

Research Article

Modeling the Spatial Correlations among Energy Consumption, Economic Growth, and the Ecological Environment

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Received 31 July 2021; Accepted 25 August 2021; Published 17 September 2021

Academic Editor: Daqing Gong

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To clarify whether there is a spatial correlation problem among China's provincial energy consumption, economic growth, and ecological environment, this paper adopts the panel data of 31 provinces in China from 2008 to 2019 and uses a spatial data analysis method. This work studies economic growth and the spatial distribution pattern of the ecological environment, as well as the spatial effects of its energy consumption and economic growth on the ecological environment. Moreover, the spatial autocorrelation model, spatial-temporal transition method, and generalized moment estimation method are adopted to conduct empirical analysis on the research object. The results show that (1) there are spatial correlations among energy consumption, economic growth, and the ecological environment in China's provinces, and there are obviously different agglomeration areas in spatial distribution; (2) energy consumption, economic growth, and the ecological environment level show different growth trends, and the differences between different provinces in provincial units are shrinking; and (3) regarding energy consumption, the spatial impact of economic growth on the ecological environment is obvious, and there are obvious "path dependence" characteristics in the spatial distribution and positive correlations. Finally, this paper puts forward research conclusions and relevant suggestions on the basis of empirical analysis.

1. Introduction

Since its reform and opening up, China's sustained and rapid economic growth has attracted much attention. The country's total economic volume has achieved development-by-leaps growth, with an average annual GDP growth rate of 9.26% and an annual per-capita GDP growth rate of 8.3%. China's GDP surpassed that of Japan in 2011, and China officially became the world's second largest economy. In 2019, China even reached a scale of 15.54 trillion US dollars. However, behind this phenomenon is the cost of a large amount of energy consumption and the destruction of the ecological environment. For a long time, China's coal-based energy structure, extensive energy production, and consumption patterns have made the contradiction between China's economic growth and resources and the environment increasingly sharp. China's total energy consumption has increased from 0.571 billion tons of standard coal in 1978 to 3.97 billion tons of standard coal in 2019, becoming the

world's largest energy consumption country. At the same time, China's carbon emissions also show a trend of rapid growth. According to data released by the International Energy Agency (IEA), global carbon dioxide (CO₂) emissions reached a historical high of 33 billion tons in 2019, and China's CO₂ emissions accounted for 23% of the world's total, far higher than that of the United States (11%). Although the caliber of different statistical agencies in the world is different, and the conclusions drawn are also different to some extent, it is undeniable that China's total energy consumption, total carbon emissions, and total economic volume show a trend of synchronous high-speed growth. The energy consumption, environmental pollution, and ecological destruction of China's economic growth have also attracted great attention worldwide. The World Bank's Development Report lists China and India as countries with both high economic growth and high environmental pollution. The extensive economic growth mode of "high energy consumption, low efficiency, and high emissions" can no

longer adapt to the current situation of resource shortages and environmental restrictions in China. Only by changing the economic growth mode, from high resource consumption to low resource consumption, does the increase in environmental pollution transform to a decrease in resource consumption and environmental pollution. Moreover, accelerating the construction of a two-type society of “resource-saving and environmentally friendly” has become the top priority of China’s scientific development.

According to statistics from China’s National Bureau of Statistics, its total energy consumption was approximately 0.571 billion tons of standard coal in 1978 and reached 3.97 billion tons of standard coal in 2019, with consumption increasing. China’s energy consumption per unit of GDP was 0.73 in 2019. From 2017 to 2019, China’s energy consumption per unit of GDP decreased by 3.7%, 3.1%, and 5%, respectively, compared with the previous year, although it showed a downward trend year by year; however, China’s energy consumption per unit of GDP is still far higher than that of developed countries such as the United States, Japan, Germany, and the United Kingdom, at 2.5 times the world average, exceeding most emerging economies, such as Brazil, India, and Mexico. At present, China’s economic growth mode is still an extensive growth state of “high consumption, high emissions, and low output.” The lack of efficient energy consumption and an unscientific energy structure have brought about severe environmental pollution problems. To cope with the tense situation of resources and the environment, China’s “13th Five-Year Plan” not only clearly controls the total emission of pollutants (for example, the total emissions of chemical oxygen demand and sulfur dioxide decreased by 8%) but also puts forward clear requirements for environmental protection fund investment (the government’s environmental protection financial investment reached 1.5% of GDP). At the same time, China’s regional economic development is unbalanced, and its degree of environmental pollution is different. In the process of economic development, it is necessary to find the best balance between the protection and governance of the regional economy and the environment to give overall consideration to the protection and governance of the regional economy and the environment, which is a key topic that scholars need to consider. Therefore, starting from the actual situation of the dual constraints of China’s regional energy consumption and environmental pollution, this paper uses the spatial econometric method to explore the spatial correlations among China’s provincial energy consumption, economic growth, and ecological environment, which has both theoretical and practical significance.

2. Literature Review

Rapid economic growth, especially excessive energy consumption, will inevitably bring about pollution problems, and the relationships among these issues are currently a hot topic in academia. Scholars have performed much research on the relationships among energy consumption, economic growth, and the ecological environment and put forward a series of policy suggestions, achieving rich scientific research

results. Regarding the relationship between energy consumption and economic growth, some scholars have adopted classical measurement methods, such as the Anselin and Glasure and Lee [1, 2] causality test and the vector autoregressive (VAR) or data envelopment analysis (DEA) methods, to measure the efficiency of energy consumption on economic growth. Galeotti et al. [3] examined the impact of the consumption of coal, oil, natural gas, electricity, and other energies on economic growth, and the empirical results show that there is a two-way Granger relationship between various types of energy consumption and economic growth. Madlener and Sunak [4] studied the causal relationship between energy consumption and GDP in 16 countries and concluded that there is either a one- or two-way causal relationship between energy consumption and economic growth in most countries. Antonakakis et al. [5] conducted an empirical study on energy consumption and economic growth in the United States in recent years and concluded that energy consumption, capital investment, and labor force have a significant positive impact on economic growth. Dogan and Aslan [6] used the panel VAR (PVAR) model and panel cointegration test method to carry out an empirical analysis on 106 countries and all EU member states, concluding that economic growth and energy consumption affect each other. The relationship between economic growth and environmental pollution has always been a hot topic in academia. Maddison [7] used Kuznets’s famous “inverted U” curve hypothesis on the relationship between income distribution and economic growth for reference and thought that there might also be an inverted U-shaped relationship between economic growth and environmental quality. Based on empirical data, Caviglia-Harris et al. [8] have confirmed that there exists an inverted U-shaped environmental Kuznets curve (EKC) between per-capita GDP and pollutant emission level, and SO₂ and atmospheric suspended solids increase with the increase in per-capita GDP. Kwsqwa [9] found that when the sample data of global countries are selected, there is a monotonous relationship between per-capita sulfur emissions and per-capita income, and when the sample of high-income countries is selected, it is an “inverted U” type relationship; emissions reduction is not related to income. Li and Wang [10] used the comprehensive index of ecological footprint to measure environmental quality and found that there was no EKC inverted U-shaped relationship between ecological footprint and economic growth. Guan and Jin [11] further analyzed the spatial correlations of provincial environmental pollution by using a spatial econometrics model and proposed the existence of obvious spatial dependence and spatial spillover effects in China’s provincial environmental pollution, concluding that the higher the provincial per-capita income, the more serious the environmental pollution.

The environmental pollution and ecological balance caused by the development and utilization of energy resources are increasingly important sources of international environmental problems and react to the energy utilization and economic development strategies of various countries and regions. Therefore, how to maintain the sustainable

development of energy, the environment, and the economy has become an important problem that needs to be urgently solved in today's society. Scholars' previous discussions on energy, the environment, and economic issues focused on three aspects. (1) The first was the establishment of a coordination model of energy, the environment, and economic system. Rupasingha et al. [12] disassembled carbon emission efficiency into three kinds of efficiencies, including technology, pure technology, and scale, as the evaluation index of the carbon emission system and then established a coordinated evaluation system of "regional carbon emissions-economic development-environmental protection." Mirshojaeian and Rahbar [13] built a three-system coupling model of energy, the environment, and the economy on the basis of the system coordination mechanism and transition mode. (2) The second aspect was the summary of the temporal and spatial characteristics of the coordinated development of energy, the environment, and the economy. Hosseini and Kaneko [14] took the Great Lakes region of the United States as an example to discuss the temporal and spatial characteristics of the coordinated development of the human settlement environment and economy in the region from 2000 to 2015. Manello [15] taking 8 typical countries in Europe, America, and Asia as examples, using the revised model of coordinated development degree to analyze the energy resources of each country from 1961 to 2011, summarized and analyzed the coordination characteristics of the environment and economy. (3) The third aspect was the scientific calculation of the coscheduling of energy, the environment, and economic system. Goldar and Goldar [16] used the Malmquist productivity index method to conduct an in-depth study on the economic performance of energy consumption and the changing trend of the environmental performance of energy output and input in Britain from 2000 to 2010. Niu and Sun [17] conducted scientific calculations on the coscheduling of the energy, environment, and economic systems of 30 provinces in China from 2004 to 2010. In general, due to differences in the research period, model methods, and even the actual national conditions of various countries chosen by scholars, the conclusions drawn from the relevant results are contradictory, even opposing.

Through a review of the above literature, the existing research has three deficiencies. (1) Affected by different factors such as data availability, model methods, and the index evaluation system, current studies on the interactive state of and problems in the evolution among energy, the environment, and the economy are mostly based on static analysis, and there are some differences in their conclusions, which leads to the relatively insufficient depth of empirical research and theoretical discussion. (2) The research on the interactive relationships among energy, the economy, and the environment is mainly from the economics perspective, lacking the revelation of temporal and spatial differences from the perspective of geography. (3) Scholars mostly measure environmental pollution by the emissions of a single pollutant such as sulfur dioxide, carbon dioxide, and three industrial wastes, a method that lacks overall consideration. Based on this factor, this paper attempts to overcome the above shortcomings and studies the relationships among the degree of environmental pollution, energy

consumption, and economic growth in China's provinces on the basis of summarizing the existing spatial econometric analysis technologies.

The structure of this paper is as follows: the first part is the introduction, which briefly introduces the environmental pollution problem caused by China's economic development and the significance of coordinating economic growth, energy consumption, and environmental governance. The second part is the literature review. This paper discusses the extant research on the relationship between energy consumption and economic growth and between pollution emissions and economic growth. The third part is the selection of research models and research indexes. This paper expounds on the research methods and models adopted in this paper and puts forward the index factors involved in the model. The fourth part is an empirical analysis, taking 31 provinces in China as the research objects, using panel data from 2008 to 2019, and analyzing the spatial correlations among energy consumption, economic growth, and ecological environment in China's provinces. The fifth part presents the conclusions and countermeasures. On the basis of empirical research, this paper puts forward research conclusions and solutions.

3. Research Model and Index Selection

In order to analyze the relationship between energy consumption, economic growth, and ecological environment, this paper adopts spatial autocorrelation model, spatial-temporal transition method, and generalized moment estimation method to study it, so as to explore the interaction and influence among the three. In essence, the spatial autocorrelation model can evaluate the potential interdependence between the observed data in the same distribution area and describe the cluster situation of regional activity spatial distribution. In addition, it can also detect spatial anomalies of regional activities. Spatio-temporal transition method can observe the spatial dynamic transition process between energy consumption, economic growth, and ecological environment in Moran index scatter plot. Panel data is two-dimensional data obtained from both temporal and spatial cross sections. The generalized moment estimation method can greatly improve the sample size and effectively solve the multicollinearity problem of model parameters. Therefore, the accuracy of parameter estimation is improved.

3.1. Spatial Autocorrelation Model

3.1.1. Global Spatial Autocorrelation Model. Global spatial autocorrelation analysis is mainly used to judge whether a certain phenomenon has agglomeration characteristics in space. Generally, Moran's I exponential analysis is adopted [18] and the specific formula is as follows:

$$\text{Moran's } I = \frac{\sum_{i=1}^n \sum_{j=1}^n W_{ij} (X_i - \bar{X})(X_j - \bar{X})}{S^2 \sum_{i=1}^n \sum_{j=1}^n W_{ij}}, \quad (1)$$

where X_i is the observed value of region i , n is the total number of regions, $S^2 = 1/(n \sum_{i=1}^n (X_i - \bar{X})^2)$, $\bar{X} = 1/(n \sum_{i=1}^n X_i)$, and

W is the spatial weight matrix; the W setting principle is as follows:

$$W_{ij} = \begin{cases} 1, & \text{when region } i \text{ is adjacent to region } j, \\ 0, & \text{when region } i \text{ and region } j \text{ are not adjacent,} \\ 0, & \text{when } i = j. \end{cases} \quad (2)$$

The abovementioned ‘‘adjacent’’ includes left and right sides, upper and lower sides, and diagonals. That is, as long as the two regions have a common boundary or intersection, they are defined as adjacent.

The value range of the Moran’s I index is $[-1, 1]$, with values greater than 0 indicating that there is a positive spatial correlation and that a region with a similar level of phenomenon agglomerates in space; with values less than 0 indicating that there is a negative spatial correlation and that a certain phenomenon presents a polarization trend in space; and with values close to 0 indicating that there is no spatial correlation and that a certain phenomenon is randomly distributed in space. At the same time, a Z statistical significance test is needed for the results of global spatial autocorrelation analysis. The Z statistical formula is as follows:

$$Z = \frac{I - E(I)}{SD(I)}, \quad (3)$$

where $E(I)$ and $SD(I)$ are the mean and variance of the variables, respectively.

3.1.2. Local Spatial Autocorrelation Model. Local spatial autocorrelation analysis is based on global spatial autocorrelation analysis and further analyzes the spatial difference degree between each region and adjacent regions and then examines whether the local areas tend to have high-high agglomeration or low-low agglomeration in space. The specific formula is as follows:

$$I_i = \frac{\sum_{j=1}^n W_{ij} (X_i - \bar{X})(X_j - \bar{X})}{\sum_{j=1}^n (X_j - \bar{X})^2}, \quad (4)$$

where I_i is the local Moran’s I index, X_i is the observed value of region i , and W_{ij} is the spatial weight matrix.

Local spatial autocorrelation can be analyzed by Moran’s I scatterplot, which can be divided into four quadrants, with each quadrant representing one spatial correlation mode [19]. Among them, the first quadrant (H-H) represents high-value region agglomeration, the second quadrant (L-H) represents a low-value region being surrounded by a high-value region, the third quadrant (L-L) represents low-value region agglomeration, and the fourth quadrant (H-L) indicates that the high-value area is surrounded by the low-value area. H-H and L-L show that there is homogeneity among regions, and the differences tend to converge; L-H and H-L show that there is heterogeneity among regions, and the differences tend to disperse.

3.2. Temporal and Spatial Transition Measurement Method.

Because the spatial autocorrelation model explores only the spatial distribution pattern of a certain phenomenon from the spatial dimension and is mainly used for cross-sectional data, it ignores the temporal dimension of the change in a certain phenomenon to a large extent. Aiming at this defect, Rey [20] integrated the time factor into the spatial autocorrelation model and proposed the space-time analysis method; therefore, the transformation from the spatial autocorrelation model to exploratory spatiotemporal data analysis is realized. Rey divided the space-time transition into four types: Type I (self-transition-domain stability), Type II (self-stability-domain transition), Type III (self-transition-domain transition), and Type IV (self-stability-domain stability). Among them, Type I includes $HH_t \rightarrow LH_{t+1}$, $LH_t \rightarrow HH_{t+1}$, $HL_t \rightarrow LL_{t+1}$, and $LL_t \rightarrow HL_{t+1}$; Type II includes $HH_t \rightarrow HL_{t+1}$, $HL_t \rightarrow HH_{t+1}$, $LH_t \rightarrow LL_{t+1}$, and $LL_t \rightarrow LH_{t+1}$; Type III includes $HH_t \rightarrow LL_{t+1}$, $LL_t \rightarrow HH_{t+1}$, $LH_t \rightarrow HL_{t+1}$, and $HL_t \rightarrow LH_{t+1}$, the first two directions are the same, and the last two directions are the opposite; and Type IV indicates that both itself and the units of neighboring provinces remain in the original state. The spatial stability of a certain phenomenon can be measured by an index S_t , and the calculation formula is as follows:

$$S_t = \frac{F_{0,t}}{n}, \quad (5)$$

where $F_{0,t}$ represents the number of provinces that observe a certain phenomenon of a IV-type transition in the study period from 0 to t , that is, the number of provinces that have not changed, and n is the number of all provinces that may have transitioned, that is, the number of provinces studied. The S_t value range is in $[0, 1]$, and the larger the value of S_t , the stronger the spatial stability of a certain phenomenon, and the larger the jump resistance and dilemma.

3.3. Model Setting of Influencing Factors. Referring to the research methods of previous scholars [21, 22] and combining the selection of influencing factors (as shown in Table 1), this paper adopts generalized method of moments (GMM) estimation, takes the ecological environment as the explained variables and energy consumption and economic growth as the explanatory variables, analyzes the interaction degree among the ecological environment, energy consumption, and economic growth, and sets the regression model as follows:

$$\ln X_{it} = \beta_0 + \beta_1 IS_i + \beta_2 TI_i + \beta_3 OP_i + \beta_4 GI_i + \varepsilon_i. \quad (6)$$

Here, X represents the ecological environment, IS represents energy consumption, TI represents economic growth, and ε_i is an error item.

3.4. Selection of Indicators. With full reference [23, 24] this paper constructs China’s energy consumption, economic growth, and ecological environment measurement index system, focuses on energy utilization and the impact degree

of economic growth on the ecological environment, refers to the relevant achievements of scholars in index selection [25, 26], and sorts out and screens them. Based on scientificity, representativeness, accessibility, and integrity principles, this paper constructs the index system of the influencing factor model. As shown in Table 1, the selection and interpretation of specific indicators as follows:

- (1) Energy consumption index layer: investigate the current situation and development potential of China's energy utilization. Taking advantage of the current situation, this paper selects three indicators—total energy consumption, the proportion of nonfossil energy consumption, and energy consumption per unit of GDP—to represent the total energy consumption, consumption structure, and economic efficiency, respectively. In terms of development potential, this paper selects two indexes, namely, the energy industry investment and energy consumption elasticity coefficient, to characterize the future infrastructure construction of the energy industry and the trend of the energy industry level.
- (2) Index layer of economic growth: investigate China's economic scale and potential. In terms of economic scale, this paper selects four indicators—gross industrial output value, added value of the tertiary industry, investment in fixed assets, and total retail sales of social consumer goods—to represent the overall level of the economy. In terms of economic potential, this paper selects the proportion of fiscal expenditure, the tertiary industry proportion, and economic density of these three indicators to represent the vitality and prospect of future economic development.
- (3) Ecological Environment Index layer: investigate China's environmental pollution degree and environmental governance level to reveal the overall situation of the ecological environment. In terms of environmental pollution, due to the wide sources of environmental pollution and the complex and diverse environmental quality evaluation parameters, this paper focuses on the industrial industries that have the greatest impact on the ecological environment, selects industrial wastewater discharge and industrial SO₂ discharge, chooses three indexes of industrial smoke and dust emissions to represent the degree of environmental pollution, and selects two indexes of the comprehensive utilization of industrial solid waste and the intensity of environmental governance to represent the level of environmental governance.

4. Empirical Analysis

4.1. Data Sources. This paper takes 31 provinces, cities, and autonomous regions in China from 2008 to 2019 (except Macao and Taiwan, where statistical data are missing) as research objects to construct a spatial panel dataset. Empirical data come from the China Statistical Yearbook, China

Energy Statistical Yearbook, China Environmental Statistical Yearbook, and the website of the China National Bureau of Statistics. All monetary units in this article are converted with 2008 as the base period to eliminate the impact of inflation. The provincial administrative zoning map of China is shown in Figure 1.

4.2. Global Spatial Differentiation Analysis. This paper uses the statistical data on the economic growth, energy consumption, and ecological environment of 31 provinces in China from 2008 to 2019, through Moran's I calculated by GeoDa software and related statistical tests. The results show that Moran's I in each year is positive, which basically passes the statistical test at the 5% significance level, as shown in Tables 2–4. The data in these tables show that China's economic growth, energy consumption, and ecological environment have obvious spatial effects and positive correlations in geographical distribution. That is, the geographical distribution pattern of pollution is not random but shows an obvious agglomeration distribution. Similarly, the economic growth and energy structure variables also have similar spatial distributions.

To further illustrate the spatial correlation, we can observe a Moran index scatterplot of economic growth, energy structure, and ecological environment (as shown in Figures 2–4). We divide the province into four quadrants: the first quadrant (H-H) indicates a high-high positive correlation, the second quadrant (L-H) indicates a low-high negative correlation, the third quadrant (L-L) indicates a positive correlation between low and low, and the fourth quadrant (H-L) indicates a negative correlation between high and low. Since the Moran's I values are all greater than 0, there are positive correlations among economic growth, energy structure, and geographical distribution of the ecological environment, and the second and fourth quadrants are atypical observation areas.

As seen from Figure 2, there are 8 and 9 provinces in the first quadrant (H-H) of China's provincial economic growth in 2008 and 2019, accounting for 25.80% and 29.03% of all statistical units, respectively. There are 3 and 6 provinces distributed in the second quadrant (L-H), accounting for 9.68% and 19.35% of all statistical units, respectively. There are 17 and 12 provinces distributed in the third quadrant (L-L), accounting for 54.84% and 38.71% of all statistical units, respectively. Two and 4 provinces are distributed in the fourth quadrant (H-L), accounting for 6.45% and 12.90% of all statistical units, respectively. It can be found that there were 25 and 21 provinces in the 31 statistical samples in 2008 and 2019, accounting for 86.65% and 67.74% of the total statistics, respectively, which has a positive spatial correlation. Other provinces are distributed in the second and fourth quadrants, accounting for 13.35% and 32.26% of the total statistics, respectively, showing different spatial autocorrelation. Although there are few spatial differences in the local correlation of economic growth, there are mainly spatial dependence characteristics.

As shown in Figure 3, China's provincial energy consumption in 2008 and 2019 is distributed in the first

TABLE 1: China’s energy consumption, economic growth, and ecological environment measurement index system.

Target layer A	Indicator layer B	Indicator layer C	Unit
Energy consumption (IS)	Utilization status quo (X_1)	Total consumption of energy (x_{11})	Ten thousand tons
		Proportion of nonfossil energy in total energy consumption (x_{12})	%
	Development potential (X_2)	Energy consumption per unit of GDP (x_{13})	Tons of standard coal/ten thousand yuan
		Investment in energy industry (x_{21})	Billion yuan
Economic growth (TL)	Economic scale (X_3)	Energy consumption elasticity coefficient (x_{22})	%
		The total value of industrial output (x_{31})	Billion yuan
		Tertiary industry value added (x_{32})	Billion yuan
	Economic potential (X_4)	Fixed asset investment (x_{33})	Billion yuan
		Total retail sales of consumer goods (x_{34})	Billion yuan
		Proportion of fiscal expenditure (x_{41})	%
Ecological environment (X)	Environmental pollution (X_5)	Proportion of tertiary industry (x_{42})	%
		Economic density (x_{43})	Billion yuan/km ²
		Industrial wastewater discharge (x_{51})	Ten thousand tons
	Environmental governance (X_6)	Industrial SO ₂ emissions (x_{52})	Ton
		Industrial smoke emissions (x_{53})	Ton
		Comprehensive utilization of industrial solid waste (x_{61})	Ten thousand tons
Environmental governance intensity (x_{62})	%		



FIGURE 1: China provincial administrative zoning map.

quadrant (H-H) in 11 and 11 provinces, accounting for 35.49% and 35.49% of all statistical units, respectively. There are 7 and 6 provinces distributed in the second quadrant (L-H), accounting for 22.58% and 19.35% of all statistical units, respectively. There are 9 and 10 provinces distributed in the third quadrant (L-L), accounting for 29.03% and 32.26% of all statistical units, respectively. There are 4 provinces distributed in the fourth quadrant (H-L), accounting for 12.90% of all statistical units. It can be found that there are 20 and 21 provinces in the 31 statistical samples in 2008 and 2019, accounting for 64.51% and 67.74% of the total statistics, respectively, which have positive spatial correlation. The remaining provinces are distributed in the second and fourth quadrants, accounting for 35.49% and 32.26% of the total statistics, respectively, showing that they have different spatial autocorrelations. Thus, although there are a few

spatial differences in the local correlation of energy consumption, there are mainly spatial dependence characteristics.

As seen from Figure 4, there are 12 and 10 provinces distributed in the first quadrant (H-H) in China’s provincial ecological environment in 2008 and 2019, accounting for 38.71% and 32.26% of all statistical units, respectively. There are 10 and 8 provinces distributed in the second quadrant (L-H), accounting for 32.26% and 25.81% of all statistical units, respectively. There are 8 and 8 provinces distributed in the third quadrant (L-L), accounting for 25.81% and 25.81% of all statistical units, respectively. There are 1 and 5 provinces distributed in the fourth quadrant (H-L), accounting for 2.23% and 16.13% of all statistical units, respectively. It can be found that there are 20 and 18 provinces in the 31 statistical samples in 2008 and 2019, accounting for 64.52% and 58.06% of the total statistics, respectively, which have positive spatial correlation, and the rest of the provinces are distributed in the second and fourth quadrants, accounting for 35.48% and 41.94% of the total statistics, respectively, showing that they have different spatial autocorrelations. Although there are few spatial differences in the local correlation of the ecological environment, there are mainly spatial dependence characteristics.

4.3. Local Spatial Differentiation Analysis. Moran’s I and the Moran scatterplot simply describe the agglomeration of economic growth, energy structure, and ecological environment, so it is impossible to deeply study the local spatial correlation mode; however, the LISA index can be used to verify whether the high or low values of the research variables in local areas present regional agglomeration in geographical distribution. Using GeoDa, we can divide 31 provinces in China into 5 types: (1) low-low type; (2) low-

TABLE 2: Global Moran's I statistical indicators of economic growth in 31 provinces in China from 2008 to 2019.

Year	Moran's I	$E(I)$	$SD(I)$	z	P value
2008	0.4857	-0.032	0.115	5.014	0.001
2009	0.4932	-0.032	0.119	5.118	0.001
2010	0.5116	-0.032	0.113	4.739	0.003
2011	0.5428	-0.032	0.117	4.858	0.001
2012	0.4990	-0.032	0.111	4.904	0.002
2013	0.4672	-0.032	0.114	4.830	0.001
2014	0.5227	-0.032	0.118	5.133	0.001
2015	0.4883	-0.032	0.116	4.772	0.003
2016	0.4658	-0.032	0.113	4.849	0.001
2017	0.4750	-0.032	0.112	4.560	0.002
2018	0.5189	-0.032	0.114	4.997	0.002
2019	0.4764	-0.032	0.117	5.102	0.001

Note: $E(I)$ is $-1/(n - 1)$, which represents the expected value of I ; $SD(I)$ is the variance of I ; z is the z test value of I ; and P is its accompanying probability.

TABLE 3: Global Moran's I statistical indicators of energy utilization in 31 provinces of China from 2008 to 2019.

Year	Moran's I	$E(I)$	$SD(I)$	z	P value
2008	0.2375	-0.041	0.116	1.832	0.052
2009	0.1247	-0.041	0.118	2.550	0.041
2010	0.2113	-0.041	0.113	2.689	0.037
2011	0.1951	-0.041	0.117	1.756	0.025
2012	0.1639	-0.041	0.118	2.094	0.018
2013	0.2258	-0.041	0.115	1.881	0.011
2014	0.1787	-0.041	0.112	1.779	0.007
2015	0.1596	-0.041	0.114	2.203	0.042
2016	0.2064	-0.041	0.117	2.657	0.035
2017	0.1833	-0.041	0.117	1.893	0.043
2018	0.2320	-0.041	0.119	2.501	0.027
2019	0.1745	-0.041	0.118	1.899	0.016

Note: $E(I)$ is $-1/(n - 1)$, which represents the expected value of I ; $SD(I)$ is the variance of I ; z is the z test value of I ; and P is its accompanying probability.

TABLE 4: Global Moran's I statistical indicators of the ecological environment in 31 provinces of China from 2008 to 2019.

Year	Moran's I	$E(I)$	$SD(I)$	z	P value
2008	0.2485	-0.028	0.116	2.318	0.013
2009	0.2847	-0.028	0.119	2.107	0.011
2010	0.2550	-0.028	0.111	2.439	0.117
2011	0.2389	-0.028	0.115	2.515	0.115
2012	0.2776	-0.028	0.114	2.130	0.119
2013	0.2381	-0.028	0.118	2.446	0.008
2014	0.2692	-0.028	0.113	2.392	0.015
2015	0.2874	-0.028	0.117	2.403	0.012
2016	0.2963	-0.028	0.112	2.188	0.016
2017	0.2107	-0.028	0.115	2.511	0.013
2018	0.2310	-0.028	0.118	2.296	0.024
2019	0.2719	-0.028	0.113	2.145	0.018

Note: $E(I)$ is $-1/(n - 1)$, which represents the expected value of I ; $SD(I)$ is the variance of I ; z is the z test value of I ; and P is its accompanying probability.

high type; (3) high-low type; (4) high-high type; and (5) no data type, which indicates the region where data cannot be obtained.

As seen from Figure 5, China's economic growth has formed two different agglomeration areas in terms of geographical distribution: (1) centered in Beijing, Beijing-Tianjin-Hebei areas with high economic growth, including Tianjin, Hebei, etc., and centered in Shanghai, high-value areas of economic growth in the Yangtze River Delta including Jiangsu, Zhejiang, etc., and (2) the economic growth

low-value agglomeration areas formed in the vast western regions and other places are in line with China's current economic situation.

As seen from Figure 6, China's energy consumption has formed two different agglomeration areas in terms of geographical distribution: (1) high-value areas of traditional major coal-producing provinces centered on Shanxi and Henan and (2) northwest and other low-value-gathering areas centered on Xinjiang and Qinghai. At the same time, from the change in the LISA cluster diagram, it can also be

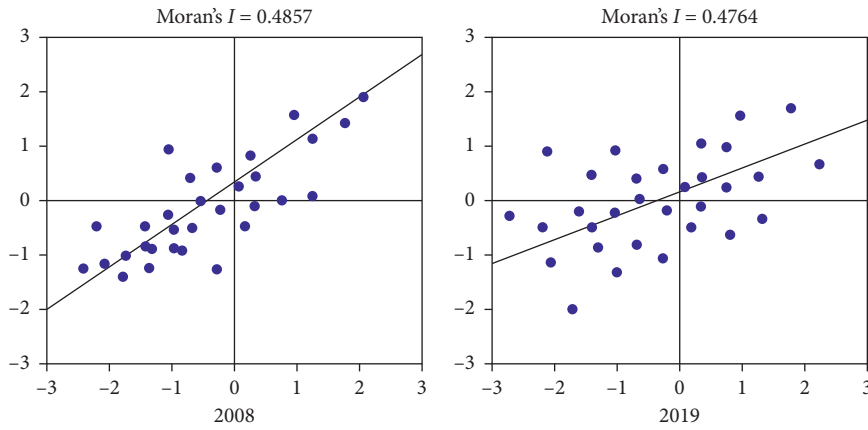


FIGURE 2: Moran index scatterplot of economic growth in 31 provinces of China in 2008 and 2019.

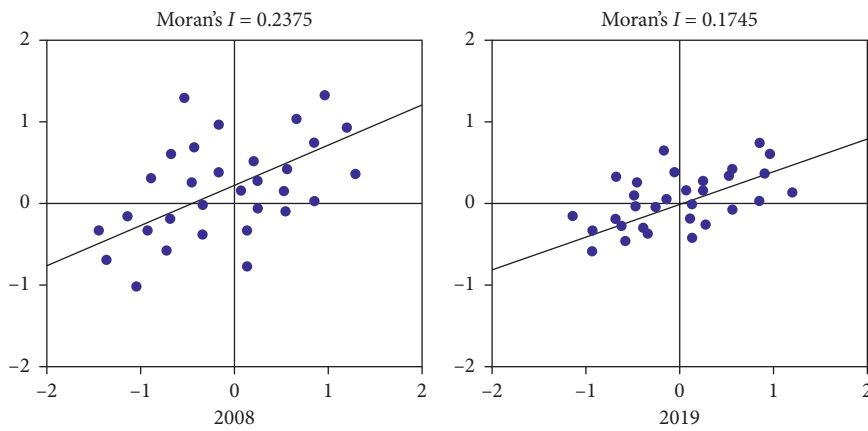


FIGURE 3: Moran index scatterplot of energy consumption of 31 provinces in China in 2008 and 2019.

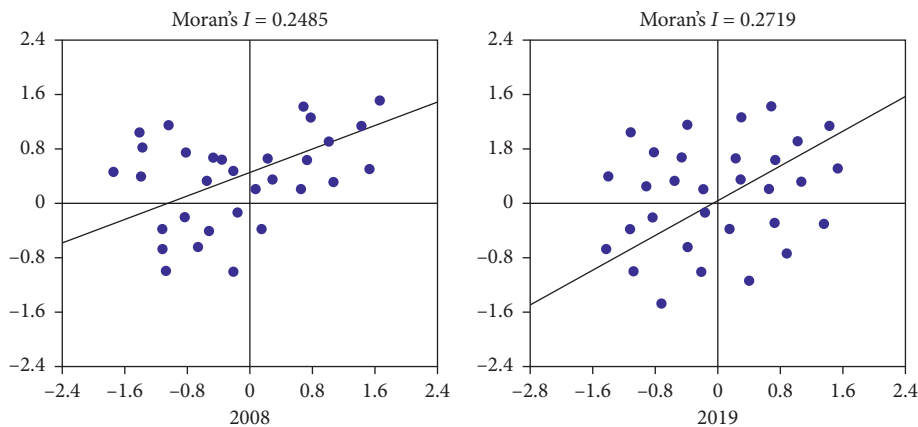


FIGURE 4: Moran index scatterplot of the ecological environment in 31 provinces of China in 2008 and 2019.

found that the provinces whose energy consumption is mainly coal in the current provincial economic development have not decreased but gradually spread. Shandong, Hubei, and other regions have also joined high-value-gathering areas, and the proportion of coal consumed by Xinjiang and other provinces is also increasing.

As seen from Figure 7, the geographical distribution of China's ecological environment mainly forms two different

agglomeration areas. (1) Taking Hebei as the center, including Shanxi, Henan, Shandong, and so on, the ecological environment seriously gathers in areas in North China. Figure 7 shows that the ecological environmental conditions in the areas surrounding Anhui are serious. (2) The low-value-gathering area of the ecological environment is centered on Xinjiang, and the pollution in Sichuan is more serious than that in surrounding areas. However, with the

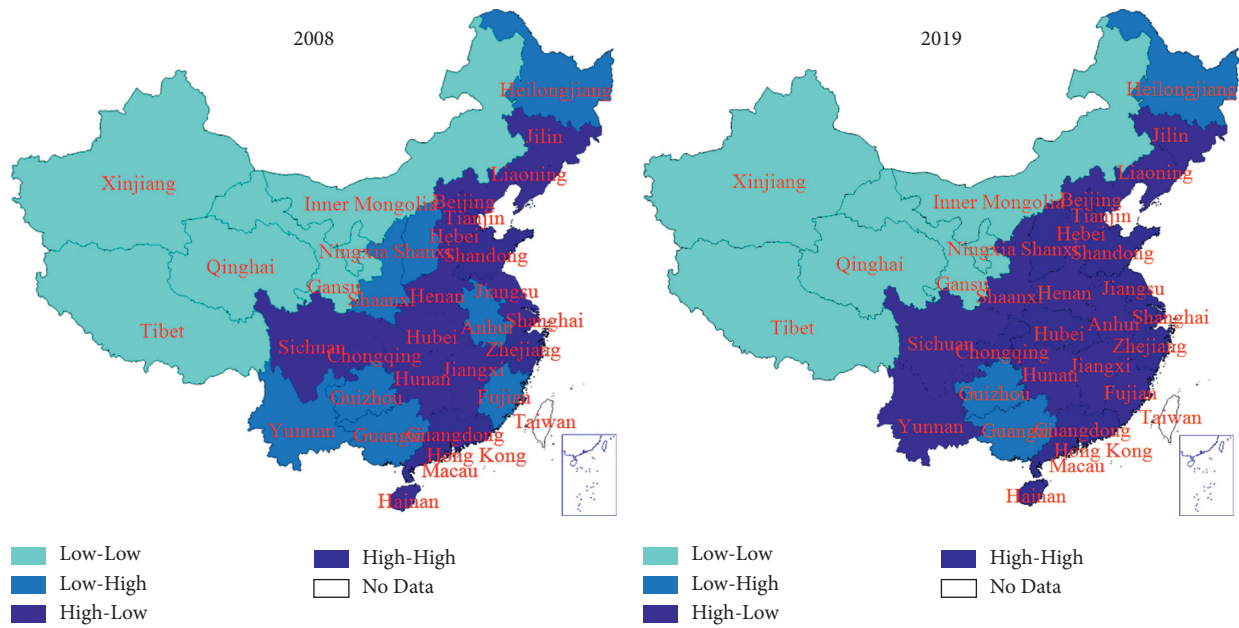


FIGURE 5: Regional agglomeration map of economic growth in China's provinces in 2008 and 2019.

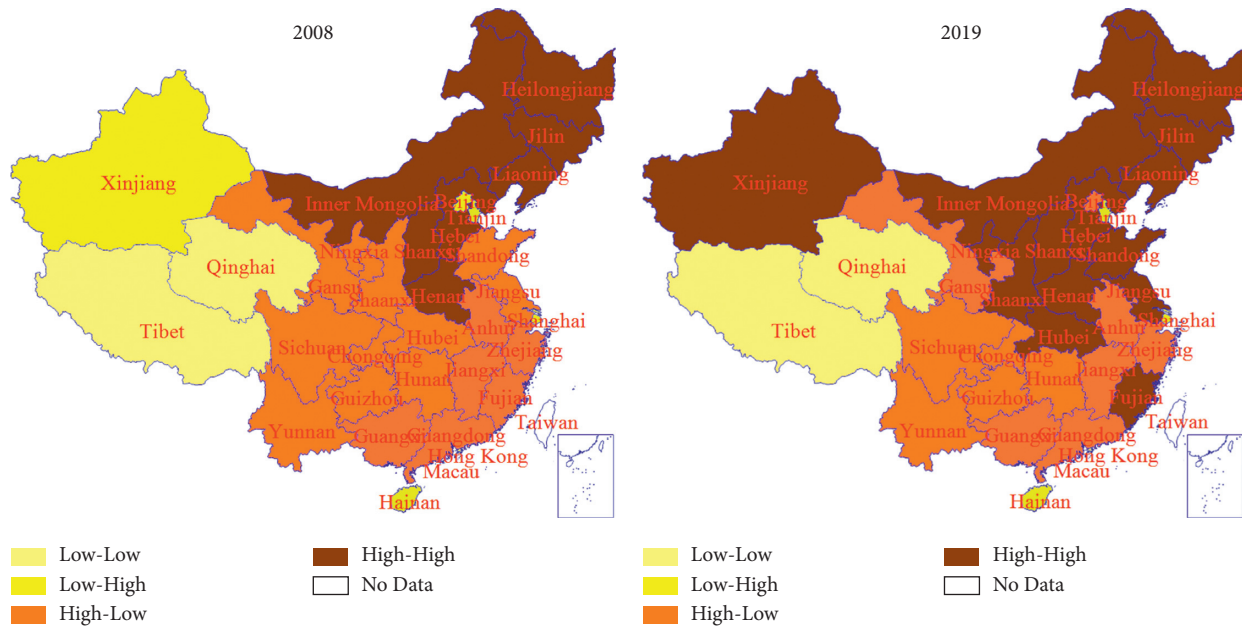


FIGURE 6: Regional agglomeration map of energy consumption in China in 2008 and 2019.

continuous improvement of the economic level in the western region, the ecological environment level in the western region is obviously strengthened, especially in Xinjiang. As far as China is concerned, the ecological environment has not only been limited to traditional areas such as Beijing-Tianjin-Hebei but also begun to spread to central and western provinces.

From the statistical results of the geographical distribution pattern and agglomeration effect of economic growth, energy consumption, and ecological environment, it can be found that there is a relatively significant

“path dependence” in geographical distribution, namely, agglomeration; however, there is a slight difference among the three in the gathering area, as the area where the high value of energy consumption distribution gathers is generally the area where the high value of ecological environment gathers. Generally, the area where energy consumption distribution gathers low value is also the area where ecological environment gathers low value. The relationship between energy consumption and the ecological environment is similar to that between economic growth and the ecological environment. To

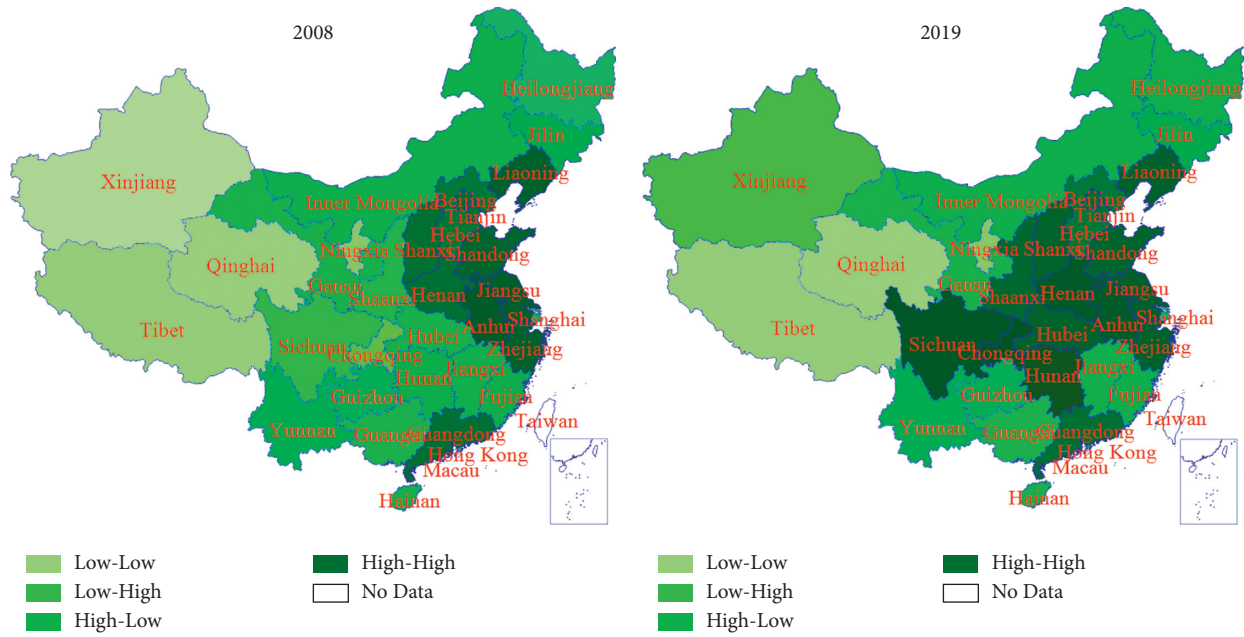


FIGURE 7: Regional agglomeration map of the ecological environment in various regions of China in 2008 and 2019.

further investigate the spatial relationship of these three factors, we will use a spatial econometric model for testing.

4.4. Dynamic Transition. By observing the Moran index scatterplot, we find the spatial dynamic transition process of economic growth, energy structure, and ecological environment. Using the spatiotemporal transition method used by Rey (2006), there are four main types of spatiotemporal transitions: (1) the region itself has changed while the surrounding areas have not; (2) the region has not changed while the surrounding areas have; (3) both the region and its surrounding areas have changed; (4) neither the region itself nor its surrounding areas have changed. The details are shown in Table 5.

Through Table 5, we can see that the three variables of economic growth, energy consumption, and ecological environment accounted for the vast majority of provinces belonging to the fourth type during the inspection period. This shows that there is a high degree of spatial stability in economic growth, energy consumption, and ecological environment in China’s provinces, and it shows a relatively strong “path-dependent feature” in space.

4.5. Correlation Analysis. This paper conducts GMM analysis on the impact of China’s energy utilization (utilization status X_1 , development potential X_2) and economic growth (economic scale X_3 , economic potential X_4) on the ecological environment from 2008 to 2019 using States 14.0.

Table 6 shows that there are great differences in the impact degree of each index on the ecological environment.

Specifically, the negative change of 1 unit of energy development potential will cause a 0.55% decrease in the ecological environment coefficient. With the continuous increase in the consumption of energy resources, the impact on the ecological environment has also gradually increased, causing different degrees of ecological environmental damage. Therefore, the Chinese government must strengthen the development and popularization of green and clean energy in the future and maximize economic benefits as much as possible while consuming energy resources at the minimum cost and ensuring the quality of the ecological environment.

The size of the economic scale has also had a great impact on the ecological environment. A positive change in one unit caused a 0.34% increase in the ecological environment. In the early stage of economic development, it caused great damage to the ecological environment, but with the continuous improvement of the economic level, the guidance of national policies, scientific and technological support, and capital investment effectively controlled the phenomenon of ecological environment destruction.

The negative change of 1 unit of economic potential indicates that there is a negative correlation between economic potential and the ecological environment, which will cause a 1.58% reduction in the ecological environment. In the process of economic development, economic investors may cause equal or greater damage to the ecological environment.

TABLE 5: Economic growth, energy consumption, and ecological environment space transition of the Moran scatterplot (2008–2019).

Type	Economic growth		Energy consumption		Ecological environment	
	Changing route	Representative province	Changing route	Representative province	Changing route	Representative province
First	$HH_t \rightarrow LH_{t+1}$	Shanxi	$HH_t \rightarrow LH_{t+1}$	Jilin, Liaoning	$HH_t \rightarrow LH_{t+1}$	Henan, Hubei
	$LH_t \rightarrow HH_{t+1}$	Liaoning, Inner Mongolia	$LH_t \rightarrow HH_{t+1}$	Hubei, Hunan	$LL_t \rightarrow HL_{t+1}$	Tibet, Qinghai
	$LL_t \rightarrow HL_{t+1}$	Chongqing, Sichuan	$LL_t \rightarrow HL_{t+1}$	Gansu and Ningxia	—	—
	—	—	$HL_t \rightarrow LL_{t+1}$	Henan	—	—
Second	$HL_t \rightarrow HH_{t+1}$	Xinjiang, Heilongjiang	$HH_t \rightarrow HL_{t+1}$	Shaanxi	$HH_t \rightarrow HL_{t+1}$	Sichuan
	—	—	$LL_t \rightarrow LH_{t+1}$	Zhejiang, Jiangsu	$LH_t \rightarrow LL_{t+1}$	Guangxi, Yunnan
	—	—	$HL_t \rightarrow HH_{t+1}$	Jiangxi, Fujian	—	—
Third	—	—	$HH_t \rightarrow LL_{t+1}$	Beijing	$HH_t \rightarrow LL_{t+1}$	Guizhou
Fourth	—	Remaining 24 provinces	—	Remaining 14 provinces	—	Remaining 23 small portions

TABLE 6: Parameter estimation results of impact factors of energy and the economy on the environment.

Variability	Coefficient	Standard deviation	Z statistic
X	2.7140853***	0.5120197	0.06
X_1	0.1421165	2.5930254	2.63
X_2	-0.5538029***	0.2301528	2.31
X_3	0.3406082**	0.1503396	-3.29
X_4	-1.5812034***	0.4402281	5.48

Note: *** is a significance level of 1%; ** is a significance level of 5%; and * is a significance level of 10%.

5. Conclusions and Suggestions

5.1. *Research Conclusions.* Based on the analysis of the evolution of China’s energy utilization, economic growth, and ecological environment from 2008 to 2019, this paper further discusses the internal relations among these three factors. The main conclusions are as follows:

- (1) Energy utilization, economic growth, and the ecological environment level show different trends of growth, and the differences between regions are shrinking. Specifically, China’s energy utilization level has experienced a process from polarization to regional gap-narrowing gradually, but the overall trend is good. The level of economic development shows that the east is higher than the middle and west, and the whole parts of east, west, and west show an upward trend. The ecological environment level has gradually narrowed from polarization to regional gap, and the effect has obviously improved.
- (2) Development potential, economic growth, and economic potential have a significant impact on the output of the ecological environment, while the current development situation has no significant impact on the environment. On the one hand, in the process of developing energy and improving the economy, it will inevitably have a certain impact on the ecological environment. On the other hand, with the growth of the economic scale and the improvement of scientific and technological level, energy efficiency will be improved, and carbon emissions will be reduced.

- (3) Ecological environment puts forward higher requirements for energy utilization and economic growth at the same time, which forces the improvement of energy utilization efficiency and the change of economic growth mode. On the one hand, the improvement of ecological environment is premised on the improvement of energy utilization efficiency. The improvement of ecological environment requires changing the traditional way of energy production and utilization, so as to continuously carry out technological innovation in energy production and utilization and then reduce energy consumption and pollutant emission. On the other hand, economic growth cannot be simply reflected in the increase in quantity but should be more reflected in the improvement in quality. Therefore, it should adopt the mode of quality development rather than the mode of quantity expansion, such as the improvement of industrial structure, the promotion of industrial technology, the promotion of the concept of green development, etc.

5.2. *Countermeasures and Suggestions.* Based on the above research, the following suggestions are put forward:

- (1) In terms of energy utilization, energy resources play an important role in promoting economic development, but an unreasonable energy consumption structure, high energy consumption, and low energy efficiency are the main factors hindering the improvement of the economic level and the

deterioration of the ecological environment system. Therefore, encouraging the innovation of energy technology to improve the efficiency of energy utilization and vigorously promoting efficient clean energy, such as water energy, wind energy, and solar energy, to optimize the energy consumption structure, are the only ways to rationally develop and utilize China's energy resources in the future.

- (2) In terms of economic development, the demand for economic growth is an important factor for the continuous increase in energy resource consumption, and the extensive economic development model for a long time has placed great pressure on the fragile ecological environment system. In the future, China's eastern, central, and western regions should give full play to their respective comparative advantages, drive technological innovation with economic strength, promote industrial restructuring with policy advantages, fully support the green science and technology industry, strengthen the horizontal economic ties among the three major regions, and promote the regional division of labor and cooperation.
- (3) In terms of the ecological environment, all regions should strengthen the research and development of high-tech environmental science and technology, strengthen environmental protection in industrial adjustment and layout, resolutely shut down enterprises with high pollution and low production capacity, and reduce carbon emissions.
- (4) The government should regulate and control the issue of population growth in order to reduce the excessive demand for energy resources and the great pressure on the ecological environment, and it should correctly guide and guarantee the adjustment of energy consumption structure, industrial optimization and upgrading, and high-tech environmental protection in policy. In addition, the government should also provide corresponding guidance and opinions according to the current situation of different energy, economy, and environment in various provinces and cities, so as to realize benign interactive development of energy utilization, economic growth, and ecological environment.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

This research was supported by the general program of Natural Science Foundation of Shandong Province (No.

ZR2019MG021) and the key projects of National Statistical Scientific Research Plan (No. 2019LZ19). The research was also supported by the Social Science Planning (Dominant Discipline) Research Project of Shandong Province (No. 19BYSJ19).

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