Comprehensive Evaluation Research on the Sustainable Development Level of Rural Energy Based on CRITIC-MABAC in Henan Province

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Abstract

Energy shortages are a key issue at present, and climate problems caused by the extraction and use of traditional fossil energy sources are also creating new challenges for rural development, with sustainable rural energy development being a priority at present. This paper takes the sustainable development of rural energy as the research object, and evaluates the development of rural energy in each prefecture-level city in Henan Province. On the one hand, rural development is viewed from the perspective of energy, on the other hand, the evaluation results provide a reference for each prefecture-level city, and most of the energy data can be obtained directly and with a high degree of accuracy, based on the CRITIC – MABAC methodology to determine the weights from an objective point of view and to rank the evaluation results, which is capable of obtaining the most accurate evaluation results. Finally, we

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used energy-related data from Henan Province in 2022 to conduct empirical analyses, and verified that Shangqiu City has a high level of sustainable rural energy development, which verifies the feasibility of the methodology proposed in this paper, and gives relevant recommendations.

Keywords: CRITIC, MABAC, rural energy, sustainable development.

1 Introduction

The proposal of the "dual-carbon" target is our country's initiative to assume the responsibility of responding to global climate change as a great nation. Energy as an important material basis for social development [1], its sustainable development has a significant effect on energy saving and emission reduction, on the sustainable development of energy [2, 3] and energy structure optimization [4] and other aspects of many scholars have carried out a lot of research. Rural areas as an important area to achieve energy saving and emission reduction in China is also one of the main administrative areas to promote China's economic development, coupled with the environmental friendliness and sustainability of renewable energy [5], which is gradually replacing the traditional electric power, so it is crucial to study and evaluate the sustainable development of rural energy. In the process of rural economic development, a scientific, rational and accurate assessment of the level of sustainable development of rural energy is crucial to the scientific guidance of the coordinated development of rural revitalization and the protection of the ecological environment. A number of scholars have also conducted research on resources, sustainable development evaluation, energy and other aspects.

In the evaluation of sustainable development of resources, scholars have mostly constructed an evaluation index system based on the theory of sustainable development, which mainly evaluates the sustainability of various types of resources from the economic and technical levels. Nurºah constructed a sustainable development evaluation model considering the uncertain characteristics of renewable energy sources as a way to rank the substitution of renewable energy sources [6]. Liu et al. constructed a multiple evaluation framework for the sustainable development of China's resource-based cities, which has important reference value for the sustainable transformation of RBCs [7]. Mostafa pointed out that cutting-edge technology plays a pivotal role in achieving sustainable development in terms of environment and resources [8], so technological sustainability is closely related to resource sustainability. Yang et al. conducted a continuous assessment of the sustainable development of resources and environment in the Yangtze River Delta to provide reference for coordinating regional development [9]. Among all the sustainable development goals, energy as the current hotspot and focus of attention, energy sustainability is also an important aspect of scholars' research.

From the perspective of sustainable energy development, energy endowment, consumption patterns, industrial structure, resources and the environment to meet the needs of rural development is very critical, and similarly for the measurement and evaluation of the level of sustainable development of energy are mostly centered on these indicators, but how to target these aspects of the scientific research, a number of scholars have carried out relevant research. Xu et al. analyzed energy sustainability mainly from the perspective of resource endowment, constructed a comprehensive evaluation system of energy options for clean heating in rural areas of northern China, and identified locally adapted heating options from the perspective of sustainable development [10]. Zhang et al. consider the impact of energy intensity on rural energy sustainability in order to assess the characteristics of rural energy sustainability thinking [11]. Xu et al. determined the electrical energy and construction benefits of rural PV projects through quantitative analyses, which provided a reference for energy sustainability assessment from an economic perspective [12]. Dong et al. pointed out the importance of energy mix for sustainable energy development, especially the share of clean energy supply [13]. Fei et al. constructed a rural economic development evaluation index system in Jiangsu Province as an example to provide reference for Jiangsu Province to promote the sustainable development of rural energy [14]. Ugur et al. investigated the interrelationship between renewable energy intensity and renewable energy share and environmental sustainability to achieve energy efficiency and carbon reduction by improving the energy mix [15].

From the above studies, it can be found that the current research on resource sustainability and energy sustainability is more in-depth. In the evaluation of the level of development, many scholars have studied the low-carbon development of industry [16], transportation [17], construction [18] and other industries, in addition to the direct evaluation of the level of industrial development [19], but most of these studies are focused on the study of the level of green development, and they all adhere to the principle of objective and scientific measurements, which is in line with the transformation of economic development and the construction of environmental civilization, and the assessment of the sustainable development of rural energy needs to be further in-depth, and the present paper focuses on the study of this issue. In addition, in terms of the evaluation indicator system, this paper conducts a comprehensive study from five aspects: economy, society, resources, environment and technology. Section 2 is the evaluation indicator system of sustainable development level of rural energy, Section 3 is the evaluation model of sustainable development of rural energy, Section 4 is the example analysis based on the data of Henan Province, and Section 5 is the conclusion.

2 Indicator System for Evaluating the Level of Sustainable Development of Rural Energy

The evaluation of the level of development is a macro-development issue, so when the construction of the system of indicators of the level of sustainable development of rural energy is carried out, there will be some indicators that cannot be quantified. In order to guarantee the objectivity and accuracy of the evaluation results, for the indicators that are difficult to quantify, this paper seeks to replace the electricity indicators with high relevance, because at present, most of the rural energy utilization is electricity and coal, while the use of electricity is much cleaner and more extensive from the perspective of sustainability, and the electricity data can also reflect the living and production of the rural residents from the side. Therefore, the evaluation of the level of sustainable rural energy development using a combination of energy and electricity data is more applicable to the current development situation.

Based on the connotation of sustainable energy development – the use of emerging technologies for the rational and efficient use of traditional fossil energy and new energy sources, thereby improving energy efficiency, to ensure the use of energy for future generations and a good living environment [20], coupled with the sustainable development of energy and economic and social as well as technological development is inextricably linked to the energy-economic-environmental mutual coupling relationship [21], this paper builds a sustainable development of rural energy from the five levels of economic sustainability, resource sustainability, environmental sustainability, technological sustainability, as well as social sustainability to evaluate the level of rural energy index system. These are shown below:

(1) Economic sustainability

Under the economic sustainability dimension, GDP per capita, the primary industry output value ratio, general public budget revenues, year-end ownership of agricultural machinery, and year-end loan balances of financial institutions were selected. Among them, GDP per capita refers to the ratio of the GDP of a prefecture-level city to its resident population for the year, which is the most typical indicator for measuring the macroeconomic situation and reflecting the living standard of the local people. The primary industry output value ratio refers to the proportion of the added value of the primary industry to the GDP, thus reflecting the actual development of the primary industry as the most important industry in rural areas. General public budget revenues, including all taxes and non-tax revenues, are revenues derived from the State Treasury's participation in the distribution of social goods. Year-end ownership of agricultural machinery refers to the amount of mechanized equipment used by farmers in the process of growing food during the accounting year, thus measuring, among other things, the prevalence of mechanized farming. Year-end loan balances of financial institutions refer to loans that have not been repaid by enterprises to financial institutions in the year of enumeration.

(2) Social sustainability

Under the social sustainability dimension, the main components are per capita disposable income of farmers, the consumer price index for rural residents, rural employment, the rural resident population, and the health insurance participation rate. Per capita disposable income of farmers refers to the income that rural residents can freely dispose of, including wages, business and other incomes, and is used to measure the living standards and purchasing power of rural residents. The consumer price index for rural residents is a relative measure of the trend and extent of change in the prices of consumer goods and services purchased by rural inhabitants during the statistical year. Rural employment refers to the total number of people currently in employment in the countryside, while the rural resident population refers to the total number of people permanently living in the countryside in the year of the statistics, mainly reflecting the production and living conditions in the countryside. The health insurance participation rate is the ratio of the number of people participating in health insurance to the resident population, reflecting the basic livelihood security of the residents.

(3) Resource sustainability

The most commonly used renewable energy sources in rural areas are biogas and solar energy, so biogas projects, solar water heaters, electricity consumption of industrial enterprises above the scale, electricity consumption of the whole society and energy consumption intensity are selected at the level of resource sustainability. In particular, biogas projects are the number of biogas projects in operation in rural areas within a prefecture-level municipality, which is used to measure the utilization of rural biomass energy. Solar energy is the area of solar water heaters and distributed rooftop photovoltaics installed and in use in rural areas, and is used to measure solar energy utilization. The electricity consumption of industrial enterprises above the scale refers to the electricity consumption of industrial enterprises with annual main business income of more than twenty million yuan in a year, reflecting the level of industrial electrification. The electricity consumption of the whole society refers to the sum of the electricity consumption of the primary, secondary and tertiary industries as well as urban and rural residents in the year of statistics. Energy consumption intensity is the ratio of comprehensive energy consumption to GDP, which is a negative indicator; the larger the value, the greater the energy consumption per unit of GDP, and the less efficient the use of energy.

(4) Environmental sustainability

Environmental sustainability is mainly studied in terms of the percentage of green cover and the area removed from waterlogging. The percentage of green cover is the ratio of green cover to administrative area, which is a sideways reflection of the level of low-carbon development in the countryside because of the higher capacity of woodlands to absorb carbon dioxide. The area removed from waterlogging means to exempt the flood-prone arable land from inundation through the construction of flood control projects or the use of water facilities such as drainage machinery, so as to safeguard the rural cultivation environment.

(5) Technological sustainability

Technical support is indispensable for achieving sustainable development, so corporate innovation and investment in research are essential. The technology sustainability dimension consists of three main indicators, namely research expenditure, the number of enterprises with innovative activities and technology market turnover. Research expenditure refers to expenditure on basic research, applied research and experimental development, including labor costs, acquisition of fixed assets, management fees and other costs, which are essential for technological innovation and development. The number of enterprises with innovative activities is the number of enterprises organizing

Table 1 Indicator system for evaluating the level of sustainable development of rural energy

Target Level	Normative Layer	Indicator
Level of sustainable rural energy development	Economic sustainability	GDP per capita
		Primary industry output value ratio
		General public budget revenues
		Year-end ownership of agricultural machinery
		Year-end loan balance of financial institutions
	Social sustainability	Per capita disposable income of farmers
		Consumer price index for rural residents
		Rural employment
		Rural resident population
		Medical insurance participation ratio
	Resource sustainability	Biogas projects
		Solar energy
		Electricity consumption of industrial enterprises above the scale
		Electricity consumption of the whole society
		Energy consumption intensity
	Environmental sustainability	Proportion of green coverage area
		Area removed from waterlogging
	Technological sustainability	Research funding expenditure
		Number of enterprises with innovative activities
		Technology market turnover

and implementing innovative activities. Technology market turnover refers to the total amount of technology market contract turnover projects, reflecting technology transfer and transformation of scientific and technological achievements.

Through the screening of the above indicators, this paper finally establishes the final indicator system from the five aspects of economic sustainability, social sustainability, resource sustainability, environmental sustainability and technological sustainability, as shown in Table1 below.

3 Rural Energy Sustainable Development Assessment Model

From the indicator system, it is evident that the level of sustainable rural energy development is a systematically comprehensive evaluation problem assessed from multiple aspects and dimensions. Within these dimensions, all indicator data can be conveniently obtained through government reports, ensuring a certain level of reliability in the acquisition of indicator values. The determination of indicator values can be quantitatively processed. In this study, the CRITIC method is employed for objective weighting during the weight processing stage, and MABAC is utilized for quantitative processing, resulting in objective and accurate evaluation outcomes.

3.1 CRITIC

CRITIC is an objective weighting method proposed by Diakoulaki. It provides accurate results based on the characteristics of the data, primarily by calculating the indicator conflict and contrast intensity. The calculation process as follows:

(1) Positive-Directional Decision Matrix X. Eliminating the dimensional units among different indicators x to obtain x'. The formula for X is shown in (1) below.

$$x'_{ij} = \begin{cases} \dfrac{x_{ij} - x_{i\min}}{x_{i\max} - x_{i\min}} & x_{ij}\text{-}\textit{positive} \\ \dfrac{x_{i\max} - x_{ij}}{x_{i\max} - x_{i\min}} & x_{ij}\text{-}\textit{negative} \end{cases} \tag{1}$$

Where, i is the number of indicators, and j is the number of objects to be evaluated, $i = 1, 2, \ldots, m, j = 1, 2, \ldots, n$.

(2) Calculate the contrast intensity of indicators. The contrast intensity is the standard deviation S_i between indicators, where a larger standard deviation indicates a higher contrast intensity for that particular indicator. The calculate formula for contrast intensity as shown in (2)–(3).

$$\overline{x_i} = \frac{1}{n}\sum_{j=1}^{n} x'_{ij} \tag{2}$$

$$S_i = \sqrt{\frac{\sum_{j=1}^{n}(x'_{ij} - \overline{x_i})^2}{n-1}} \tag{3}$$

(3) Calculate the conflict of indicators. The conflict R_{ik} between indicators is relative to the correlation r_{ik}, where a larger correlation implies a smaller conflict between indicators. The calculate formula for conflict as shown in (4).

$$R_i = \sum_{k=1}^{m}(1 - r_{ik}) \tag{4}$$

Where, k is also the number of indicators, in order to distinguish it from the symbol i.

(4) Calculate information content C_i as shown in (5) below. Information content is the product of contrast intensity and conflict, with a larger value indicating a more significant role for that particular indicator.

$$C_i = S_i R_i \tag{5}$$

(5) Calculate the objective weight W_i as shown in (6) below. The objective weight is the normalized result of the information content.

$$W_i = \frac{C_i}{\sum_{i=1}^{m} C_i} \tag{6}$$

3.2 MABAC

MABAC, which stands for Multi-Attribute Border Approximation Area Comparison, was proposed by Pamucar and Cirovic. It primarily calculates the distance between the evaluation objects and the boundary approximation areas, thereby ranking the objects to be evaluated. The calculation process as follows:

(1) On the basis of weight calculation, the standardized decision matrix $S = S_{ij}$ is weighted to obtain the weighted matrix $Z = z_{ij}$. The formula for Z as shown in (7).

$$z_{ij} = W_i * (1 + S_{ij}) \tag{7}$$

(2) Determine the matrix of border approximation areas $L = l_j$. The formula for L conflict as shown in (4).

$$l_j = \left(\prod_{i=1}^{m} z_{ij}\right)^{1/m}, \ j = 1, 2, \ldots, n \tag{8}$$

(3) Calculate the matrix of distances $H = h_{ij}$ between evaluation objects and boundary approximation areas. The formula for h_{ij} as shown in (9).

Where, when $h_{ij} < 0$, it indicates that the i^{th} indicator of evaluation object j is in the lower approximation area, and when $h_{ij} > 0$, it indicates that the i^{th} indicator of evaluation object j is in the upper approximation area.

$$h_{ij} = z_{ij} - l_j \tag{9}$$

(4) Determine the priority order of the objects to be evaluated as shown in (10) below.

$$d_i = \sum_{j=1}^{n} h_{ij},\ i = 1, 2, \ldots, m \tag{10}$$

4 Case Analysis Based on the Actual Situation in Henan Province

4.1 Calculation Process

Henan Province is a typical agricultural powerhouse. Therefore, our takes the data from various cities in Henan Province in the year 2022 as an example. It calculates the level of sustainable rural energy development in each prefecture-level city, including Zhengzhou, Pingdingshan, Luohe, Xuchang, Shangqiu, Kaifeng, Zhoukou, Luoyang, Sanmenxia, Nanyang, Zhumadian, Xinyang, Jiaozuo, Anyang, Hebi, Xinxiang, and Puyang. The development of each prefecture-level city is assessed through the above city-level indicator system. The specific process of calculation and analysis is as follows:

(1) Weight determination

The indicator system for sustainable rural energy development level is subjected to forwardization and standardization processing. Formulae (1)–(3) are employed to calculate the contrast intensity of the computed indicators, further calculating the conflict and information content of the indicators. This process helps determine the weights of each indicator, resulting in the contrast intensity, conflict, information content, and weights for each indicator, as shown in Table 2.

(2) After calculating the weights, the MABAC method is used to compute the boundary approximation area for each indicator, as shown in Table 3.

(3) The final obtained priority order of sustainable rural energy development levels for each prefecture-level city in Henan Province is presented in Table 4.

Table 2 Calculate the weight

Indicator	Contrast Intensity S_i	Contrast Intensity R_i	Information Content C_i	Weights W_i
GDP per capita	0.2836	18.9572	5.3764	0.0665
Primary industry output value ratio	0.3028	20.2746	6.1384	0.0760
General public budget revenues	0.2193	12.5817	2.7585	0.0341
Year-end ownership of agricultural machinery	0.2879	15.4736	4.4543	0.0551
Year-end loan balance of financial institutions	0.2266	12.9636	2.9369	0.0364
Per capita disposable income of farmers	0.2193	15.8882	3.4846	0.0431
Consumer price index for rural residents	0.2421	18.5543	4.4927	0.0556
Rural employment	0.2820	13.6190	3.8400	0.0475
Rural resident population	0.2829	14.0192	3.9664	0.0491
Medical insurance participation ratio	0.2172	21.5179	4.6743	0.0579
Biogas projects	0.2313	19.7165	4.5608	0.0564
Solar energy	0.2938	18.0838	5.3126	0.0658
Electricity consumption of industrial enterprises above the scale	0.2746	15.2405	4.1845	0.0518
Electricity consumption of the whole society	0.2431	12.4816	3.0337	0.0375
Energy consumption intensity	0.2659	15.5238	4.1283	0.0511
Proportion of green coverage area	0.2323	15.8385	3.6798	0.0455
Area removed from waterlogging	0.2860	18.0645	5.1663	0.0639
Research funding expenditure	0.2365	12.9558	3.0642	0.0379
Number of enterprises with innovative activities	0.2231	11.6636	2.6021	0.0322
Technology market turnover	0.2309	12.7286	2.9392	0.0364

4.2 Related Analysis and Suggestions

In response to the above calculations, we extract experiences and computational processes from prefecture-level cities with more successful rural revitalization rankings, offering the following relevant recommendations:

(1) Economic sustainability

In the context of the five aspects, economic sustainability serves as a crucial foundation for achieving sustainable energy development. In the process

Table 3 Border Approximation area

Indicator	Border Approximation Aera
GDP per capita	1.4835
Primary industry output value ratio	1.9223
General public budget revenues	1.0716
Year-end ownership of agricultural machinery	1.4611
Year-end loan balance of financial institutions	0.9724
Per capita disposable income of farmers	1.5988
Consumer price index for rural residents	1.6695
Rural employment	1.6304
Rural resident population	1.6130
Medical insurance participation ratio	2.0140
Biogas projects	1.0020
Solar energy	1.5518
Electricity consumption of industrial enterprises above the scale	1.3083
Electricity consumption of the whole society	1.3103
Energy consumption intensity	2.0451
Proportion of green coverage area	1.1091
Area removed from waterlogging	1.4021
Research funding expenditure	1.0690
Number of enterprises with innovative activities	1.1406
Technology market turnover	0.9799

of evaluating the level of sustainable rural energy development, economic sustainability carries significant weight. In prefecture-level cities with high levels of rural energy sustainability, the economic sustainability is often correspondingly high. This is reflected in robust agricultural development and the flourishing of local distinctive economic activities. Moreover, considering the specific circumstances in Henan, regions with higher economic sustainability also tend to exhibit notable grain production. Therefore, it is recommended to enhance residential electrification, promote agricultural development, and boost local economies, particularly through the vigorous development of electrified agricultural machinery and equipment.

(2) Social sustainability

Social sustainability is a crucial guarantee for achieving sustainable energy development. The ability to further develop sustainable energy relies on achieving a certain standard of living for the population. As evident from the determined weights and evaluation results of rural energy sustainability levels, social sustainability holds a significance second only to resource

Table 4 The order of priority of each evaluation object

Rank	Prefecture-level City	Distance
1	Shangqiu	14.5215
2	Zhumadian	13.8776
3	Kaifeng	12.1417
4	Zhoukou	12.0062
5	Xinyag	10.6138
6	Pingdingshan	8.4928
7	Luoyang	8.0516
8	Nanyang	7.2112
9	Anyang	5.8127
10	Jiaozuo	4.0520
11	Xuchang	3.1805
12	Luohe	3.0637
13	Hebi	2.6103
14	Puyang	2.5512
15	Xinyang	1.9921
16	Sanmenxia	0.8374
17	Zhengzhou	−26.8115

and economic sustainability, far surpassing technological and environmental sustainability. This underscores that the pursuit of high-level sustainable energy development requires robust social support and a higher standard of living as a foundation. Therefore, it is recommended for cities with lower evaluation rankings to vigorously explore regionally distinctive rural industries. Support should be provided to key enterprises with evident catalytic roles, enabling residents to more extensively share in the added value along the entire agricultural industry chain and value chain. Additionally, efforts should be made to strengthen and improve grid-like service management mechanisms for rural internet, power grid, road network, and other services. This includes reinforcing responsibilities for rural safety production, public health, disaster prevention and reduction, emergency response and rescue, emergency broadcasting, food, medicine, transportation, fire safety, and other safety measures to ensure the well-being of rural residents.

(3) Resource sustainability

In terms of resource sustainability, clean energy plays a crucial role as an important means of achieving sustainable development. Our primarily focuses on biogas and photovoltaics, both of which are crucial aspects in the process of sustainable energy development. To advance the installation of clean energy, the approach involves strengthening local distributed photovoltaic promotional efforts. Additionally, considering the local natural environment, it advocates adapting strategies to choose the most suitable clean energy sources and increasing investment accordingly. Moreover, the energy consumption of rural GDP is closely tied to agricultural machinery irrigation and grain harvesting. Given that the use of diesel in agricultural machinery results in carbon emissions, there is an urgent need to further enhance the development of new agricultural machinery, accelerating the electrification of agriculture and residential areas.

(4) Environmental sustainability

A sound ecological environment is the most universally beneficial to people's well-being and represents the greatest advantage and precious wealth in rural areas. Environmental sustainability demands the development of rural areas to be low-carbon, green, and sustainable, serving as a means to achieve sustainable energy. In order to further advance energy conservation and emission reduction, it is necessary to promote the transformation of electricity production towards green methods. Additionally, in the context of residential heating, vigorous efforts should be made to promote clean heating for residents, reducing reliance on coal combustion, which is a crucial measure for energy conservation and emission reduction.

(5) Technological sustainability

Technological progress is a crucial means for sustainable development, and the uncertainty and volatility of renewable energy pose new challenges to the grid integration of renewable power. Advancing the implementation of technology is of paramount importance. On one hand, it is necessary to increase investment in scientific and technological research and development, fostering further technological innovation and advancement. On the other hand, optimizing management systems to enhance work quality and efficiency is essential in providing robust support for technological progress. This, in turn, facilitates the optimization of the conversion of technological achievements and improves the environment for technological innovation.

5 Conclusion

Our examines the assessment of rural energy's sustainable development level and establishes an evaluation index system based on five dimensions:

economic, social, resource, environmental, and technological sustainability. We have proposed a new comprehensive evaluation model, CRITIC-MABAC, which characterizes some difficult-to-quantify indicators using indicators from the perspective of electricity with strong correlation. This makes the evaluation system more scientific and objective. The CRITIC and MABAC methods are utilized for evaluating and ranking processes based on standardized treatment of index values. We analyze relevant data from Henan Province in 2022 as a typical agricultural province to obtain our final results. Our findings indicate that Shangqiu, Zhumadian, Kaifeng, and Zhoukou have relatively high levels of sustainable development in rural energy. Based on our calculation process and results, we provide recommendations for developing rural energy in Henan Province.

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Biography

Li Peng (1985–) is doctor of management and senior economist. His main research direction is Rural energy transformation, Integrated County Energy Systems and Energy Internet Application Technology.