emission, to calculate a comprehensive index of environmental pollution and measure the unexpected output (Table 2).

Table 2. Indicator system for energy efficiency.

Target Level	Type	Criteria Level	Indicator Level
Energy efficiency	Input	Labor	Number of employees at the end of the year
		Capital	Capital stock
		Resources	Total energy consumption
	Output	Expected output	Actual GDP
		Unexpected output	Comprehensive index of environmental pollution

3.1.3. Mediating Variable

Based on existing studies, this paper selected technological innovation as the mediating variable.

Technological Innovation (TI): Technological innovation needs to be transformed into actual productivity to have an impact on production and consumption. Given the close relationship between patents and technological innovation, patent data was selected as the measurement indicator for technological innovation [25]. Patent data include the number of patent applications and grants. Given the comprehensive nature of a region's research output quality and market application level, the number of invention patents per capita reflects the true level of innovation. Therefore, this paper used the number of invention patents per capita to measure the technological innovation level of a region.

3.1.4. Control Variables

Based on existing studies [18], this paper selected human capital, urbanization level, the degree of foreign direct investment, and industrial structure upgrading as the four control variables.

① Human capital (HC): Human capital has a significant impact on improving environmental quality, reducing energy consumption, alleviating climate change and its impacts, and green development [26]. Therefore, this paper selected the number of college students enrolled in each region to represent human capital.

② Urbanization level (UBL): Urbanization will encourage rural population migration to cities, leading to increased energy consumption and affecting regional green development. Therefore, this paper selected the ratio of urban population to total population at the end of each year in each region to measure the urbanization level [21].

③ Foreign direct investment (FDI): Cities can use foreign investment to bring about abundant capital flows and advanced production management experience, thus promoting the transformation and upgrading of local industry, to a certain extent, and positively impacting regional economic green development [27]. At the same time, because high-energy and high-pollution industries are among those that receive investment, regional environmental pollution may be exacerbated and have a negative impact on regional green development. Therefore, this paper used the ratio of actual foreign direct investment in each region in GDP to measure the degree of openness to the outside world.

④ Industrial structure upgrading (IS): In the course of industrialization, the industrial structure gradually evolves towards the post-industrial stages of the "tertiary, secondary, and primary sectors," signifying a process of industrial structure sophistication [28]. Therefore, this paper used the ratio of the value-added of the third level of industry to the value-added of the second industry level to measure industrial structure upgrading.

3.2. Research Methods

3.2.1. Super-SBM Model

This study adopted the Super-SBM model method to measure energy efficiency, based on relevant research by Tone et al. [29]. Compared to the traditional DEA model, this model takes into account the impact of the non-expected output indicator (environmental pollution) on the efficiency value, and avoids the problem of slack variables in inputs or outputs, allowing for a more accurate comparison of the efficiency values of the effective units [30].

Assume there are n decision-making units (DMUs) containing m input elements, S_1 expected outputs, and S_2 non-expected outputs. The formula is as follows:

$$\min\rho = \frac{\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{ih}}}{1+\frac{1}{s_1+s_2}\left(\sum_{i=1}^{s_1}\frac{s_r^g}{y_{rh}^g}+\sum_{i=1}^{s_2}\frac{s_1^b}{y_{lh}^b}\right)} \tag{1}$$

$$s.t.\begin{cases} x_{ih} \geq \sum\limits_{j=1,j\neq h}^{n} x_{ij}\lambda_j - s_i^- \\ y_r^g \leq \sum\limits_{j=1,j\neq h}^{n} y_{rj}^g\lambda_j + s_r^g \\ y_l^b \geq \sum\limits_{j=1,j\neq h}^{n} y_{lj}^b\lambda_j - s_l^b \\ \lambda, s^-, s^g, s^b \geq 0 \end{cases} \tag{2}$$

In this formula, ρ represents the energy efficiency values of each decision-making unit, i.e., cities in the Yellow River Basin, which are strictly decreasing; s^-, s^g, and s^b represent the slack variables of the input variables, the expected output variables, and the non-expected output variables; and λ represents weight coefficients.

3.2.2. Entropy-Weighted TOPSIS Method

The weights of indicators reflect their different levels of importance in the evaluation process, and the entropy weight method objectively considers the utility value of indicators, avoiding subjective factors. TOPSIS can calculate the distance between each evaluation object and the optimal and worst solutions for obtaining the relative proximity between the evaluation object and the optimal solution [31]. Based on this, ranking the evaluation objects is simple, and the results are reasonable. By combining these two methods, this paper can more objectively and accurately reflect the temporal evolution characteristics of green development in the Yellow River basin [32]. Therefore, we used the entropy-weighted TOPSIS method to measure the level of green development.

Step 1: Normalize the indicators.

Positive indicators:

$$X_{ij} = \frac{x_{ij} - x_{\min}}{x_{\max} - x_{ij}} \tag{3}$$

Negative indicators:

$$X_{ij} = \frac{x_{\max} - x_{ij}}{x_{\max} - x_{\min}} \tag{4}$$

In this formula, x_{ij} is the original value of the jth index in the ith year; x_{ij} is the normalized value of the jth index in the ith year; $x_{\min}$ is the minimum value of the jth index; and $x_{\max}$ is the maximum value of the jth index.

Step 2: Calculate the weight of the jth indicator, P_{ij}:

$$P_{ij} = \frac{x_{ij}}{\sum\limits_{i=1}^{n} x_{ij}} \tag{5}$$

Step 3: Calculate the entropy value of the jth indicator, E_j:

$$E_j = \frac{\sum\limits_{i=1}^{n} p_{ij}\ln p_{ij}}{\ln n} \tag{6}$$

Step 4: Calculate the entropy weight of the *j*th indicator, W_j:

$$W_i = \frac{1 - E_j}{\sum\limits_{i=1}^{n} (1 - E_j)} \tag{7}$$

3.2.3. STIRPAT Model

The STIRPAT model, as an effective method for quantitatively analyzing the impacts of various influencing factors on environmental load, has been widely applied in the field of environmental assessment research [33,34]. Therefore, based on our research aims, this study built a benchmark model to analyze the impact of energy efficiency on green development in the Yellow River Basin.

$$\ln GD_{it} = \gamma_0 + \chi_1 \ln EE_{it} + \chi_2 \ln X_{it} + \varepsilon_{it} \tag{8}$$

At the same time, considering the non-linear interaction effects between energy efficiency variables, the model includes the second-degree term of energy efficiency.

$$\ln GD_{it} = \gamma_0 + \chi_1 \ln EE_{it} + \chi_2 \ln EE_{it}^2 + \chi_3 \ln X_{it} + \varepsilon_{it} \tag{9}$$

In this formula, *GD* represents the dependent variable (green development level); *EE* represents the explanatory variable (energy efficiency); *X* represents the control variables (human capital (*HC*), urbanization level (*UBL*), degree of foreign direct investment (*FDI*), and industrial structure upgrading (*IS*)); *i* and *t* represent the city and year, respectively; γ_0 is the constant term; ε_{it} is the random error term; and $\chi_0 \sim \chi_3$ represents the regression coefficients of each variable.

3.2.4. Stepwise Regression Analysis

In the mechanisms relating energy efficiency and green development, energy efficiency not only directly promotes regional green development, but also affects the transformation of green development by improving the level of technological innovation. Therefore, this study took technological innovation as an intermediary variable and used the stepwise regression method to analyze the impact process and mechanism of energy efficiency impact on green development in greater depth [35].

$$\ln GD_{it} = \alpha_0 + c \ln EE_{it} + \alpha_1 \ln X_{it} + \varepsilon_{it} \tag{10}$$

$$\ln TI_{it} = \beta_0 + a \ln EE_{it} + \beta_1 \ln X_{it} + \varepsilon_{it} \tag{11}$$

$$\ln GD_{it} = \lambda_0 + c' \ln EE_{it} + b \ln TI_{it} + \lambda_1 \ln X_{it} + \varepsilon_{it} \tag{12}$$

In this formula, α_i, β_i, and λ_i are the estimated parameters for the variables; *c* represents the total effect of energy efficiency on green development; *a* represents the impact of energy efficiency on technological innovation; other variables have the same meanings as before.

Table 3 shows the models and methods used in this study.

Table 3. Research models.

Research Methods/Models	Variable	Purpose
Super-SBM model	EE	To calculate energy efficiency values
Entropy-weighted TOPSIS method	GD	To measure the level of green development
STIRPAT model	GD, EE, HC, UBL, FDI, IS	To explore the impact of energy efficiency and green development
Stepwise regression analysis	GD, EE, TI, HC, UBL, FDI, IS	To test whether there are mesomeric effects on technological innovation

3.3. Study Area and Data Sources

According to the definition of the administrative regions of the Yellow River Basin established by the Ministry of Water Resources Yellow River Conservancy Commission, the Yellow River Basin covers nine provinces and regions, including Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan, and Shandong. However, since Sichuan is located in the Yangtze River Basin, and the Yellow River only flows through the Aba and Ganzi areas in Sichuan [2], it is not included in the scope of this study. Considering the availability of data, this study finally selected 64 prefecture-level cities in the Yellow River Basin as the research sample, and divided them into three regions (the upper reaches, middle reaches, and lower reaches of the Yellow River) based on the division standards of the Yellow River Yearbook (Figure 2). The data for various indicators were mainly obtained from the Statistical Yearbook of each prefecture-level city, the Statistical Bulletin of National Economic and Social Development of each prefecture-level city, the Environmental Status Bulletin, the China Energy Statistical Yearbook, the China City Statistical Yearbook, and the Statistical Yearbook of each province, among others. Some missing data were supplemented using data from the official websites of the regions or by using mean replacement methods and interpolation methods. The base map data of the Yellow River Basin were obtained from the National Bureau of Surveying and Mapping. The descriptive statistics for the main variables are reported in Table 4.

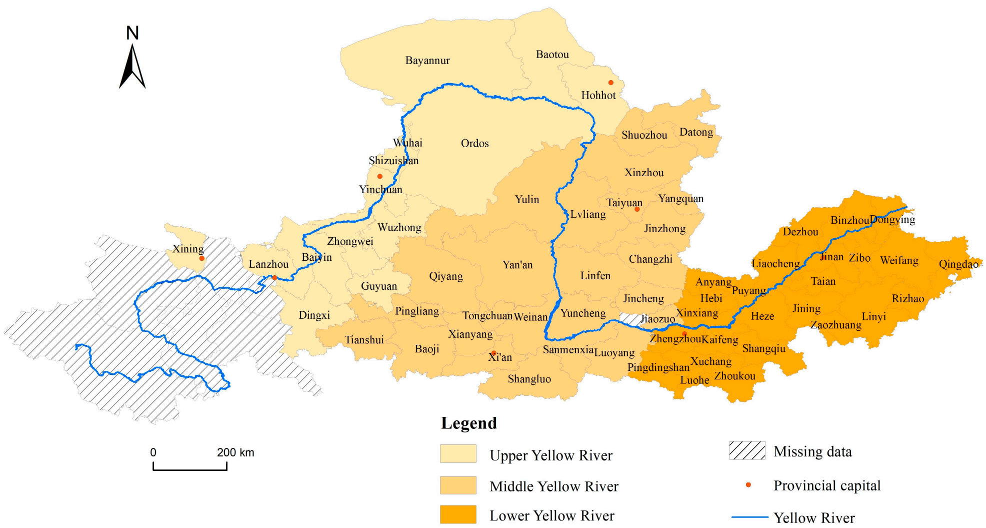

Figure 2. The research area.

Table 4. Descriptive statistics of variables.

Variable	Obs	Mean	Standard Deviation	Min	Max
GD	640	0.2817	0.0892	0.1155	0.6280
EE	640	0.3734	0.1476	0.1051	1.0000
lnTI	640	0.9779	1.1016	−3.2216	4.0480
lnHC	640	3.5599	1.1825	−0.3638	5.9377
lnUBL	640	3.9591	0.2653	3.0568	4.5578
lnFDI	640	−0.4963	1.3993	−4.3608	2.9848
lnIS	640	−0.0730	0.5186	−1.4347	1.5386

4. Empirical Analysis

4.1. Spatiotemporal Evolution Analysis

Based on the previous text, the Super-SBM model was used to calculate the energy efficiency of the Yellow River Basin, and the entropy-weighted TOPSIS method was used to calculate the green development level of the Yellow River Basin. Figures 3 and 4 were drawn based on the calculation results.

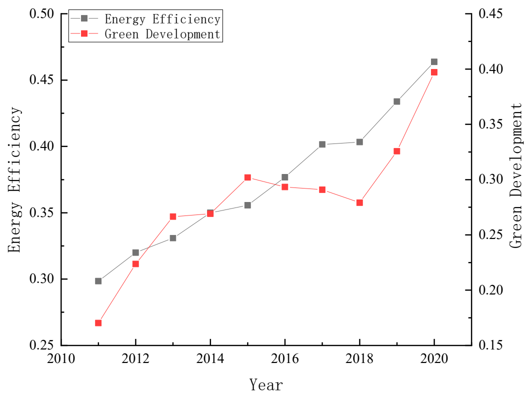

Figure 3. Overall trend of energy efficiency and green development in the Yellow River Basin from 2011 to 2020.

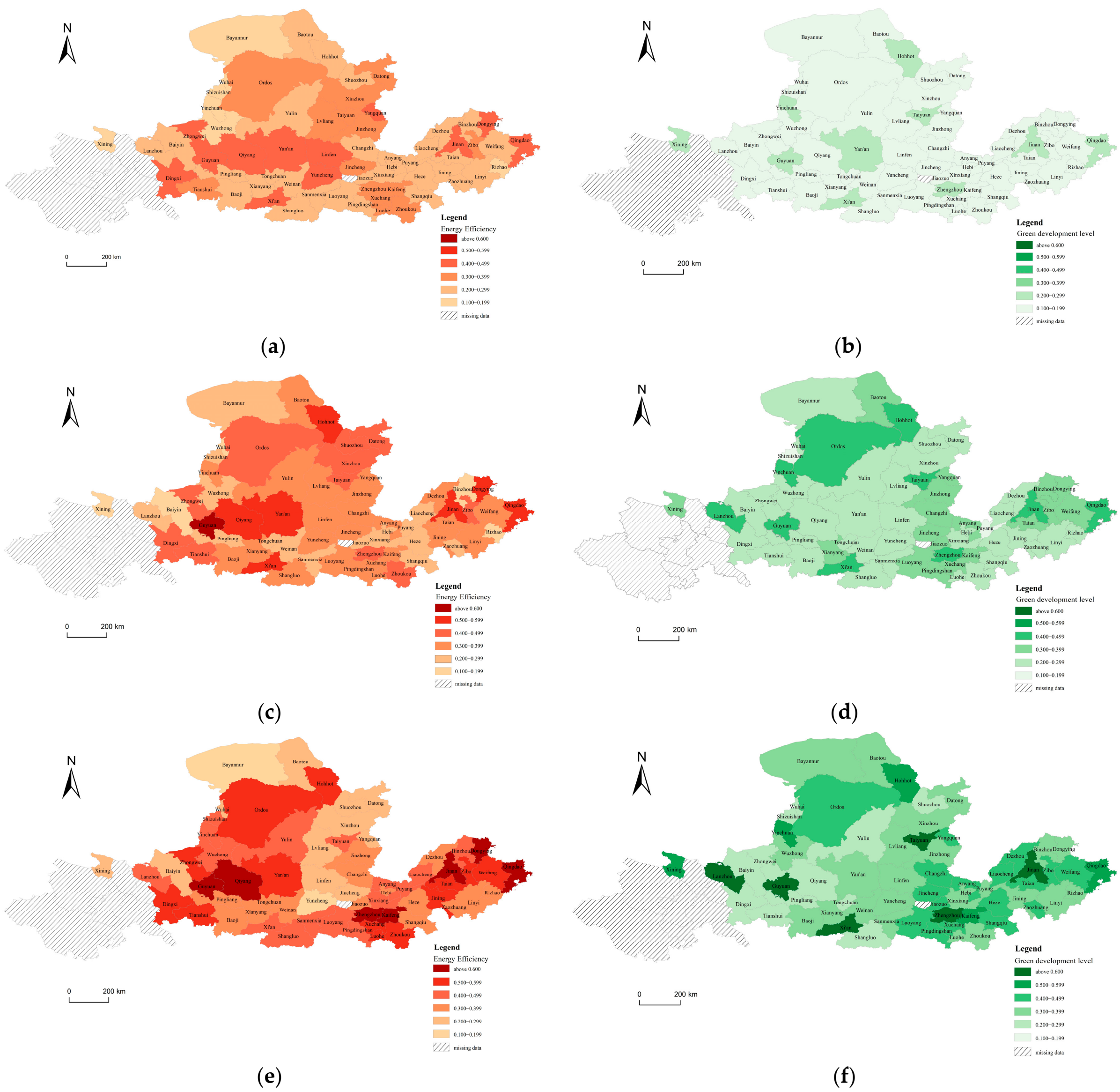

Figure 4. Spatial pattern of green development and energy efficiency in prefecture-level cities in the Yellow River Basin in 2011, 2015, and 2020. (**a**) Energy efficiency in 2011; (**b**) Green development level in 2011; (**c**) Energy efficiency in 2015; (**d**) Green development level in 2015; (**e**) Energy efficiency in 2020; (**f**) Green development level in 2020.

Regarding the temporal evolution of energy efficiency in the Yellow River Basin as a whole (Figure 3), the mean energy efficiency increased from 0.298 in 2011 to 0.464 in 2020, with an average annual growth rate of 6.2%, showing a steady upward trend. Based on the regional division, from 2011 to 2016, the overall energy efficiency in the Yellow River Basin was in the order of midstream area > downstream area > upstream area, while from 2017 onwards, it was in the order of downstream area > midstream area > upstream area. During the study period, the level of green development in the Yellow River Basin fluctuated between 0.170 and 0.397, with an average annual growth rate of 14.8%, showing a fluctuating upward trend. The average level of green development in the Yellow River Basin increased steadily from 2011 to 2015, declined from 2015 to 2018, and then, rebounded after 2018, showing an overall upward trend. The temporal evolution trends of the average levels of green development in the upstream, midstream, and downstream regions of the Yellow River Basin are generally consistent, and are ranked by region as follows: downstream area > midstream area > upstream area.

The energy efficiency and green development levels of the prefectural cities in the Yellow River Basin in 2011, 2015, and 2020 were visually displayed using ArcGIS (Figure 4). Overall, the average energy efficiency and green development levels of the prefectural cities in the Yellow River Basin from 2011 to 2020 showed an upward trend and had spatially heterogenous characteristics.

In terms of energy efficiency, our study found that the Yellow River Basin had spatial distribution characteristics of "high in the east and low in the west and central regions", and showed a clear spatial clustering trend. However, there was an unbalanced development trend in the upper, middle, and lower reaches of the Yellow River Basin. In 2011, the energy and chemical industries accounted for a large proportion in the upper reaches of the Yellow River Basin, and the dependence on fossil fuels was high, resulting in low energy efficiency due to unreasonable energy development and utilization. The middle and lower reaches of the Yellow River Basin had good natural and economic conditions, advanced technologies, and high energy efficiency compared to the upper reaches. After 2015, with the implementation of the "Two Mountains" theory and increased ecological protection efforts, the Yellow River Basin's ecological environment was improved and its energy structure optimized through the development of clean energy, which improved the overall energy efficiency in the region. This improvement was mainly concentrated in Shandong and Henan provinces in the lower reaches of the Yellow River Basin, where cities such as Jinan, Qingdao, and Zhengzhou had a high level of economic development, as well as large service and advanced manufacturing industries, resulting in a relatively high demand for clean energy and effective improvement in energy efficiency. The upper reaches of the Yellow River Basin were dominated by heavy industries, such as steel and metallurgy, which had high primary energy demand, leading to low energy efficiency. Other regions had moderate-to-low energy efficiency levels, and while they showed improvement in energy efficiency, they also produced high carbon emissions due to the adjustment and upgrading of their industrial structure.

In terms of green development, during the study period, the Yellow River Basin showed a spatial distribution pattern centered on the capital cities, radiating outwards. The green development level gradually spread from high levels at city centers to lower levels around cities such as Jinan, Zhengzhou, Taiyuan, and Xi'an, forming a development trend centered on these cities. In 2011, the overall green development level in the Yellow River Basin cities was relatively low. In 2020, the green development level had significantly improved and showed a spatial clustering trend, with cities such as Guyuan, Xi'an, Zhengzhou, Taiyuan, Jinan, and Qingdao showing higher green development levels, and with some areas radiating from the capital cities to surrounding cities. Due to the presence of high-energy, high-emission industries in the upper reaches of the Yellow River Basin, these areas produced high emissions of industrial pollutants and inflicted serious damage on the ecological environment, hindering regional green development. In recent years, the upper reaches of the Yellow River Basin have developed clean energy and achieved significant results in green development; however, the development of industry still relies on fossil fuels such as coal and oil, the proportion of new energy is relatively small, and the green development levels in these areas are still lower than those in the middle and lower reaches. The cities in the middle and lower reaches of the Yellow River Basin have benefited from a national development plan and innovation-driven development strategies, such as those implemented by the Guanzhong Plain City Group and Shandong Peninsula City Group, and are committed to comprehensive economic, societal, and ecological development; this plays a significant role in promoting the overall energy efficiency and green development levels in the Yellow River Basin.

4.2. Benchmark Regression Analysis

(1) Analysis of Regression Results

In this study, Stata 16.0 software was used to process the data. To ensure the scientific validity of the model setup, a Hausman test was conducted on the sample data before regression. The test results (prob > chi2 = 0.0000) rejected the null hypothesis, indicating the selection of a fixed-effect panel measurement model.

There is a significant linear relationship between energy efficiency and green development in the Yellow River Basin, as shown in Table 5. Table 5 includes (1) regression without control variables and (2) regression with control variables. The results show that the estimated energy efficiency coefficient is positive, regardless of whether the control variables are included, and that energy efficiency has a significant promoting effect on the transformation of green development in the Yellow River Basin, as seen in the results of the 1% significance test. In order to test whether there is a non-linear relationship between energy efficiency and green development, (3), the second term of energy efficiency was included in the regression. The results show that the estimated coefficient of the second term of energy efficiency failed the significance test, which means that there is no non-linear relationship between energy efficiency and green development. Among all the control variables in the regression model, the estimated coefficients of human capital, urbanization level, and industrial structure upgrading are positive and significant, indicating that they have a promoting effect on green development in the Yellow River Basin. This verifies the important impacts of human capital, urbanization level, and industrial structure upgrading on green development in the Yellow River Basin. These impacts include improving the quality of human capital, accelerating urbanization, improving the traditional industrial structure, developing strategic emerging industries, and accelerating industrial structure upgrading, and play an important role in promoting ecological protection and high-quality development in the Yellow River Basin. The level of foreign direct investment has a positive correlation with green development, but it failed the significance test, which means that the behavior of Yellow River Basin cities in attracting foreign investment has a limited impact on green development.

Table 5. Regression results of the effect of energy efficiency on green development in the Yellow River Basin.

Variables	**lnGD**		
	(1)	**(2)**	**(3)**
lnEE	0.504 ***	0.167 ***	0.084
	(12.28)	(3.60)	(0.81)
$lnEE^2$			−0.030
			(−0.68)
lnHC		0.087 **	0.086 **
		(2.41)	(2.35)

Table 5. *Cont.*

Variables	lnGD		
	(1)	(2)	(3)
lnUBL		0.872 ***	0.874 ***
		(11.37)	(11.39)
lnFDI		0.007	0.007
		(0.60)	(0.61)
lnIS		0.146 ***	0.148 ***
		(4.87)	(4.91)
_cons	−0.784 ***	−4.992 ***	−5.024 ***
	(−17.76)	(−14.58)	(−14.52)
Fixed	YES	YES	YES
R^2	0.21	0.47	0.47
Observed Value	640	640	640

Note: The values in parentheses are the *t*-values; *** and **, respectively, indicate significance at the 1% and 5% levels.

(2) Mediating Effect

Energy efficiency promotes green development in the Yellow River Basin by enhancing technological innovation capabilities. In Table 6, case (4) reflects the baseline regression results of the impact of energy efficiency on green development in the Yellow River Basin, showing the total effect of energy efficiency improvement on green development. The estimated results show that the total effect coefficient (c) is 0.167, and is significant at the 5% level, indicating that improved energy efficiency can effectively promote low-carbon transformation and green development in the Yellow River Basin. Case (5) represents the regression results of the effects of energy efficiency on technological innovation, with the estimated coefficient (a) being 0.828 and significant, indicating that improvement in energy efficiency can drive green technological innovation by forcing enterprises to increase investment in technological innovation, and that it can promote the popularization and application of green technologies. In case (6), the coefficient (b) of the effect of technological innovation on green development in the Yellow River Basin is 0.029 and significant at the 1% level. This indicates that technological innovation is the intrinsic driving force promoting green development in the Yellow River Basin, helping to adjust the energy consumption structure, promote energy conservation and emission reduction, and improve the ecological environment, thus realizing the comprehensive green transformation of the economy and society in the Yellow River Basin. The estimated coefficient (c′) of energy efficiency is 0.143 and is significant. In summary, technological innovation has a significant indirect effect on energy efficiency, affecting green development in the Yellow River Basin. Based on the model estimation results, and with reference to the coefficient product test method for the mediating effect analysis, it can be concluded that $c = ab + c'$; technological innovation has a partial mediating effect on energy efficiency, affecting green development in the Yellow River Basin; the mediating effect accounts for 14.4%. This verifies that improvement in energy efficiency can drive enterprises to accelerate green technological innovation. It can promote R&D and the popularization and application of green and low-carbon technologies, thus assisting in transformative green development and achieving high-quality development in the Yellow River Basin.

Table 6. The mediating role of technological innovation.

Variables	lnGD	lnTI	lnGD
	(4)	(5)	(6)
lnEE	0.167 *** (1.97)	0.828 ** (2.37)	0.143 *** (3.50)
lnTI			0.029 ** (2.11)
lnHC	0.087 ** (2.41)	0.170 *** (2.95)	0.090 ** (2.48)
lnUBL	0.872 *** (11.37)	1.045 *** (9.26)	0.825 *** (10.34)
lnFDI	0.007 (0.60)	0.004 (1.60)	0.006 (0.51)
lnIS	0.146 *** (4.87)	0.156 * (1.92)	0.149 *** (4.97)
_cons	−4.922 *** (−14.58)	−7.314 *** (−9.82)	−4.832 *** (−13.82)
Fixed	YES	YES	YES
R^2	0.43	0.38	0.47
Observed Value	640	640	640

Note: The values in parentheses are the *t*-values; ***, **, and *, respectively, indicate significance at the 1%, 5%, and 10% levels.

(3) Further Analysis

The recent book on "The Impact of Energy Technology Innovation in China on Energy Conservation and Emission Reduction: Theory and Evidence" points out that technological innovation has both direct and indirect impacts on the improvement of energy efficiency. Therefore, based on Equation (8), an interaction term between energy efficiency and technological innovation was added, as shown in Equation (13), and the regression results can be seen in Table 7, situation (7). The estimated coefficient is positive and passes the 10% significance test, indicating that technological innovation plays a promoting role in the dynamic process of energy efficiency and green development.

$$\ln GD_{it} = \gamma_0 + \chi_1 \ln EE_{it} + \chi_2 \ln TI_{it} + \chi_3 \ln X_{it} + \chi_4 (\ln EE_{it} \times \ln TI_{it}) + \varepsilon_{it} \tag{13}$$

Furthermore, energy efficiency may impact the green development of the Yellow River Basin under different levels of technological innovation. This paper built a panel threshold model based on Equation (8) [36], as shown in Equation (14).

$$\ln GD_{it} = \xi_0 + \xi_1 \ln EE_{it} I(q \leq \gamma) + \xi_2 \ln EE_{it} I(q > \gamma) + \xi_3 \ln X_{it} + \varepsilon_{it} \tag{14}$$

In this formula, q is the threshold variable, $I(\cdot)$ is a function that takes a value of 0 or 1, and γ is the specific threshold value.

Based on Equation (8), a panel threshold model [36] was constructed using technological innovation as the threshold variable and energy efficiency as the core explanatory variable. The results of the test can be seen in situation (8) in Table 6. Technological innovation passed the single-threshold test (p = 0.046), and its threshold value is 1.557. The estimated coefficients are positive, indicating that energy efficiency can effectively promote the transformation of green development in the Yellow River Basin, regardless of whether the technological innovation level crosses the threshold value. When the technological innovation level crosses the threshold value, the coefficient increases from 0.052 to 0.156 and passes the 1% significance test, showing that as the technological innovation level continues to improve, the research and promotion of green and low-carbon technologies, new products, etc., and the driving effect of energy efficiency on the transformation of green development in the Yellow River Basin, become significantly stronger, effectively promoting ecological protection and high-quality development in the Yellow River Basin.

Table 7. Regression results.

Variables	lnGD	
	(7)	**(8)**
lnEE	0.140 *** (2.63)	
lnTI	0.030 ** (3.69)	
$LnTI^2$		
lnEE × lnTI	0.002 * (1.75)	
lnEE(lnTI ≤ 1.557)		0.052 (1.39)
lnEE(lnTI > 1.557)		0.156 *** (3.88)
lnHC	0.088 ** (2.41)	0.081 ** (2.21)
lnUBL	0.831 *** (10.38)	0.821 *** (10.77)
lnFDI	0.006 (0.52)	0.005 (0.49)
lnIS	0.145 *** (4.85)	0.143 *** (4.86)
_cons	−4.812 *** (−13.48)	−4.748 *** (−13.97)
Fixed	YES	YES
R^2	0.47	0.50
Observed Value	640	640

Note: The values in parentheses are the *t*-values; ***, **, and *, respectively, indicate significance at the 1%, 5%, and 10% levels.

4.3. Robustness Test

To ensure the robustness of the above empirical results, the following three methods were used for robustness testing, and the results are shown in Table 8.

① Endogeneity test: This paper used the system GMM method to solve possible endogeneity problems, and the results are shown in Table 8 (9). The energy efficiency and technological innovation coefficients did not change, and they passed the significance test. The autocorrelation test and Hansen test were then conducted on the model; the results showed that the model had first-order autocorrelation but no second-order autocorrelation, and the selected instrumental variables were effective.

② Replacing the technological innovation explanatory variable: In addition to using the number of patent grants to measure technological innovation level, patent applications can also be used, so this paper replaced the technological innovation variable with the number of inventions per 10,000 people, and the regression results are shown in Table 8 (10). The coefficient of the explanatory variable was significantly positive and passed the significance test.

③ Trimming the tails: This paper used winsorization to trim the outliers in the text, and the regression results obtained after processing the data are shown in Table 8 (11). The signs are consistent with the benchmark regression results.

In conclusion, through the above three methods, it is found that energy efficiency and technological innovation have a positive impact on green development, indicating the reliability and validity of the empirical results in this paper.

Table 8. Estimated results of robustness tests.

Variables	lnGD		
	(9)	(10)	(11)
L.lnGD	0.429 *** [4.32]		
lnEE	0.167 * [1.70]	0.150 *** (3.66)	0.130 *** (3.09)
lnTI	0.179 ** [2.05]	0.027 * (1.81)	0.028 ** (2.12)
_cons	0.355 ** [1.98]	−4.926 *** (−14.04)	−4.957 *** (−13.79)
AR(1) p value	0.003		
AR(2) p value	0.557		
Hansen	0.139		
Control variables	YES	YES	YES
Fixed	YES	YES	YES
R^2		0.47	0.47
Observed Value	576	640	640

Note: The values in square brackets [ ] are z-values and the values in parentheses ( ) are t-values; ***, **, and *, respectively, indicate significance at the 1%, 5%, and 10% levels.

5. Conclusions and Recommendations

This paper built an evaluation index system for energy efficiency and green development levels in the Yellow River Basin, and calculated the energy efficiency and green development level indexes of 64 prefecture-level cities in the Yellow River Basin from 2011 to 2020. The evolution trends of the spatial and temporal patterns were analyzed, and the impact of energy efficiency on green development was explored using the STIRPAT model. The mediating effect of technological innovation was also tested through the mediating effect model. The following are the main conclusions:

(1) The overall energy efficiency and green development level in the Yellow River Basin show a significant upward trend, and there is spatial heterogeneity among the prefecture-level cities, with higher energy efficiency and green development levels in provincial capitals such as Jinan, Zhengzhou, and Xi'an.
(2) Improving energy efficiency can improve resource allocation, speed up energy conservation and emission reduction, and promote the transition to green development in the Yellow River Basin. Human capital, urbanization level, and the upgrading of the industrial structure have significant positive impacts on green development, while the level of foreign direct investment has a limited impact.
(3) Technological innovation plays a partial mediating role in the transition to green development in the Yellow River Basin, as it passed the single-threshold test with a mediating effect ratio of 14.4%. When technological innovation exceeds the threshold value, the driving effect of energy efficiency on green development is significantly enhanced.

Based on these research conclusions, the following suggestions are made:

(1) Promoting the transition to green development in the Yellow River Basin and improving energy efficiency. This can be achieved through: development of the green economy, improved resource allocation, and the comprehensive improvement of energy utilization efficiency; the consideration of heterogeneity among regions, resolute curbing of the development of high-energy and high-emission projects in upstream areas with abundant energy resources, and narrowing of the differences between upstream and downstream

areas; taking full advantage of the potential for energy conservation and emission reduction in downstream areas; encouragement of central cities to play a radiating role and assist in the high-quality development of the Yellow River Basin.

(2) Stimulating the vitality of green development in the Yellow River Basin, as well as new industries. This can be achieved through: the reasonable adjustment of the industrial structure, and acceleration of the development of emerging strategic industries; reasonable control of coal development intensity; promotion of the greening and intelligentization of the coal industry; enhancement of energy saving and environmental protection, clean production, and clean energy industries, among others; promotion of the transformation of the Yellow River Basin's dominant manufacturing industries to green energy; upgrading of industrial green transformation and promotion of low-carbon development of downstream industrial areas; acceleration of the formation of an industrial structure with low energy consumption and low environmental pollution.

(3) Leading the transition to green development in the Yellow River Basin with technological innovation. This can be achieved by: enhancing the support capacity of scientific and technological innovation and fully supporting green technological innovation; focusing on the implementation of green technological innovation in the energy and environmental fields in the Yellow River Basin; building a joint innovation platform; establishing a green, low-carbon scientific and technological innovation system for high and new technology industries; establishing a transformation fund for scientific and technological achievements in the Yellow River Basin; promoting the transfer and transformation of achievements through various means to promote the green and low-carbon development of the Yellow River Basin.

Finally, this article attempts to explain green development in the Yellow River Basin from the perspective of energy efficiency. However, whether green development also impacts energy efficiency is not thoroughly analyzed in this article, and thus warrants further research and exploration in the future. There are many factors that affect energy efficiency and green development, but due to the lack of data availability, this study does not include all controllable variables. It is necessary to contact relevant departments to obtain more data and conduct a more in-depth analysis of the impact mechanisms involved.

Author Contributions: Conceptualization, J.L.; investigation, L.P. and M.S.; methodology, Y.Z. and H.W.; supervision, J.L. and L.H.; data curation, Y.Z. and H.W.; writing—original draft, Y.Z. and L.H.; writing—review and editing, J.L. and L.P. All authors have read and agreed to the published version of the manuscript.

Funding: This study was funded by the Soft Science Major Project of Henan Province (Grant No. 212400410002), the National Social Science Foundation of China (21FGLB092), and the Henan Institute for Chinese Development Strategy of Engineering & Technology (Grant No. 2022HENZDA02).

Data Availability Statement: The data used in this study are available in a publicly accessible repository.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

GD	Green development level
EE	Energy efficiency
Super-SBM	Super-slacks-based measure
STIRPAT	Stochastic impacts by regression on population, affluence, and technology
TOPSIS	Technique for order preference by similarity to an ideal solution
TI	Technological innovation
HC	Human capital
UBL	Urbanization level
FDI	Foreign direct investment
IS	Industrial structure upgrading

References

1. Bouman, T.; Verschoor, M.; Albers, C.J.; Bohm, G.; Fisher, S.D.; Poortinga, W.; Whitmarsh, L.; Steg, L. When worry about climate change leads to climate action: How values, worry and personal responsibility relate to various climate actions. *Glob. Environ. Chang.* **2020**, *62*, 102061. [CrossRef]
2. Liu, J.; Shi, T.; Huang, L. A Study on the Impact of Industrial Restructuring on Carbon Dioxide Emissions and Scenario Simulation in the Yellow River Basin. *Water* **2022**, *14*, 3833. [CrossRef]
3. Huang, L.; Hou, Z.; Fang, Y.; Liu, J.; Shi, T. Evolution of CCUS Technologies Using LDA Topic Model and Derwent Patent Data. *Energies* **2023**, *16*, 2556. [CrossRef]
4. Liu, J.; Wang, H.Y.; Ho, H.W.W.; Huang, L.C. Impact of heterogeneous environmental regulation on manufacturing sector green transformation and sustainability. *Front. Environ. Sci.* **2022**, *10*, 938509. [CrossRef]
5. Lin, B.Q.; Zheng, Q.Y. Energy efficiency evolution of China's paper industry. *J. Clean. Prod.* **2017**, *140*, 1105–1117. [CrossRef]
6. Li, M.J.; Tao, W.Q. Review of methodologies and polices for evaluation of energy efficiency in high energy-consuming industry. *Appl. Energy* **2017**, *187*, 203–215. [CrossRef]
7. Sun, H.; Edziah, B.K.; Sun, C.W.; Kporsu, A.K. Institutional quality and its spatial spillover effects on energy efficiency. *Socio-Econ. Plan. Sci.* **2022**, *83*, 101023. [CrossRef]
8. Sueyoshi, T.; Goto, M. Energy Intensity, Energy Efficiency and Economic Growth among OECD Nations from 2000 to 2019. *Energies* **2023**, *16*, 1927. [CrossRef]
9. Xue, L.M.; Li, H.Q.; Xu, C.; Zhao, X.Y.; Zheng, Z.X.; Li, Y.S.; Liu, W. Impacts of industrial structure adjustment, upgrade and coordination on energy efficiency: Empirical research based on the extended STIRPAT model. *Energy Strat. Rev.* **2022**, *43*, 100911. [CrossRef]
10. Khan, D.; Nouman, M.; Ullah, A. Assessing the impact of technological innovation on technically derived energy efficiency: A multivariate co-integration analysis of the agricultural sector in South Asia. *Environ. Dev. Sustain.* **2022**, *25*, 3723–3745. [CrossRef]
11. Chen, M.; Sinha, A.; Hu, K.X.; Shah, M.I. Impact of technological innovation on energy efficiency in industry 4.0 era: Moderation of shadow economy in sustainable development. *Technol. Forecast. Soc. Chang.* **2021**, *164*, 120521. [CrossRef]
12. Pan, X.; Guo, S.C.; Han, C.C.; Wang, M.Y.; Song, J.B.; Liao, X.C. Influence of FDI quality on energy efficiency in China based on seemingly unrelated regression method. *Energy* **2020**, *192*, 116463. [CrossRef]
13. Shah, W.U.H.; Hao, G.; Yan, H.; Yasmeen, R.; Padda, I.U.; Ullah, A. The impact of trade, financial development and government integrity on energy efficiency: An analysis from G7-Countries. *Energy* **2022**, *255*, 124507. [CrossRef]
14. Wu, Y.S.; Wang, Y.S.; Chen, H. "Three-Circle Model" under the Green Development. *IOP Conf. Series: Earth Environ. Sci.* **2019**, *237*, 052041. [CrossRef]
15. Yang, Y.Y.; Guo, H.X.; Chen, L.F.; Liu, X.; Gu, M.Y.; Ke, X.L. Regional analysis of the green development level differences in Chinese mineral resource-based cities. *Resour. Policy* **2019**, *61*, 261–272. [CrossRef]
16. Lu, Y.Y.; Cao, B.; Hua, Y.D.; Ding, L. Efficiency measurement of green regional development and its influencing factors: An improved data envelopment analysis framework. *Sustainability* **2020**, *12*, 4361. [CrossRef]
17. Zhu, B.Z.; Zhang, M.F.; Zhou, Y.H.; Wang, P.; Sheng, J.C.; He, K.J.; Wei, Y.M.; Xie, R. Exploring the effect of industrial structure adjustment on interprovincial green development efficiency in China: A novel integrated approach. *Energy Policy* **2019**, *134*, 110946. [CrossRef]
18. Mensah, C.N.; Long, X.L.; Dauda, L.; Boamah, K.B.; Salman, M.; Appiah-Twum, F.; Tachie, A.K. Technological innovation and green growth in the Organization for Economic Cooperation and Development economies. *J. Clean. Prod.* **2019**, *240*, 118204. [CrossRef]
19. Jia, L.J.; Hu, X.L.; Zhao, Z.W.; He, B.; Liu, W.M. How environmental regulation, digital development and technological innovation affect China's green economy performance: Evidence from dynamic thresholds and system GMM panel data approaches. *Energies* **2022**, *15*, 884. [CrossRef]
20. Guo, Y.H.; Tong, L.J.; Mei, L. The effect of industrial agglomeration on green development efficiency in Northeast China since the revitalization. *J. Clean. Prod.* **2020**, *258*, 120584. [CrossRef]
21. Erdoğan, S.; Onifade, S.T.; Altuntaş, M.; Bekun, F.V. Synthesizing urbanization and carbon emissions in Africa: How viable is environmental sustainability amid the quest for economic growth in a globalized world? *Environ. Sci. Pollut. Res.* **2022**, *29*, 24348–24361. [CrossRef]
22. Zakari, A.; Khan, I.; Tan, D.J.; Alvarado, R.; Dagar, V. Energy efficiency and sustainable development goals (SDGs). *Energy* **2022**, *239*, 122365. [CrossRef]
23. Androniceanu, A.; Enache, I.C.; Valter, E.N.; Raduica, F.F. Increasing Energy Efficiency Based on the Kaizen Approach. *Energies* **2023**, *16*, 1930. [CrossRef]
24. Xu, G.Y.; Chang, H.Y.; Yang, H.L.; Schwarz, P. The influence of finance on China's green development: An empirical study based on quantile regression with province-level panel data. *Environ. Sci. Pollut. Res.* **2022**, *29*, 71033–71046. [CrossRef] [PubMed]
25. Yang, Y.P.; Wu, D.; Xu, M.; Yang, M.T.; Zou, W.J. Capital misallocation, technological innovation, and green development efficiency: Empirical analysis based on China provincial panel data. *Environ. Sci. Pollut. Res.* **2022**, *29*, 65535–65548. [CrossRef] [PubMed]
26. Sarkodie, S.A.; Adams, S.; Owusu, P.A.; Leirvik, T.; Ozturk, I. Mitigating degradation and emissions in China: The role of environmental sustainability, human capital and renewable energy. *Sci. Total Environ.* **2020**, *719*, 137530. [CrossRef]

27. Demena, B.A.; Afesorgbor, S.K. The effect of FDI on environmental emissions: Evidence from a meta-analysis. *Energy Policy* **2018**, *138*, 111192. [CrossRef]
28. Liang, G.F.; Yu, D.J.; Ke, L.F. An empirical study on dynamic evolution of industrial structure and green economic growth—Based on data from China's underdeveloped areas. *Sustainability* **2021**, *13*, 8154. [CrossRef]
29. Tone, K.; Sahoo, B.K. Degree of scale economies and congestion: A unified DEA approach. *Eur. J. Oper. Res.* **2004**, *158*, 755–772. [CrossRef]
30. Domagała, J.; Kadłubek, M. Economic, Energy and Environmental Efficiency of Road Freight Transportation Sector in the EU. *Energies* **2022**, *16*, 461. [CrossRef]
31. Wang, M.; Zhao, X.L.; Gong, Q.X.; Ji, Z.G. Measurement of regional green economy sustainable development ability based on entropy weight-topsis-coupling coordination degree—A case study in Shandong Province, China. *Sustainability* **2019**, *11*, 280. [CrossRef]
32. An, Y.; Tan, X.C.; Gu, B.H.; Zhu, K.W.; Shi, L.J.; Ding, Z.Y. An assessment of renewable energy development in Belt and Road Initiative countries: An entropy and TOPSIS approach. *Energy Rep.* **2023**, *9*, 166–181. [CrossRef]
33. York, R.; Rosa, E.A.; Dietz, T. STIRPAT, IPAT and IMPACT: Analytic tools for unpacking the driving forces of environmental impacts. *Ecol. Econ.* **2003**, *46*, 351–365. [CrossRef]
34. Pyzheva, Y.I.; Zander, E.V.; Pyzhev, A.I. Impacts of Energy Efficiency and Economic Growth on Air Pollutant Emissions: Evidence from Angara–Yenisey Siberia. *Energies* **2021**, *14*, 6138. [CrossRef]
35. Mo, Y.; Sun, D.; Zhang, Y. Green Finance Assists Agricultural Sustainable Development: Evidence from China. *Sustainability* **2023**, *15*, 2056. [CrossRef]
36. Jahanger, A.; Usman, M.; Ahmad, P. A step towards sustainable path: The effect of globalization on China's carbon productivity from panel threshold approach. *Environ. Sci. Pollut. Res.* **2022**, *29*, 8353–8368. [CrossRef] [PubMed]