As China experiences rapid economic development, tasks involving poverty alleviation, energy conservation and ecological protection need to be addressed. Whether poverty alleviation, energy conservation and ecological protection in China have coordinated development has become a question worth studying. Based on the coupling coordination degree model and the GM (1, 1) model, this paper calculates and forecasts the development level of poverty alleviation, energy conservation and ecological protection of 30 provinces (cities) in China and analyses the synergy of the three systems spatially and temporally.

The results show that first, from 2010 to 2019, the development level of China’s poverty alleviation system, energy conservation system and ecological protection system presented increasing trends, but regional differences could be seen in development trends. Second, the coupling coordination degree of the three systems in China showed an upwards trend. The average coupling coordination degree of 30 provinces (cities) rose from slight coordination in 2010 to moderate coordination in 2019. Third, in the following years, development level will still be on an upwards trend in the four regions of China from 2020 to 2025. The development level of the ecological protection system will be the highest in China, and poverty alleviation and energy conservation will rank second and third. Fourth, the coupling coordination degree of the three systems of 30 provinces (cities) in China will rise significantly, indicating that the development of the three systems in China will be more coordinated in the following years.

1. Introduction

Since the reform and opening up in the late 1970s, China’s economy has developed rapidly. According to the National Bureau of Statistics, China’s GDP exceeded 100 trillion yuan in 2020, making it the world’s second largest economy. Scholars believe that China’s economy was in an extensive development stage in recent years, which depended on factor input and fossil energy consumption [1] that has caused ecological and environmental deterioration [2]. Meanwhile, according to the 3% threshold set by the World Bank, China has already eliminated abject poverty [3]. However, the Gini coefficient of Chinese residents’ income has been above 0.4 for a long time [4], which means that the challenge of relative poverty remains to be addressed. With rapid economic development, China needs to address the tasks of poverty alleviation, energy conservation and ecological protection. Whether poverty alleviation, energy conservation and ecological protection in different regions of China have coordinated development has become a question worth studying.

Research on the relationship among the economy, energy and ecological environment has evolved from the dual system of economy and ecological environment, economy and energy, and energy and ecological environment to the multisystem. The famous environmental Kuznets curve (EKC) [5] is used to show the inverted U-shaped relationship between the ecological environment and economic
development [6]. Scholars have analysed the relationship between environmental pollution and residents’ income through the EKC and found that when in the low-income level, people would rather sacrifice the environment to pursue higher income, but when at the high-income level, people’s tolerance of environmental pollution decreases [7]. In terms of the relationship between the ecological environment and energy, scholars have reached a consensus that the increase in energy consumption and the problem of energy consumption structure have aggravated ecological environmental pollution [8–10]. In terms of the relationship between the economy and energy, scholars have found that socioeconomic factors are direct and important factors that affect residents’ energy choice through the energy ladder hypothesis. With the improvement of economic development and the increase in income, household energy consumption will gradually shift to clean and efficient modern low-carbon energy [11–13]. In addition, with more in-depth research, scholars found that there have been interactions among multiple systems and began to study the relationship among the economy system, energy system and ecological environment system, thus forming the 3E (Economy-Energy-Environment) system theory. Research on the 3E system mainly focused on the measurement of its coordinated level, and the methods of the coordination level mainly include the analytic hierarchy process method [14], principal component analysis method [15], entropy weight method [16], data envelopment analysis method [17], and fuzzy comprehensive evaluation method [18]. For example, Zhu and Wang [19] demonstrated the feedback among the economy, resources and ecology environment through the system dynamic production model and explored the sustainable development capacity of Jiangxi, China. Wang et al. [20] used the entropy weight method to establish the capability evaluation index system and measured the regional sustainable development capacity of Shandong, China. Scholars also studied the key influencing factors of the coordination development of the 3E system. Wu and Ning [21] combined a system dynamics model and geographic information system to analyse the 3E system both temporally and spatially, which explored the interaction of economics, energy, and the ecological environment and the effects of key influencing factors. Zhao et al. [22] constructed a 3E system model based on the theory of system dynamics and studied the internal operation mechanism of the carbon emissions trading system and its impact on the 3E system of the Beijing-Tianjin-Hebei region.

By reviewing the above studies, we found that most of the existing studies focused on the relationship among economic development, energy conservation and ecological protection systems, while few studies focused on poverty alleviation, energy conservation and ecological protection systems. The economic development of a region does not equal poverty alleviation. Poverty was initially defined as an economic phenomenon, a condition in which the income of an individual household does not meet the basic standards of living [23]. With socioeconomic development, the definition of poverty has gradually shifted from the shortage of an economic income to a multidimensional measurement, including the lack of access to basic education, medical care, housing and other social deprivations [24–26]. Therefore, based on studies of the relationship of the 3E system, this paper builds a poverty alleviation indicator system using an economic development indicator, income indicator, education indicator, medical and health indicator and public service indicator. The coupling coordination degree model and the GM (1, 1) model were used to measure and forecast the development level of each system and the relationships between poverty alleviation, energy conservation and ecological protection systems to analyse the coordination degree of the four major regions in China spatially and temporally, thus promoting high-quality development in the poverty alleviation, energy conservation and ecological protection of China.

2. Study Area and Data

2.1. Study Area. To formulate long-term national development plans, regional policies and services, China is divided into four major regions: the eastern region, northeast region, central region, and western region [27]. To observe the results of the study, we selected 30 Chinese provinces (cities) and divided them into four regions. The eastern region includes ten provinces (cities): Beijing, Tianjin, Hebei, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, and Hainan. The northeast region includes three provinces: Liaoning, Jilin, and Heilongjiang. The central region includes six provinces: Shanxi, Henan, Hubei, Hunan, Anhui, and Jiangxi. The western region includes twelve provinces (cities): Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Inner Mongolia, Ningxia, Xinjiang, and Tibet. Due to the unavailability of data from Tibet, the sample for statistical analysis does not include Tibet. This paper separately calculates different provinces (cities) or regions for a more convenient analysis.

2.2. Data Source. To ensure the study’s authenticity, integrity, and continuity, all data used for this paper are from the China Statistical Yearbook (2011–2020), China Energy Statistical Yearbook (2011–2020), China Statistical Yearbook on Environment (2011–2020), China Health Yearbook (2011–2020), and the official website of the National Bureau of Statistics (http://www.stats.gov.cn/).

2.3. Index Selection. Researchers have studied poverty alleviation [28], energy conservation [29], and ecological protection [30] and presented different evaluation indicators. Among them, Xin et al. [31] evaluated poverty alleviation from two aspects, infrastructure perfection and residents’ living standards. Qin et al. [32] used poverty alleviation pressures, poverty alleviation inputs, and poverty alleviation effects and fifteen basic indicators to evaluate the poverty alleviation system. In terms of energy conservation, Wang et al. [33] established an indicator system based on three input indicators, one good output indicator, and four bad output indicators to estimate energy-environment efficiency. Yan et al. [34] used six indicators to build up the
energy system, such as primary energy production, primary energy consumption, energy intensity index, net energy imports, and carbon dioxide emissions. Regarding the ecological environment, Liu et al. [35] studied the ecological environment from three aspects with seven basic indicators, such as total water resources, the green coverage rate of built-up areas, green areas, and household garbage harmless disposal rates. Liao [36] established an ecological environment system with two targets: ecological environmental pollution and ecological environment management. Based on the research above and considering data availability and regional situation, we establish a comprehensive evaluation index system including three parts: the poverty alleviation index, energy conservation index, and ecological protection index. The detailed explanation of the three parts is as follows:

2.3.1. Poverty Alleviation System Index Selection. The poverty alleviation system index includes three scales: the economic development scale, livelihood scale, and social security scale. First, the economic development scale adopts per capita GDP, ratio of the output value of the service industry, and gross industrial output value. The per capita GDP reflects the overall level of economic development, and the ratio of the output value of the service industry and gross industrial output value are used to reflect the promotion of economic growth. Second, the livelihood scale adopts the per capita disposable income of the urban population, which reflects the livelihood of the urban population. Third, the social security scale adopts fiscal expenditures on public services, total retail sales of consumer goods, the student-teacher ratio of primary schools, the number of medical staff, and the number of beds in health care institutions. Fiscal expenditure on public services and total retail sales of consumer goods reflects the structure of social security, and the student-teacher ratio of primary schools, number of medical staff for every 10000 people, and number of beds in health care institutions for every 10000 people reflects the situation of social security.

2.3.2. Energy Conservation System Index Selection. The energy conservation system index includes four scales: energy security pressure, energy supply and demand state, energy system impact and energy development response. First, we use the ratio of energy consumption per GDP to reflect the energy security pressure scale, which combines energy pressure with economic development. Second, the energy supply and demand state scale adopts the energy supply and demand rate, fossil energy production share, growth rate of total energy consumption, and fossil energy consumption share. These indicators reflect the current situation and development of China’s energy supply and demand, and the indicators of fossil energy production and consumption reflect the development of nonrenewable energy. Third, the energy system impact scale adopts energy consumption elasticity. Finally, we use the proportion of electrical energy to reflect the energy development response, which could provide a decision-making reference for the sustainable and healthy development of energy consumption and utilization.

2.3.3. Ecological Protection System Index Selection. The ecological protection system index includes three scales: ecological environment level, ecological environment pollution and ecological environment protection. First, we use the cover rate of forests and water resources per capita to reflect the state of the ecological environment. The increase in forest and water resources is conducive to improving the ecological environment. Second, the ecological environment pollution scale adopts the discharge capacity of wastewater and the discharge capacity of sulfur dioxide, since they are the main pollutants of the urban ecological environment, and the increase in wastewater and sulfur dioxide emissions can increase the degree of ecological pollution. Third, the ecological environment protection scale adopts investment in environmental pollution regulation and the harmless treatment rate of domestic garbage. Increasing investment and ratios in government environmental pollution regulations and improving the harmless treatment rate of domestic garbage are conducive to the improvement of ecological environmental protection.

The indices of the poverty alleviation system, energy conservation system and ecological protection system and the corresponding variables are shown in Table 1.

3. Methods

3.1. Coupling Coordination Degree (CCD) Model. Coupling is a concept in physics that describes the interaction and degree of interaction between two or more related systems. The CCD model can be used for research in multiple fields, such as the relationship between tourism and finance [37], urbanisation and geological hazards [38], and water governance and tourism [39].

To reflect the development level and the coordination effect of the regional poverty alleviation system, energy conservation system and ecological protection system and to measure the level of coordinated development among the three systems effectively, we collect the relevant data of the three systems in 30 provinces (cities) in China. The coupling definition and coefficient model in physics are used to measure the coupling coordination degree of the poverty alleviation system, energy conservation system and ecological protection system.

First, we employ the entropy value method to evaluate the comprehensive indices for the poverty alleviation system, energy conservation system and ecological protection system. According to the methods, the raw data are standardised by formula (1) or (2) in positive or negative dimensions, respectively, to reduce the differences caused by the different units of measurement of different indicators:

\[ x_{ij}^+ = \frac{x_{ij} - \min\{x_{1j}, \ldots, x_{nj}\}}{\max\{x_{1j}, \ldots, x_{nj}\} - \min\{x_{1j}, \ldots, x_{nj}\}}. \]

\[ x_{ij}^- = \frac{\max\{x_{1j}, \ldots, x_{nj}\} - x_{ij}}{\max\{x_{1j}, \ldots, x_{nj}\} - \min\{x_{1j}, \ldots, x_{nj}\}}. \]
where $x_{ij}$ represents the value of indicator $j$ in region $i$ ($i = 1, ..., n$, $j = 1, ..., m$), $\max\{x_{ij}, ..., x_{nj}\}$ and $\min\{x_{ij}, ..., x_{nj}\}$ are the maximum and minimum values of indicator $x_{ij}$, respectively, $x_{ij}^{+}$ represents the positive dimension indicator, and $x_{ij}^{-}$ represents the negative dimension indicator.

Then, we can calculate the sample index weight $p_{ij}$ by $p_{ij} = x_{ij}/\sum_{i=1}^{n} x_{ij}$. To avoid the situation of $\ln p_{ij} = 0$, the denominator and numerator of $p_{ij}$ need to pulse 1 by

$$p_{ij} = \frac{(1 + x_{ij})}{\sum_{i=1}^{n} (1 + x_{ij})}. \quad (3)$$

Second, we calculate the entropy of indicator $j$ by

$$e_j = -k \sum_{i=1}^{n} p_{ij} \times \ln p_{ij}, \quad (4)$$

where the constant variable $k$ is related to the sample number $n$ and estimated by $k = 1/\ln n$, and $0 \leq e_j \leq 1$. We obtain the utility value $d_j$ of each index by using $d_j = 1 - e_j$, and the informational entropy weight $w_j$ can be calculated by $w_j = d_j/\sum_{j=1}^{m} d_j$.

Third, the standardised data of each description index are multiplied by the corresponding weight value, and the development level $U$ of the poverty alleviation system, energy conservation system and ecological protection system is calculated by

$$U = \sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij}^{+} (or x_{ij}^{-}) \times w_j. \quad (5)$$

We calculate the coupling correlation of the three systems as follows:

$$c = \frac{3(U_1U_2 + U_2U_3 + U_1U_3)}{(U_1 + U_2 + U_3)^2}, \quad (6)$$

$$d = \sqrt{c} \times t, \quad (7)$$

$$t = \alpha U_1 + \beta U_2 + \gamma U_3. \quad (8)$$

For formulas (6)–(8), $c$ indicates the degree of coupling correlation among the three systems, $d$ indicates the degree of coupling coordination among the three systems, $t$ indicates the comprehensive development level of the three systems, and $\alpha$, $\beta$, and $\gamma$ are weights of the three systems. We consider $\alpha$, $\beta$, and $\gamma$ to be 1/3 in this study.

The coupling coordination degree refers to the relative product coefficient. According to the research [40], we classify the coupling of these three systems into the following levels, as shown in Table 2.

### 3.2 The GM (1, 1) Model
The grey forecasting model theory includes four kinds of models, the GM (1, 1) model, the
DGM (1, 1) model, the GM (1, N) model and the Verhulst model, among which the GM (1, 1) model is the most commonly used. The GM (1, 1) model is a time series forecasting model that requires less data, high accuracy, and simple calculation principles. The GM (1, 1) model has three basic operations: (1) accumulated generation, (2) inverse-accumulated generation, and (3) grey modelling. The GM (1, 1) model can be used to predict the poor alleviation degree of the economic development level in 2010 and annual net income of rural households [42]. In addition, scholars found that the GM (1, 1) model can be used to predict the coupling coordination degree [43].

The GM (1, 1) model, i.e., a single variable first-order grey model, is summarised as follows:
First, for an initial time sequence
\[ X^{(0)} = \{X^{(0)}(1), X^{(0)}(2), \ldots, X^{(0)}(i), \ldots, X^{(0)}(n)\}, \]
where \( X^{(0)}(i) \) is the time series data at time \( i \), and \( n \) must be equal to or larger than 4.

Second, a new sequence \( X^{(1)} \) is set up on the basis of the original sequence \( X^{(0)} \) through the accumulated generating operation to provide the middle message of building a model and to weaken the variation tendency, as follows:
\[ X^{(1)} = \{X^{(1)}(1), X^{(1)}(2), \ldots, X^{(1)}(i), \ldots, X^{(1)}(n)\}, \]
where
\[ X^{(1)}(k) = \sum_{i=1}^{k} X^{(0)}(i) \quad k = 1, 2, \ldots, n. \]

Third, the first-order differential equation of the GM (1, 1) model is then the following:
\[ \frac{dX^{(1)}}{dt} + aX^{(1)} = b, \]
and its difference equation is
\[ X^{(0)}(k) + aZ^{(1)}(k) = b, \]
and from formula (13), we obtain
\[
\begin{bmatrix}
X^{(0)}(2) \\
X^{(0)}(3) \\
\vdots \\
X^{(0)}(n)
\end{bmatrix} =
\begin{bmatrix}
-Z^{(1)}(2)1 \\
-Z^{(1)}(3)1 \\
\vdots \\
-Z^{(1)}(n)1
\end{bmatrix}
\times
\begin{bmatrix}
a \\
b
\end{bmatrix},
\]
where \( a \) and \( b \) are the coefficients to be identified.

Let
\[ Y(n) = \left[ X^{(0)}(2), X^{(0)}(3), \ldots, X^{(0)}(n) \right]^T. \]
\[ B = \begin{bmatrix}
-Z^{(1)}(2) \\
-Z^{(1)}(3) \\
\vdots \\
-Z^{(1)}(n)
\end{bmatrix} \]
Take
\[ Z^{(1)}(k + 1) = \frac{1}{2} \left( X^{(1)}(k) + X^{(1)}(k + 1) \right) \quad k = 1, 2, \ldots, (n - 1), \]
and
\[ A = [a, b]^T, \]
where \( Y(n) \) and \( B \) are the constant vector and the accumulated matrix, respectively. \( Z^{(1)}(k + 1) \) is the \((k + 1)\)th background value. Applying the ordinary least-square method to formula (17) based on formulas (15)–(18), the coefficient \( A \) becomes
\[ A = (B^T B)^{-1} B^T Y_n. \]
Fourth, substituting \( A \) in formula (13) with (19), the approximate equation becomes
\[ \tilde{x}^{(1)}(k + 1) = \left( X^{(0)}(1) - \frac{b}{a} \right) e^{-ak} + \frac{b}{a}, \]
where \( \tilde{x}^{(1)}(k + 1) \) is the predicted value of \( x^{(1)}(k + 1) \) at time \( (k + 1) \). After the completion of an inverse-accumulated generating operation on formula (20), \( \tilde{x}^{(0)}(k + 1) \), the predicted value of \( x^{(0)}(k + 1) \) at time \( (k + 1) \) becomes available and
\[ \tilde{x}^{(0)}(k + 1) = \tilde{x}^{(1)}(k + 1) - \tilde{x}^{(1)}(k) \quad k = 0, 1, 2, \ldots, n. \]

4. Results and Analysis

4.1. Indices of the Development Level. According to formula (5), we use the panel data of poverty, energy and ecology of 30 provinces (cities) in China from 2010 to 2019 to calculate the development level of the poverty alleviation system, energy conservation system and ecological protection system. The comprehensive development level of the three systems in different regions is shown in Figure 1.

Figure 1 shows the calculation results of the development levels for the three systems in different regions, which comprehensively reflects China’s developing trends in the poverty alleviation system, energy conservation system and ecological protection system. From the perspective of the time series, the development level of the poverty alleviation system, energy conservation system and ecological protection system in the four regions showed upward trends from 2010 to 2019, but the trends of the development level for the three systems showed differences during the study period. First, the poverty alleviation system level in 2010 was lower.
than 0.3 in all four regions, which was the lowest among the three systems. However, the increase in the poverty alleviation system level was obvious, and in 2019, it was higher than the energy conservation system level in the eastern and northeast regions. Second, the energy conservation system level showed an upward trend during the study period, but the added value was lower than that of the poverty alleviation system level and the ecological protection system level. In 2019, the index for the energy conservation system level was lower than that of the poverty alleviation system level in the eastern and northeast regions and lower than the index of the ecological protection system level in the central and western regions. Third, the ecological protection system level was the highest among the three systems at the end of the study period. In terms of regional differences, the tendency of the three systems showed two types. In the first type, the ecological protection system level was always the highest in the study period, and the poverty alleviation system level was the lowest at the beginning of the study period, but it was higher than the energy conservation system level at the end of the study period. The second type was in the central and western regions, which showed that the energy conservation system level was the highest at the beginning of the study period but lower than the ecological protection system level at the end of the study period, while the poverty alleviation system level was the lowest during the study period. Although the three systems showed a positive correlation during the study period and were in a state of mutual promotion and coordinated development, there were great differences in the development level and developing speed of China’s poverty alleviation system, energy conservation system and ecological protection system. Therefore, we next analyse the coupling coordinated development among the poverty alleviation system, energy conservation system and ecological protection system.

4.2. Results of the CCD Model

4.2.1. The Temporal Trend of the Coupling Coordination Degree. We calculate the average coupling coordination degree of the poverty alleviation system, energy conservation system and ecological protection system of 30 provinces (cities) in China from 2010 to 2019 and present it as a time series. The result is shown in Figure 2.

The result can be seen in Figure 2. From the perspective of the time series, the average coupling coordination degree of 30 provinces (cities) in China shows fluctuations, but overall, there is an upward trend and three stages in the standard of coupling coordination degree can be seen during the study period. The first stage was from 2010 to 2011. During this period, the average coupling coordination
The average coupling coordination degree in China was between 0.5 and 0.6, which was at the slightly incoordination (V4) stage. The second stage was from 2012 to 2018. In this period, the average coupling coordination degree in China was between 0.6 and 0.7, which was slight coordinated (V3). The last stage was in 2019. During this period, the average coupling coordination degree in China rose to 0.709, which was moderate coordinated (V2). In general, the average coupling coordination degree of poverty alleviation, energy conservation and ecological protection in 30 provinces (cities) in China has risen from slightly incoordination (V4) to slight coordination (V3) in seven years and entered the stage of moderate coordination (V2) in 2019.

Figure 3 shows the coupling coordination degree distribution of 30 provinces (cities) in China. From 2010–2019, the coupling coordination degrees were 0.33%, 21.67%, 52.00%, 25.67%, and 0.33%, corresponding to superior coordination (V1), moderate coordination (V2), slight coordination (V3), slightly incoordination (V4), and moderately incoordination (V5), respectively. The order of proportion from large to small was slight coordination (V3), slightly incoordination (V4), moderate coordination (V2), moderately incoordination (V5) and superior coordination (V1). From 2010 to 2019, the superior coordination (V1) and moderate coordination (V2) increased gradually, slightly incoordination (V4) decreased from 76.67% in 2010 to 0 in 2017, and moderately incoordination (V5) decreased from 3.33% in 2010 to 0 in 2011. From the above analysis, we concluded that the coupling coordination degree of the poverty alleviation system, energy conservation system and ecological protection system in China steadily improved during the study period.

4.2.2. The Temporal Differences of Coupling Coordination Degree among Regions. We calculated the coupling coordination degree of four regions in China from 2010 to 2019 based on the CCD model, and the regional coupling coordination degree is shown in Figure 4.

The result can be seen from Figure 4. The coupling coordination degrees of the poverty alleviation system, energy conservation system and ecological protection system in the four regions of China show upward trends during the study period. In 2010, the four regions in China were categorised as slightly incoordination (V4) and slight coordinated (V3) in the coupling coordination degree standard. However, in 2019, the coupling coordination degree of the four regions increased to some extent. The coupling coordination degree was categorised as slight coordinated (V3) or moderate coordinated (V2). In terms of regional differences, the average coupling coordination degree of the eastern region during the study period was the highest of all four regions in China in terms of the standard of coupling
coordination degree, from slight coordination (V3) to moderate coordination (V2), reflecting that the poverty alleviation, energy conservation and ecological protection systems had more coupling coordination in the eastern region. In 2010, the average coupling coordination degree in the central region and the western region was close, both at the level of slightly coordination (V4). However, in 2019, the average coupling coordination degree in the central region was at the stage of moderate coordination (V2), which was higher than the stage of slight coordination (V3) in the western region. It is worth noting that the change in the average coupling coordination degree in the northeast region was the smallest among the four regions. In 2010, the average coupling coordination degree in the northeast region was in second place among the four regions and was slightly coordinated (V4), but in 2019, the average coupling coordination degree in the northeast region was slight coordinated (V3) and ranked last among the four regions.

4.2.3. The Spatial Distribution of the Coupling Coordination Degree. The spatial distribution of the regional coupling coordination degree from 2010 to 2019 was drawn by ArcGIS 10.5 software, as shown in Figure 5.

The spatial distribution of coupling coordination degrees in China from 2010 to 2019 is shown in Figure 5. The coupling coordination degree of the four regions in China shows a great difference in spatial distribution. First, Guangdong achieved the highest degree of coupling coordination in eastern China, and China’s first superior coordination (V1) stage emerged in Guangdong Province in 2019. Other coastal provinces in the eastern region, such as Fujian, Zhejiang, Shanghai, Jiangsu and Shandong, also achieved a high value of coupling coordination degree. However, Tianjin and Hebei in the eastern region performed poorly, with a slight coordination (V3) coupling coordination degree in 2019, which was lower than that in other provinces in the eastern region. Second, the coupling coordination degree in the northeast region was the lowest among the four regions. From 2010 to 2019, the coupling coordination degree of all three provinces in the northeast region increased from slightly incoordination (V4) to slight coordination (V3). Third, the coupling coordination degree in the western region increased greatly. In 2010, 10 out of 11 provinces in western China had a slightly incoordination (V4) degree, while Gansu had a moderately incoordination (V5) degree. However, in 2019, Shaanxi, Qinghai, Ningxia and Xinjiang’s coupling coordination degree rose by one stage to slight coordination (V3). The coupling coordination degree of Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou and Yunnan increased by two stages, reaching moderate coordination (V2). The coupling coordination degree of Gansu also rose from 0.48 in 2010 to 0.66 in 2019, reaching the moderate coordination (V2) stage. Fourth, the coupling coordination degree of all six provinces in the central region increased by two stages from slightly incoordination (V4) in 2010 to moderate coordination (V2) in 2019. In general, the provinces (cities) with high values were concentrated in the eastern and central regions, while the provinces (cities) with low values were concentrated in the western and northeast regions.

4.3. The Result of the GM (1, 1) Model

4.3.1. Estimation of the Development Level. We used the GM (1, 1) model to estimate the development level of the poverty alleviation system, energy conservation system and ecological protection system in 30 provinces (cities) in China from 2020 to 2025. Some indices are above 1, such as poverty alleviation indices in Jiangsu in 2024 and 2025 and Henan in 2025, energy conservation indices in Shaanxi in 2025, and ecological protection indices in Guangdong in 2025. According to the definition of the index, we replace the indices above 1 with 1. The results are shown in Figure 6.

In Figure 6, the development levels of 2019 and before are the actual measured data, while the development levels of 2020 and after are the predicted data using the GM (1, 1) model. As seen in the figure, on the premise that other socioeconomic factors remain unchanged, the poverty alleviation system level, energy conservation system level and ecological protection system level would still be on an upwards trend in the four regions of China from 2020 to 2025. Among the indices of the three systems, the development value of the ecological protection system level was the highest in the four regions. However, there would be regional differences in the trends of the energy conservation system level and poverty alleviation system level. The trends of the energy conservation system level and the poverty alleviation system level in the eastern and northeast regions would be similar. In the next few years, the poverty alleviation system level would be higher than the energy conservation system level, but the added value of the poverty alleviation system level in the eastern region would be greater than that in the northeast region. The trends of the energy conservation system level and the poverty alleviation system level would be similar in the central and western regions. The poverty alleviation system level would surpass the energy conservation system level in the next few years, in the central region in 2023 and the western region in 2025. It is also worth noting that in 2025, the ecological protection system level and poverty alleviation system level in the eastern and central regions would be similar.

4.3.2. Estimation of the Coupling Coordination Degree. Based on the CCD model, we estimate the coupling coordination degree of the three systems by using the development level indices of the poverty alleviation system, energy conservation system and ecological protection system of the four regions in China from 2020 to 2025. The estimated results are shown in Figure 7.

Figure 7 shows the coupling coordination degree distribution in the sample area. From 2020 to 2025, the coupling coordination degree will be 37.78%, 47.78%, and 14.44%, corresponding to the stages of superior coordination (V1), moderate coordination (V2) and slight coordination (V3), respectively. The order of proportion from large to small would be moderate coordination (V2), superior
coordination (V1), and slight coordination (V3). By 2025, the coupling coordination degree of 30 provinces (cities) in China would be mainly in the stage of superior coordination (V1), and there would be 22 provinces (cities) in this stage. Six provinces (cities) would be in the stage of moderate coordination (V2), among which all three provinces in the northeast region would be in this stage. Tianjin and Ningxia would be in the stage of slight coordination (V3). The poverty alleviation system, energy conservation system and environmental protection system in most provinces will be further coordinated in the coming years.

The spatial distribution of the coupling coordination degree stage in China from 2020 to 2025 is shown in Figure 8. First, the spatial difference in the coupling coordination degree among the four regions in China will gradually decrease in the following years. In 2022, the coupling coordination degree of more than half of China’s provinces (cities) would be moderate coordinated (V2) and exceed 50% in each region. In the eastern region, 40% of provinces (cities) would be in the stage of superior coordination (V1), 50% in the stage of moderate coordination (V2), and 10% in the stage of slight coordination (V3). All three provinces in the northeast region would be moderate coordinated (V2). In the central region, 33% of provinces (cities) would be in the superior coordination stage (V1), and 67% would be in the moderate coordination stage (V2). In the western region, 27% of the provinces (cities) would be in superior coordination (V1), 55% would be in the stage of moderate coordination (V2), and 18% would be in slight coordination (V3). In 2025, the coupling coordination stage of most provinces (cities) in China would be superior coordination (V1). Among the provinces, 80% are in the eastern region, 100% are in the central region and 73% are in the western region. However, the coupling coordination degree of all three provinces in the northeast region would be moderate coordinated (V2), unlike the other three regions in China.
Figure 6: Estimation of the development level.

Figure 7: Estimation of the coupling coordination degree stage distribution.
5. Conclusion and Discussion

5.1. Conclusion. This paper constructs the coupling coordination model of poverty alleviation, energy conservation and ecological protection among the four major regions of China through coupling theory, calculates the poverty alleviation system development level, energy conservation system development level and ecological protection system development level of 30 provinces (cities) in China, and analyses and studies the spatial and temporal distribution and changing trend of the coupling coordination degree. In addition, the tendency of the poverty alleviation system level, energy conservation system level, ecological protection system level and coupling coordination degree of the three systems and the tendency of the spatial and temporal distribution in China in the following years are estimated by the GM (1, 1) model.

The results show that first, from 2010 to 2019, the development level of China’s poverty alleviation system, energy conservation system and ecological protection system presented upward trends. Regional differences could be seen through the development trends of the development level indices; that of the eastern region was similar to that of the northeast region, and that of the western region was similar to that of the central region. Second, the coupling coordination degree of the three systems in China showed an upward trend. The average coupling coordination degree of 30 provinces (cities) rose from slightly incoordination (V4) in 2010 to moderate coordination (V2) in 2019. However, differences in spatial distribution could also be seen in the study. The average coupling coordination degree of the eastern region was the highest among the four regions in 2019, with the central and western regions ranking second and third, respectively, and the northeast region ranking last. Third, the coupling coordination degree stage distribution in China has improved. In 2010, the coupling coordination degree of more than half of China’s provinces (cities) was in the slightly incoordination stage (V4), while by 2019, more than half of China’s provinces (cities) were in the moderate coordination stage (V2). Among them, the provinces (cities) with high values were concentrated in the eastern and central regions, while the regions with low values were concentrated in the western and northeast regions. Fourth, the GM (1, 1) model predicted that in the following years, the development level of these three systems in China will increase. However, the poverty alleviation system level in western and central China would exceed the energy conservation system level, while the eastern and northeast regions would not show this trend. Fifth, the coupling coordination degree index of 30 provinces (cities) in China would rise significantly in the following years, and the coupling coordination degree of more than half of the provinces (cities) would be in the stage of superior coordination (V1). Among them, in 2025, 80% will be in the eastern region, 100% in the central region and 73% in the western region. However, the coupling coordination degree of all three provinces in the northeast region would be moderate coordinated (V2), unlike the other three regions in China.

6. Discussion

According to the outline of China’s 14th Five-Year Plan, China will step up the implementation of the country’s regional development strategies and continue to promote large-scale development in the western region, the full revitalization of the northeast region, the rise of the central region, and the trailblazing development of the eastern region. The conclusion of this paper supports China’s regional development strategy. The results show that there will be differences in the development of the poverty alleviation system, energy conservation system and ecological protection system in different regions of China, and the synergy of the three systems is also obviously different. The coupling coordination degree will be the highest in the eastern region in the next few years. The coupling coordination degree in
the central region and western region will increase rapidly. The coupling coordination degree in the northeast region will be lower than that in the other three regions of China. Therefore, corresponding policies need to be formulated according to the situation of different regions in China.

The main contributions of this paper are as follows: first, China’s poverty alleviation task in the following years will be to reduce relative poverty; therefore, this paper reflects the poverty alleviation system of different provinces (cities) by introducing indicators of income, education, medical and health care, and public services and studies the relationship among the poverty alleviation system, energy conservation system and ecological protection system, thus expanding the research on the 3E system. Second, based on the CCD model and the GM (1, 1) model, this paper calculates the comprehensive development level of the three systems of poverty alleviation, energy conservation and ecological protection of 30 provinces (cities) in China, showing the development status of each of the three systems. Third, this paper shows the tendency of the development level of the poverty alleviation system, energy conservation system and ecological protection system and the synergy of the three systems in the following years. Last, this paper analyses the internal causes of the development differences among regions, which will be helpful in recommending a strategy for future development.

The link between this paper and existing theories is that the discussion of the relationship among poverty alleviation, energy conservation and ecological protection is a further study on the research of the 3E system. China has achieved remarkable achievements in economic development and poverty alleviation and has contributed to the achievement of global poverty alleviation goals [44]. However, unbalanced development among the regional economy, education, medical and health and public services persists in China, leading to regional relative poverty [45, 46]. Exploring the relationship among the poverty alleviation system, energy conservation system and ecological protection system is in line with the research of the 3E system. Thus, this paper expands upon the field of study of the 3E system relationship.

This paper presents some shortcomings, which are as follows. First, this paper uses the CCD model to study the relationship among poverty alleviation systems, energy conservation systems and ecological protection systems, and there are other methods that can be used in future studies. Second, due to the complexity of the poverty alleviation system, energy conservation system, and ecological protection system, the selection of the indicators needs to be further improved. Third, in view of the lack of Tibetan data, the data for the western region may lead to biased results.

### Data Availability

The original 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.

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