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Research On Evaluation System OfRural Renewable Energy Based On Analytic Hierarchy Process –Takeing The Central Region Of Shandong Province As An Example

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Abstract:
Background*:The development of renewable energy in rural areas is pivotal in promoting the cleanliness and low-carbon transformation of agricultural production, improving the lives of farmers, and protecting the ecological environment in rural regions. This study, through the construction of a technical framework for the utilization of clean energy in rural areas, has analysed and identified the primary approaches to clean energy utilization in the central Shandong region of China. It has also distilled the influencing factors affecting the development of renewable energy in this region.*
Materials and Methods*: The analytic hierarchy process (AHP) has been employed to assess the progress of renewable energy in rural areas, offering a scientific basis for rational planning and the transformation of rural energy.The research methodology primarily involves on-site investigations and the distribution of questionnaires, supplemented by literature reviews. Surveys were conducted in rural areas of central Shandong, China, focusing on the development of renewable energy. An evaluation index system for renewable energy development was established, encompassing four aspects: rural economic development, rural social development, rural environmental development, and rural energy development. Case studies were conducted to assess and optimize decision-making regarding the utilization of clean energy in rural areas of central Shandong, China.*
Results*: Utilizing indicators selected during rural household energy consumption and considering various characteristics of rural energy development in central Shandong, China, as well as factors influencing the development of rural renewable energy, the study conducted analyses, provided current assessments and predictive evaluations, and further delved into the underlying reasons for these findings.*
KeyWord*:Renewable energy; Analytic hierarchy process; Rural revitalization; Rural development.*

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I. Introduction

The development and utilization of renewable energy in rural areas contribute significantly to the promotion of clean and low-carbon agricultural production, improvement in the quality of rural life, cleaner and more sustainable rural transportation, and protection of the rural ecological environment. It also supports the construction of ecologically friendly and beautiful rural communities[1]. In a joint effort, the National Energy Administration, the Ministry of Agriculture and Rural Affairs, and the National Rural Revitalization Bureau issued the 'Implementation Opinions on Accelerating Rural Energy Transformation to Support Rural Revitalization.' This document emphasizes the importance of green and low-carbon energy development as a foundational and driving force for rural revitalization. It aims to promote the creation of a modern rural energy system that is clean, low-carbon, and versatile, while comprehensively improving the quality of energy use in rural areas. The ultimate goal is to ensure that rural areas have access to reliable, affordable, and efficient energy.To achieve this, it is essential to optimize energy supply methods, enhance the quality of the energy supply, and effectively develop energy resources to meet the development needs of rural regions in China[2].

At present, the development of renewable energy is influenced by various factors. Identifying the key influencing factors from among these many elements and addressing them specifically is essential for promoting the electrification of production and daily life in rural areas through renewable energy. This, in turn, fosters the scale-up development of clean energy in rural regions. Existing research has primarily focused on analysing the situation of rural energy production and consumption, as well as the rural energy supply system. There is limited literature on the construction of mechanisms affecting the development of rural renewable energy from the perspective of rural renewable energy assessment. To address this gap, this study takes the central Shandong region in China as an example to construct an evaluation system for rural renewable energy development. Through an analysis of the characteristics of rural renewable energy development and assessment, we formulated a framework for the content of rural renewable energy development[3]. We have explored the influencing factors of rural renewable energy development from multiple perspectives, extracted key indicators affecting rural renewable energy development, and established an evaluation system for rural renewable energy development using the analytic hierarchy process (AHP). By combining the characteristics of the central Shandong region in China with refined key indicators and actual data, we evaluated the development of rural renewable energy in this region. Additionally, we have optimized the evaluation system and put forth recommendations and decisions for the development of rural renewable energy in the central Shandong region of China.

II. Establishment of a mathematical model of the evaluation system

The analytic hierarchy process (AHP) was initially proposed by Thomas L. Saaty and is a method used to determine weights by employing a hierarchical approach to handle multiple factors. It has found wide applications in research fields such as safety science and environmental science [4-7]. The AHP method is designed and implemented in three steps:

1) Establishing a hierarchical structure model: First, based on the specific circumstances affecting the development of renewable energy, indicators that have an impact on renewable energy development are selected. These selected indicators are then further categorized based on their logical relationships into the goal level, criteria level, and indicator level. The goal level typically represents the main objectives of establishing the system. The criteria level serves as an intermediate link between the indicators and the achievement of goals, providing a deeper level of categorization for the selected indicators. The indicator level comprises a collection of factors that influence the evaluation system.

2) Calculating evaluation values. The formula for the renewable energy evaluation system is:

$$L = \sum_{i=1}^{m} W_i \, D_i$$

In the formula, L represents the evaluation value of rural renewable energy development in the context of rural revitalization, and D_i represents the standardized value of evaluation factor indicators, and w_i represents the weight value of selected evaluation indicators.

3) Calculating evaluation rank values: To ensure comparability in evaluations, evaluation rank standard values are established based on calculated rank comprehensive thresholds. These standards are used to create a comprehensive evaluation ranking for renewable energy, determining the interval ranges for each rank.

The rural clean energy evaluation system primarily utilizes the analytic hierarchy process (AHP) and conducts a systematic analysis of the rural clean energy utilization system, considering factors related to the economy, society, environment, and energy. The establishment of a renewable energy application evaluation system is primarily aimed at assessing the impact on rural sustainable development. This system should encompass the following components: the purpose of system establishment, the content covered by the system, the establishment of various indicators within the system, evaluation methods, and the general procedure for evaluation.

Establishment of indicators

The selection of various indicators in the rural renewable energy evaluation system is the core of the evaluation system. The chosen indicators must be representative and able to characterize the benefits of the represented project in that aspect. In addition, the selected indicators should also possess independence, meaning there should be no causal relationship among indicators at the same level; a change in one indicator should not affect others. The selection of indicators should also have comparability, data availability, dynamism, and relevance. Only indicators meeting these criteria can serve as the core of the entire evaluation system[8].

The rural renewable energy system is a complex system encompassing economic, social, and ecological aspects, characterized by a hierarchical structure. Figure 1 represents the hierarchical structure of the rural renewable energy evaluation system indicators, consisting primarily of three levels: the goal level, the criteria level, and the indicator level. By analysing various types of indicators within each level, we identify the indicators with the most significant impact on rural renewable energy and thereby establish the rural renewable energy evaluation system.

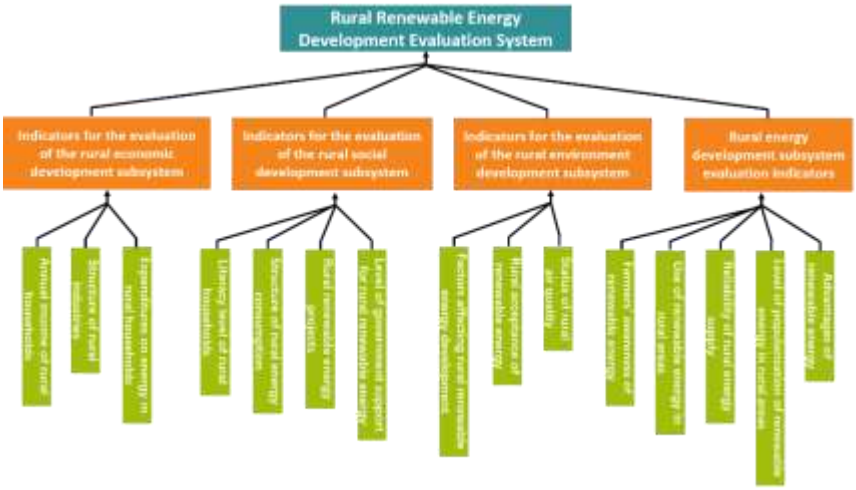

Figure 1. Rural Renewable Energy Evaluation System Model

Constructing judgment matrices

When determining the weights between factors at each level, pairwise comparisons are made among their respective indicators, and levels of importance are assessed[8]. "a_{ij}" represents the importance comparison result between factor i and factor j. Table 1 presents the 9 importance levels and their corresponding values. The matrix formed by the pairwise comparison results is referred to as the judgment matrix. The judgment matrix has the following properties:

$$a_{ij} = \frac{1}{a_{ji}}$$

The judgement matrix a_{ij} is scaled as follows:

Table 1： Scale of proportions

Factor i over factor j	quantitative value
Equally important	1
Low Priority	3
Neutral Significance	5
Moderate Importance	7
High Priority	9
Median of two adjacent judgments	2，4，6，8

Based on the table above, in conjunction with the use of the Delphi method, the constructed model is organized, summarized, and statistically weighted. Subsequently, the experts' scoring results are processed using the geometric mean method to obtain the final scores for various categories of indicators[9]. The formula for the Ho average method is:

$$G_n = \sqrt[n]{\prod_{i=1}^{n} x_i}$$

The expert statistics were obtained by normalizing them by the geometric mean:

$$\omega = (\omega_1，\ \omega_2，\ \cdots w_k)^T$$

$$\boldsymbol{\omega_i} = \frac{\boldsymbol{\omega_i'}}{\sum_{i=1}^{k} \boldsymbol{\omega_i'}} \lambda_{max} = \sum_{i=1}^{n} \frac{(AW_i)}{nW_i}$$

In the formula: λ_{max} is the largest characteristic root of the judgment matrix,and ω is its corresponding eigenvector.

Consistency test

To ensure the accuracy of the weighting indicators, it is necessary to conduct a consistency test of the indicators, The specific steps are as follows:

1）Calculate the consistency indicator CI with the formula:

$$C_I = \frac{\lambda_{max} - n}{n - 1}$$

In the formula, λ_{max} is the maximum eigenvalue of the judgement matrix, and n is the order of the comparison matrix.

Calculate the consistency ratio C_R with the formula:

$$C_R = \frac{C_I}{R_I}$$

In the formula: when $C_R < 0.1$, the judgment matrix has satisfactory consistency. R_I denotes the average random consistency index, which is found from the RI correction value in Table 2.

Table 2: Table of values for the average random consistency indicator

n	1	2	3	4	5	6	7	8	9	……
R_I	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	……

Based on the above equation, the C_R values of the judgement matrices at all levels are calculated for the consistency test, and the specific results are shown in Table 3. The analysis shows that the C_R values of the judgement matrices are all within 0.1, indicating that they all pass the consistency test.

Table 3: Judgment matrix and consistency test results for each level of evaluation indicators

hierarchical model	judgment matrix						consistency test
A-B		B1	B2	B3	B4		C_R=0.0374
	B1	1	0.7177	1.4414	0.7578		
	B2	1.3933	1	2.1184	0.4335		
	B3	0.6938	0.4721	1	0.2183		
	B4	1.3196	2.3068	4.5809	1		
B1		C1	C2	C3			C_R=0.0223
	C1	1	1.0413	5.1228			
	C2	0.9603	1	3.1165			
	C3	0.1952	0.3209	1			
B2		C4	C5	C6	C7		C_R=0.0292
	C4	1	2.2082	2	0.7578		
	C5	0.4529	1	0.5065	0.5492		
	C6	0.5	1.9743	1	0.5		
	C7	1.3196	1.8208	2	1		
B3		C8	C9	C10			C_R=0.0162
	C8	1	0.7444	2.4573			
	C9	1.3434	1	2.2369			
	C10	0.4070	0.4470	1			
B4		C11	C12	C13	C14	C15	C_R=0.0800
	C11	1	0.7579	0.4863	0.32	1.5	
	C12	1.3194	1	0.6084	1.0559	0.4592	
	C13	2.0563	1.6437	1	0.7759	1.1914	
	C14	3.0864	0.9471	1.2888	1	0.8245	
	C15	0.6667	2.1777	0.8393	1.2129	1	

Results and Analysis

The total weight value is the sum of the weights of each indicator for that target layer and is obtained using a hierarchical calculation. The specific calculation formula is:

$$W_Q = W_J \cdot BW_i$$

In the formula, W_Q is the comprehensive weight value of the indicator layer base indicator C_j, and W_j is the weight score of C_j relative to B_i. Based on the formula to derive the total weight value of the various types of indicators of the rural renewable energy development evaluation system, the specific results of the calculation are shown in Table 4.

Table 4: Total weight values of indicators of the rural renewable energy development evaluation system

Target layer	Criterion layer	Weight	Index layer	Weight
Evaluation System for Rural Renewable Energy Development	Indicators for the evaluation of the rural economic development subsystem （B1）	0.2143	Annual income of rural households （C1）	0.1044
			Structure of rural industries （C2）	0.0860

Target layer	Criterion layer	Weight	Index layer	Weight
			Expenditures on energy in rural households （C3）	0.0237
	Indicators for the evaluation of the rural social development subsystem （B2）	0.2355	Literacy level of rural households （C4）	0.0741
			Structure of rural energy consumption （C5）	0.0331
			Rural renewable energy projects （C6）	0.0466
			Level of government support for rural renewable energy （C7）	0.0817
	Indicators for the evaluation of the rural environment development subsystem （B3）	0.1145	Factors affecting rural renewable energy development （C8）	0.0433
			Rural acceptance of renewable energy （C9）	0.0511
			Status of rural air quality （C10）	0.0201
	Rural energy development subsystem evaluation indicators （B4）	0.4357	Farmers' awareness of renewable energy （C11）	0.0637
			Use of renewable energy in rural areas （C12）	0.0694
			Reliability of rural energy supply （C13）	0.1010
			Level of popularization of renewable energy in rural areas （C14）	0.1078
			Advantages of renewable energy （C15）	0.0939

According to Table 4 and Figure 3, in the evaluation system for renewable energy development in rural areas, the weights of the criteria in the standard layer are as follows: evaluation indicator B4 for the rural energy development subsystem (0.4357) > evaluation indicator B2 for the rural social development subsystem (0.2355) > evaluation indicator B1 for the rural economic development subsystem (0.2355) > evaluation indicator B3 for the rural environmental development subsystem (0.1145). This indicates that the evaluation system for rural renewable energy development should not only consider rural economic development, but also incorporate sustainable rural energy and environmental development into the evaluation system.

III. Rural energy development in Shandong, China as a case study

Evaluation system case study in central Shandong, China

Conducting an analysis of the development of renewable energy in rural areas in the central part of Shandong, China, in conjunction with the renewable energy evaluation system. Various indicators within the system were investigated through survey questionnaire options to analyse the current state of renewable energy in rural areas of the central part of Shandong, China. Toassess the level of sustainable development of renewable energy more accurately in the central part of Shandong, China, scientific analysis and evaluation of the development of renewable energy were conducted, as depicted in Figure 2 and Figure 3, incorporating radar comparison charts illustrating the state of renewable energy development in the central part of Shandong, China, and analytical graphs based on survey questionnaire results.

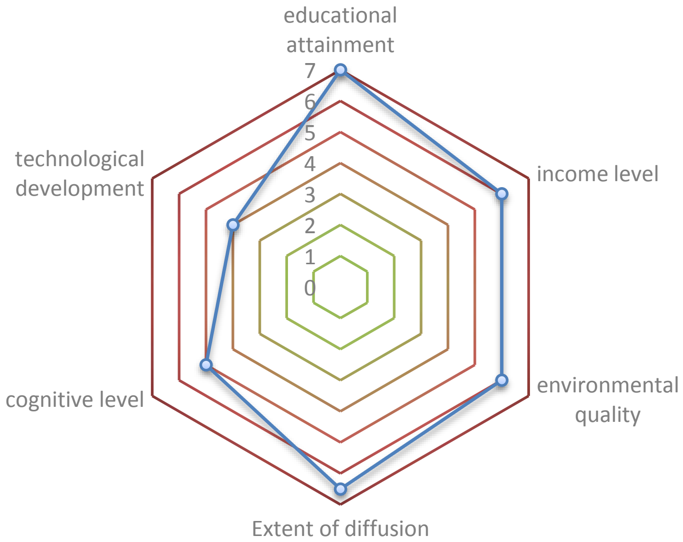

Figure 2. Radar Comparison of Rural Renewable Energy Development in Central Shandong, China

In terms of weights, rural energy sustainable development is the indicator with the highest proportion, indicating that it is a key factor influencing the application of renewable energy and rural sustainable development. It occupies an important position in the application of renewable energy and rural sustainable development, as shown in Figure 2. Therefore, in the development of rural renewable energy applications, attention should be given to the impact of energy on rural areas. Regarding the weights of various evaluation factors included in rural energy sustainable development, three evaluation factors, namely, the popularization level of renewable energy in rural areas, the reliability of rural energy supply, and the advantage index of renewable energy, have relatively high weights of 0.1078, 0.101, and 0.0939, respectively. This implies that effectively improving the popularization of renewable energy in rural areas, enhancing the reliability of the rural energy supply, and leveraging the advantages of renewable energy can significantly enhance the development of rural renewable energy. In conclusion, to promote the development of rural renewable energy, it is necessary to appropriately expand the popularization of renewable energy in rural areas, emphasize the reliability of renewable energy supply, and harness the advantages of renewable energy compared to traditional energy sources, to continuously drive the development of rural renewable energy.

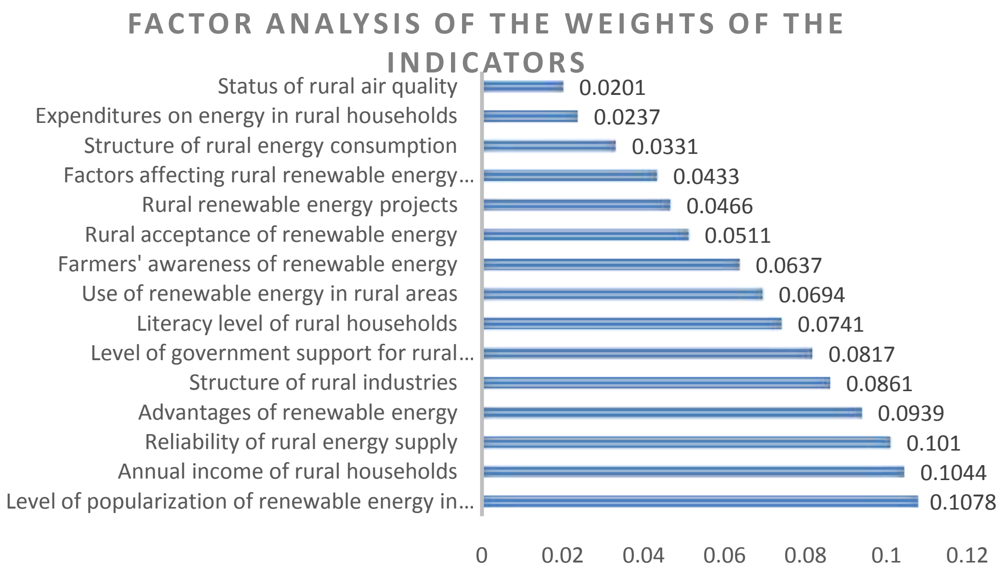

Figure3. Analysis of the weights of the indicators of the renewable energy evaluation system

Rural Household Energy Research Data Collection in Central Shandong, China

By employing a random sampling method, the central part of Shandong, China, was chosen as the research sample area. Survey questionnaires were distributed in the sample area using a combination of online and offline methods. A total of 149 questionnaires were distributed online, with 131 of them being effectively completed. Additionally, 150 questionnaires were distributed offline, and 146 of them were collected. In total, 299 questionnaires were distributed, and 277 were collected. The questionnaire survey was conducted at the household level and focused on the current energy situation. The survey content mainly included four aspects: (1) basic household information, including the number of family members, annual net income, and level of education; (2) household energy consumption; (3) utilization of renewable energy and environmental awareness, such as awareness of renewable energy utilization and knowledge of renewable energy utilization technologies; and (4) choices in rural energy consumption methods, including willingness to use renewable energy.

The data from the questionnaire survey in the central part of Shandong, China, reveal the following findings: The average permanent population of households in the sample area is 3 people, accounting for 44%. Education levels in the central part of Shandong are generally high, with 90% of respondents having a high school education or above. This provides a solid foundation for the dissemination of renewable energy. Most households in the sample area have disposable incomes ranging from 30,000 to 50,000 RMB, making up 39% of the total, indicating significant income disparities among rural households in the region. The primary sources of income in the central part of Shandong are migrant labor and farming. Regarding environmental quality in the central part of Shandong, 39% of respondents reported good or better environmental quality, with air quality being generally acceptable. In terms of awareness of renewable energy, most rural households in the region (81%) have a fair to excellent understanding. Sixty-eight percent of rural households believe that renewable energy can improve the living environment in rural areas, 17% think it does not contribute to such improvement, and others are unsure. The survey also found that over 47% of households in the central part of Shandong are already using renewable energy devices, and 56% of households are willing to actively use renewable energy devices. However, the primary source of energy consumption in households is still concentrated on grid electricity.

Findings on Rural Renewable Energy in Central Shandong, China

Based on the analysis of indicators, it can be determined that the indicator weight factor for annual household income, with a weight factor of 0.1044, is the highest among all the indicators and is a crucial factor influencing the development of renewable energy in rural areas. According to the survey questionnaire, the average annual disposable income of households in the central part of Shandong, China is 62,480.9 RMB, which exceeds the average annual income of most rural households in China. Therefore, it can better promote the development of renewable energy. The level of awareness of renewable energy in rural areas, with a weight factor of 0.1078, is also significant. The central part of Shandong, China, has a relatively high level of awareness of renewable energy, with the survey questionnaire showing that 80.15% of respondents have a fair to excellent understanding of renewable energy. This indicates that most rural households in the region have good knowledge of renewable energy. The reliability of the rural energy supply is another critical factor affecting the development of renewable energy in rural areas, with a weight factor of 0.1010, ranking third. The relatively small gap with the top two factors highlights the important role of energy supply reliability in renewable energy development. According to the survey questionnaire, 41.22% of rural households believe that renewable energy technologies are not mature enough. Therefore, the next step should focus on increasing research and development efforts to improve the reliability of renewable energy. According to the survey, the main issues for rural households considering whether to use renewable energy are traditional beliefs, followed by integration issues and technological barriers. These are also factors influencing the development of renewable energy. The combined weight of the three indicators, rural energy consumption structure, rural household energy expenditure, and rural air quality, is 0.0769, indicating a relatively lower impact on the development of renewable energy and not playing a decisive role.

IV. Conclusion

This study aimed to establish an evaluation system for the development of renewable energy in rural areas under the backdrop of rural revitalization. The research constructed an evaluation framework for rural renewable energy and conducted a systematic assessment of various influencing indicators. The analysis specifically targeted the development of renewable energy in the central part of Shandong, China, and the main research findings are as follows:

Based on the classification and study of attributes within rural energy systems, a general framework for evaluating rural renewable energy was established. Considering the issues related to rural renewable energy development within the context of rural revitalization, an evaluation indicator system for the development of rural renewable energy in the central part of Shandong, China was systematically built, covering four aspects:

rural economic development (B1), rural social development (B2), rural environmental development (B3), and rural energy development (B4). The evaluation results indicated that the weights of these aspects were in the following order: B4 > B2 > B1 > B3, highlighting the paramount importance of rural energy development in the region. However, the importance of rural social development and rural economic development should not be overlooked. Further analysis revealed that within the context of rural energy development, the weights of the indicators for the level of awareness of renewable energy in rural areas (C14) and the reliability of rural energy supply (C13) were the highest, while within rural economic development, the weight of annual household income of rural households (C1) was the most significant.

The analytic hierarchy process (AHP) method was applied to the evaluation model of renewable energy development in rural areas. This model was combined with a comprehensive analysis of the actual situation of rural renewable energy development in the central part of Shandong, China. The study found that, in the indicator with the highest weight factor, namely, annual household income, the average annual disposable income of rural households in the central part of Shandong, China, was approximately 60,000 RMB. However, the level of awareness of renewable energy and the reliability of renewable energy supply were relatively low. Based on the overall survey results and AHP analysis, recommendations were made to enhance the awareness of renewable energy in rural areas, increase research investment in renewable energy, and improve the reliability of the energy supply, providing a basis for the sustainable development of rural renewable energy in the central part of Shandong, China.

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