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Research Article

Comprehensive Evaluation of Global Clean Energy Development Level Based on Compatibility and Difference Degree

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To promote the energy structure adjustment and clean energy development, this paper evaluates the global clean energy development level. Firstly, the global clean energy development level evaluation index system is established based on index system construction principles; secondly, the comprehensive weight is determined based on additive integration model, which is used to combine subjective and objective weights. Moreover, the variance minimal optimization method is used to select the combination scheme of dimensionless method and objective weight method, which could avoid the influence from subjective selection of method and enhance the stability of weighting. Thirdly, grey relational degree method and logarithmic range method are applied to evaluate the global clean energy development level. Then using the compatibility degree maximization and difference degree minimization model considers the compatibility and difference degree of the various comprehensive evaluation methods results and chooses the result with the maximization compatibility degree and minimization difference degree as the final evaluation scheme, which makes the evaluation result more scientific, robust, and reasonable. Finally, this paper empirically analyzes the 66 countries in the world to verify the effectiveness of the method and evaluates the development level of the region according to the spatial distribution map of the development level.

1. Introduction

With the development of global economy and the advancement of industrialization, the production and consumption of fossil energy continue to increase which leads to fossil fuel's shortage. What is more, it comes a large amount of pollution in using fossil energy causing air pollution and prominent environmental deterioration [1]. These global problems are the severe challenges of sustainable development all over the world. The key of solving these problems is to promote the extensive utilization of clean energy and build a modern energy system dominated by clean energy. Moreover, with the maturity of clean energy technologies and the promotion of sustainable development awareness in various countries, clean energy is developing rapidly all over the world. Due to the regional difference of policies, technologies, engineering, and economics, the development level of clean energy is quite different. Therefore, in the current stage of clean energy development, how can comprehensively and scientifically comprehensive evaluate the development level of clean energy in various countries around the world, so as to timely evaluate the current development level and find problems in the development of clean energy, is the key to promoting the comprehensive construction of clean energy worldwide [2, 3]. And it is of great significance to promote the construction of "The Silk Road Economic Belt and 21st-Century Maritime Silk Road" and the development of the global energy Internet [4].

Scholars have designed many evaluation index systems about the clean energy industry development, mainly including SEI (Sustainable Energy Index), RECAI (Renewable Energy Country Attractiveness Index), and EPI (Environmental Performance Index). SEI is a composite evaluation index system of sustainable energy development with three main concepts [5–8]. This method integrates the three concepts of energy supply, energy efficiency, and environmental protection, but this index lacks an analysis of policy [9]. RECAI is a well-known index for evaluating national renewable energy investments and has been used by Ernst & Young for more than 10 years. And the evaluation scope covered 40 countries on six continents. This approach involved three main drivers, namely, macrodrivers, energy markets, and specific technology drivers, but the underlying data sets and weights based on subjective evaluations rather than official public data [10]. EPI is a well-known environmental impact assessment index that included ten main dimensions, namely, health impacts, air quality, water and sanitation, water resources, agriculture, forests, fisheries, biodiversity, habitats, climate, and resources [11]. EPI's indicator system covers relatively comprehensive, but the economic volume and environmental conditions of different countries are different, which will affect the comparability of index results. There are many index researches on energy, environment, and sustainability development, such as Low Carbon Energy System (LCES), Energy, Economy and Environment (3E), Energy-Economy-Environment Decision Support System (3EDSS). LCES system is a complex system formed by the mutual interaction and feedback of resources-environment-economic-social systems. This system contributes to the sustainable development of regional energy conservation and emission reduction research. The main researches of the LECS system include the determination of carbon emission coefficient, the analysis of carbon emission influencing factors, and the dynamic evolution system of carbon emission system, but the simulation prediction of sustainable development is less [12]. 3E is mainly used to support the country's decision-making on sustainable development strategy, especially in the energy sector. The model could be used to analyze the impacts of greenhouse gas reductions on socioeconomic development and emission reduction cost of various technologies [13]. 3EDSS is a comprehensive evaluation system based on 3E model with decision support system. The 3EDSS system uses the human-computer interaction method to analyze the index data and apply the mathematical model. It can provide decision-makers with policy advice guidance, improve energy-economy-environment sustainable development, and reflect the significance of decision support [14]. In addition, the global Energy Architecture Performance Index (EAPI) and Global Energy Interconnection Development Index (GEIDI) are well-known in the world. EAPI is a comprehensive index, developed by the World Economic Forum in cooperation with Accenture to directly reflect the country's energy system development level. Its research objects include 127 countries, and the core is the 18 indexes defined in the "energy triangle" on three sides, namely, economic growth and development, environmental sustainability, and energy access and security [15]. GEIDI is a comprehensive index, proposed by the Global Energy Interconnection Development and Cooperation Organization in the year of 2018, to reflect the national and regional power systems, energy systems, and economic-social-environment coordinated development based on the global energy Internet and the concept of "green, supply, synergy, and sustainability". GEIDI consists of three special indexes: power interconnection, low-carbon, and coordinated development of energy-economics-society-environment, which reflects the core meaning and strategic value of the global energy interconnection. He et al. used the improved entropy method to conduct a comprehensive evaluation of the global energy Internet development index [16]; however, only one evaluation method was used, which lead to the evaluation results that would be influenced by the artificial selection method, and the evaluation indexes were mainly clean energy installation and clean energy consumption, so the evaluation indexes are not rich.

Overall, according to the research on the comprehensive evaluation of current energy system, scholars have different focuses on the evaluation index system constructed by clean energy. Some of them concentrate on environmental impact, renewable energy supply, or renewable energy investment, the others center on comprehensive evaluation index system for clean energy. Therefore, this paper analyzed the formation of the index system one after another starting from the perspective of the process of clean energy government planning, to economic investment, to energy supply, to energy consumption and environmental impact, and then to comprehensively evaluate the development level of clean energy when constructing the evaluation index system of clean energy development level. In the research of comprehensive evaluation, the most important aspects are the weight method and the determination of comprehensive evaluation method. In the current comprehensive evaluation research, it is an urgent problem to be solved that how to select the weight method and comprehensive evaluation method to meet the characteristics and requirements of the evaluation object. At present, most scholars use subjective selection of a certain method to calculate the objective weight, which will cause the subjective impact of artificial selection. And the model cannot select the best weight method and comprehensive evaluation method to use [17]. Therefore, in this paper, a variety of dimensionless and objective weight combination methods are used to calculate the weights, and the results of the best combination method are selected as objective weights to obtain scientific weight results. In comprehensive evaluation, this paper selects the model of compatibility degree maximization and difference degree minimize model. It can not only provide criteria for judging the merits of the evaluation schemes produced by different comprehensive evaluation methods but also generate new schemes from multiple evaluation schemes. This method can enhance the scientific, reliability, and feasibility of the evaluation results [18, 19]. This paper is different from previous research reports on clean energy level assessment in the following aspects: first, this paper constructs a perfect index system, which covers quantitative and qualitative indicators and measures the level of clean energy development of a country from six aspects and angles; second, previous reports are based on expert scoring method to determine the weight of indicators, while this paper uses subjective method. The objective combination method makes the weight result more accurate. The weight value includes not only the subjective wishes of experts but also the information contained in the data. Thirdly,

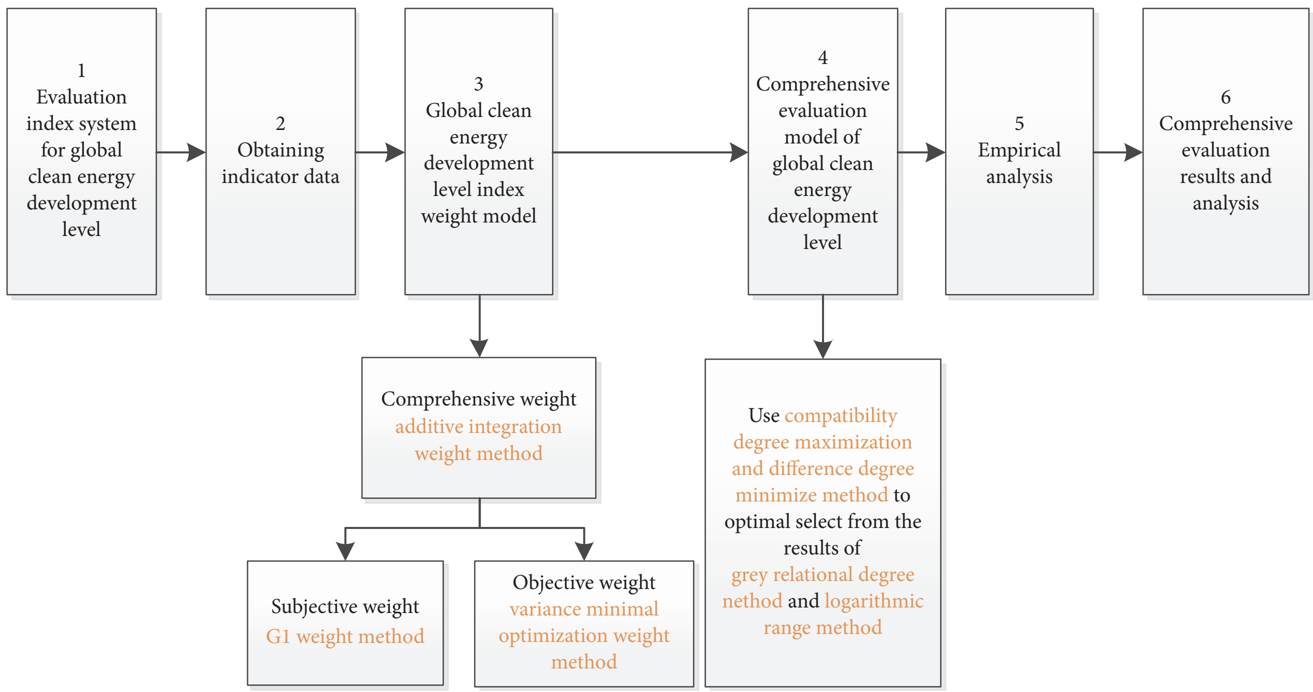

Figure 1: The research framework chart of global clean energy development level.

the comprehensive evaluation method is different from the previous research reports. The former research reports are people's subjective choice of a method for research, and this paper is based on two different comprehensive evaluation methods for analysis and then from the results of the two methods to select the best result. The results of these methods are optimized to make the evaluation results more robust and scientific.

The paper consists of seven parts: in the second section, the idea and overall frame of this study are introduced. In the third section, the global clean energy development level index system is constructed from the perspective of comprehensively considering the clean energy development and this index system consists of four secondary indexes, namely, clean energy development planning, clean energy installed capacity proportion, clean energy generation proportion, and environmental impact. The fourth section establishes the weight model of global clean energy development level index system and obtains the index weight value by means of subjective and objective combination. In the fifth section, the compatibility degree maximization and difference degree minimize model is constructed based on the characteristics of the index system and the requirements of modern scientific decision-making, which can compare multiple comprehensive evaluation method results to select the most compatible and stable results. In the sixth section, taking the 66 countries as sample, the global clean energy development level index and its spatial distribution are analyzed according to the weight model and comprehensive evaluation model. In the seventh section, the relevant conclusions and recommendations are put forward.

2. Research Framework of Global Clean Energy Development Level Index

In view of the above background and significance, this paper establishes a comprehensive evaluation model of clean energy development level based on the principles of comprehensiveness, objectivity, adaptability, and sustainability around the global clean energy development strategy. The main research ideas of the comprehensive evaluation model of clean energy development level under the global energy Internet are as shown in Figure 1.

(1) Analysis of Influencing Factors of Clean Energy Development Level and Construction of Index System. Based on the process of clean energy government planning, to economic investment, to energy supply, to energy consumption and environmental impact, and following the principle of index system construction, this paper constructs a comprehensive evaluation index system of clean energy development level. This paper provides a comprehensive evaluation index system form four aspects of clean energy development policies, economic factors, environmental constraints, and technological progress which are analyzed. And then the representative index system to measure the level of clean energy development is constructed, which can scientifically and comprehensively describe the level of clean energy development in various countries and regions.

In the aspect of index data acquisition, this topic collects relevant index data from authoritative database to ensure the relative rationality of index data. Specific data sources include United Nations Statistics Division, The World Bank, International Energy Agency, The International Renewable

Energy Agency, and global energy research unified platform database of State Grid.

(2) Study on Comprehensive Evaluation Model of Clean Energy Development Level. In the construction of weight model, other scholars choose dimensionless method and weight method by subjective will, which makes the comprehensive evaluation result affected by subjective factors and reduces the credibility of the results. Considering the characteristics of large number of evaluation objects, complex data, and large differences in the research of global clean energy development level, the selection of dimensionless method and weight method is extremely important. To reduce the influence of subjective factors and increase the reliability of comprehensive evaluation, the dimensionless method and objective weighting method are selected to construct an innovative model of minimum variance weighting method to obtain objective weights. The model chooses the best combination of various dimensionless methods and weighting methods and chooses the scheme which can represent the stable level of each method combination as the objective weighting result, which makes the weighting value closer to the reality and has better application value and increases the credibility of the evaluation results.

In the construction of the comprehensive evaluation model, the project considers the commonness and difference of different regions, uses scientific evaluation methods to continuously evaluate and analyze the level of global clean energy development, and provides methods and tools for efficient and rational promotion of global clean energy development. The comprehensive evaluation methods to be adopted in this paper include logarithmic range method, grey correlation degree comprehensive evaluation method, and compatibility degree difference minimization method.

(3) Analysis and Optimum Selection of Comprehensive Evaluation Result of Clean Energy Development Level in Major Global Regions and Countries. The global, major regions and countries are selected as the evaluation objects, and based on the above comprehensive evaluation model, the quantitative evaluation results of development level are given. The comprehensive evaluation of clean energy development level is carried out from the intercontinental level. Based on the quantitative evaluation results, corresponding development suggestions are put forward for different grades and regions to promote the healthy development of clean energy in the future.

3. Evaluation Index System for Global Clean Energy Development Level Construction

The establishment of a comprehensive evaluation index system for clean energy development level aims to comprehensively reflect the differences in clean energy development between different countries or regions and accurately describe and evaluate them, so as to facilitate the planning and improvement of clean energy construction plans in a more scientific way. The design and establishment of an objective, comprehensive, complete, scientific, and reasonable comprehensive evaluation index system are the foundation and key to the analysis of the level of clean energy development. The index system can also provide guidance and help for the development of clean energy [20]. So, in this paper, new clean energy evaluation index system formulation principles were established by learning from the ideas of the SMART principle and combining the objectives of the evaluation index system. The specific contents of the principles are shown as follows:

(1) Specific: the formulation of the index system structure, the selection of indexes, and the determination of scores should be set based on the statistical theory, system theory, management and decision-making science theory, and so on.

(2) Representative: the selection of indexes should be comprehensive and the logical relationship among indexes should be mutual adaption and consistency, but the priority, importance, and emphasis should be distinguished.

(3) Operable: the indexes system must be practical and should be able to extend in the research field.

(4) Relative independent: relatively independent and relatively low coupling indexes should be chosen when establishing evaluation index system to avoid duplication of data.

To scientifically evaluate the development level of clean energy, there is a need to build a comprehensive index system. This paper follows the principle of constructing the developing level of clean energy, starting from every process of clean energy development and application, focusing on grasping each link, exploiting the features of clean energy development, and setting the secondary indexes according to five influencing factors of clean energy development planning: economic investment, power generation, terminal consumption, and environmental impact. From the perspective of comprehensive consideration that is the characterization parameters of clean energy development, this paper analyzed and refined the factors influencing the level of clean energy development, obtaining 21 corresponding quantitative three-level indexes, and summarizing the comprehensive evaluation index system of global clean energy development level as shown in Figure 2.

4. Construction of Global Clean Energy Development Level Index Weight Model

Based on the comprehensive evaluation index system established in the previous chapter, there is a consideration that if high overlap and correlation between indexes appears. It will lead to redundancy of indexes and distortion of evaluation results, so the index system is needed to filter. In this paper, according to the Delphi method, the index system is subjectively filtered in the form of questionnaires to obtain the filtered evaluation index system. The filtered index system can be reviewed by expert opinions on the basis of the original index system to reduce the overlap and correlation between indexes. In the weight model and the comprehensive evaluation model, the weighted and comprehensive evaluation is carried out for the selected index system.

The comprehensive evaluation of clean energy development level is a complex evaluation system covering economic,

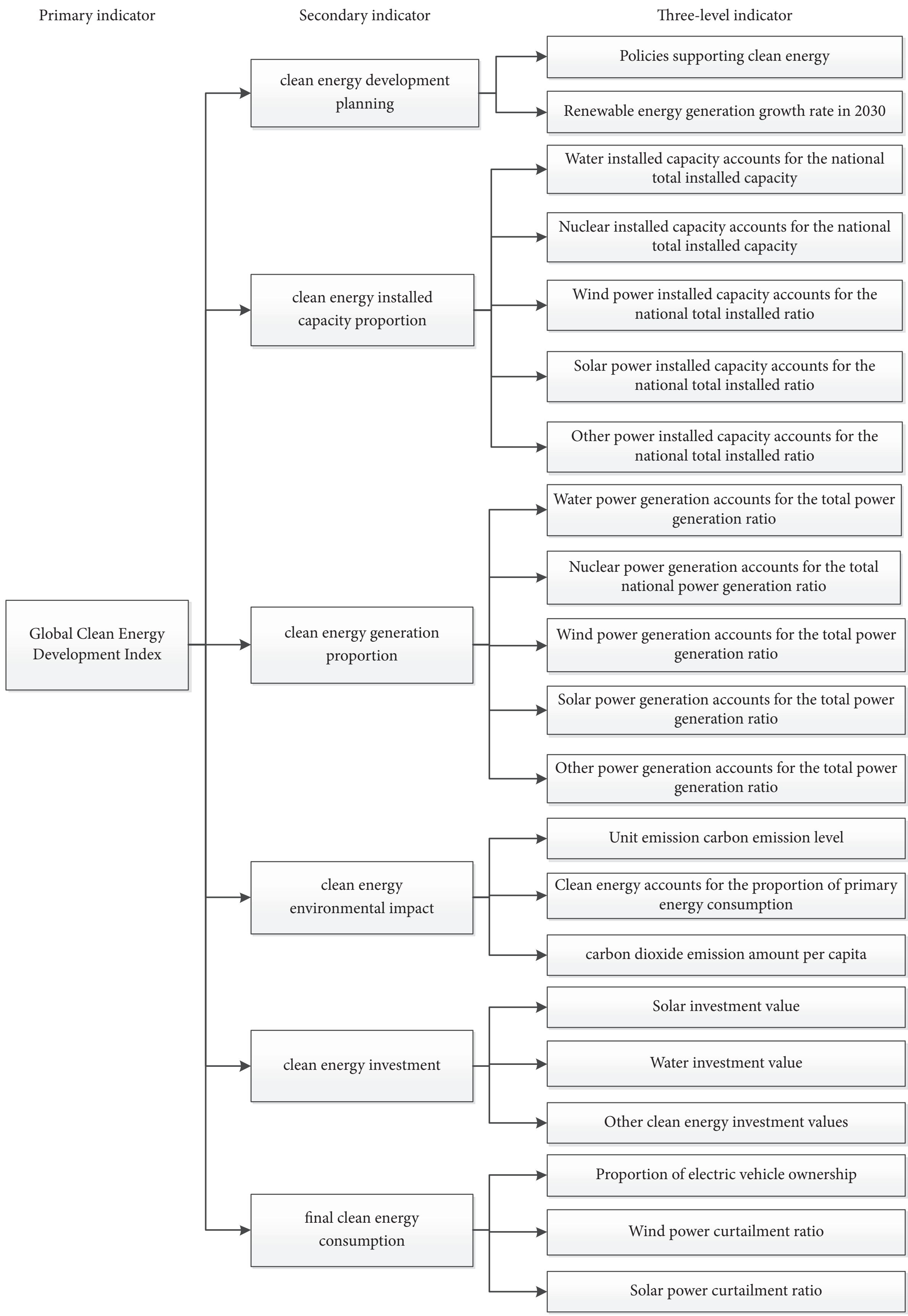

Figure 2: Comprehensive evaluation index system of global clean energy development level.

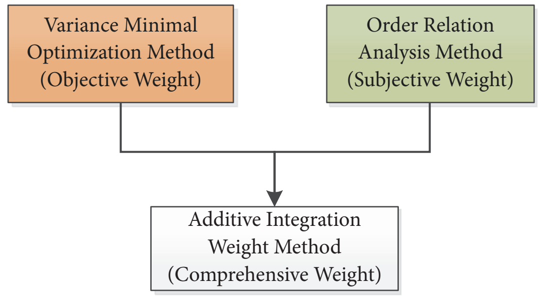

Figure 3: Weight model of global clean energy development level index system.

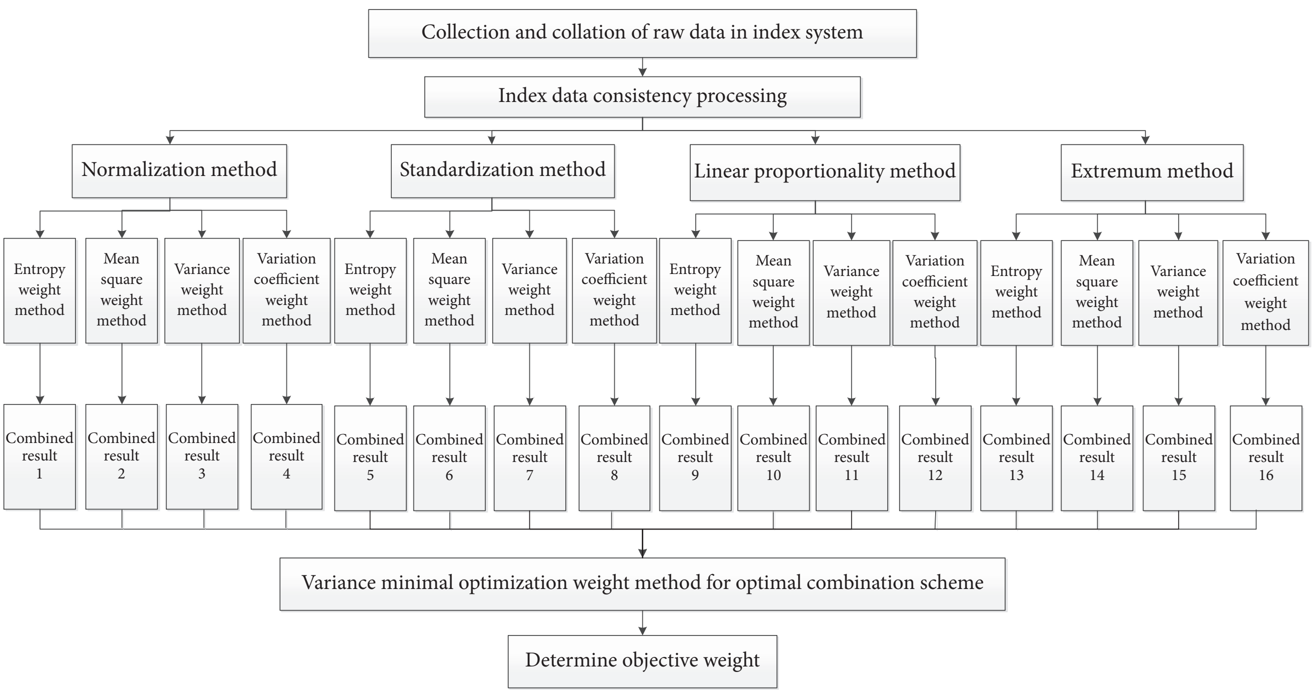

Figure 4: The variance minimal optimization weight model.

social, environmental, energy, resources and other aspects. Therefore, it is very important to choose the appropriate weight method to assign weights to its index system. The difference in index weights will have a large impact on the overall evaluation results. The method of obtaining weights is divided into subjective weighting method and objective weighting method. This paper adopts the idea of combining subjective and objective to obtain the weight of indexes. Therefore, the weight of indexes can include the experience and judgment of experts and fully consider the characteristics of the clean energy development level index system, making the weights more scientific and reasonable.

The comprehensive weight model of global clean energy development level adopted in the paper is shown in Figure 3.

In the weight model, the variance minimal optimization weight model used for subjective weight method is shown in Figure 4.

4.1. G1 Weight Method. According to the expert's score from expert evaluation score table, the G1 method is used to calculate the subjective weight of the global clean energy development level indexes. The steps are as follows [21]:

(1) Establishing the order relationship of indexes based on the results of expert evaluation score table.

(2) Determining the relative importance of adjacent indexes. Setting the importance degree rate of evaluation indexes $x_{k\text{-}1}$ and x_k from experts is shown as (1).

$$r_{\mathrm{k}} = \frac{w_{\mathrm{k}-1}}{w_{\mathrm{k}}}, \quad k = m, m-1, \ldots, 3, 2 \tag{1}$$

where m is the number of evaluation indexes and r_{k} is the relative importance between the k-th index and the k-1-th index. The value of r_k is determined by Table 1, which is given from 1 to 1.8 according to the corresponding importance.

(3) The weight w_{m} of evaluation index x_{m} is calculated according to (2) by using the relative importance degree between the evaluation indexes.

$$w_{\mathrm{m}} = \left(1 + \sum_{\mathrm{j}=2}^{\mathrm{m}} \prod_{\mathrm{i}=\mathrm{j}}^{\mathrm{m}} r_{\mathrm{i}}\right)^{-1} \tag{2}$$

Table 1: Relative importance of evaluation indexes.

r_k	The relative importance between the k-th index and the k-1-th index
1.0	Same important
1.1	Same important - slightly more important
1.2	slightly more important
1.3	slightly more important - more important
1.4	more important
1.5	more important - much more important
1.6	much more important
1.7	much more important - extremely more important
1.8	extremely more important

Then, the corresponding weight of each evaluation index is calculated according to the equation (3) by using the weight wm of the evaluation index xm.

$$w_{k-1} = r_k \times w_k, \quad k = m-1, \ldots, 3, 2 \tag{3}$$

4.2. Variance Minimal Optimization Weight Method. The process of the variance minimal optimization weight method consists of three parts. Firstly, four dimensionless methods are used for dimensionless of indexes data. Secondly, four kinds of objective weight methods are separately used to calculate the index weight based on the dimensionless results. Finally, the variances of 16 groups weight values are calculated and the best group is the scheme with the smallest variance.

4.2.1. Dimensionless Model of Clean Energy Development Indexes. Suppose there are m samples, n evaluation indexes, x_{ij} represents the j-th evaluation index of the i-th sample.

(1) Normalization Method. For the evaluation index x_{ij}, to eliminate the 0 value in x_{ij}, a suitable positive a could be added to translate the data. Let

$$x'_{ij} = a + x_{ij} \tag{4}$$

Then normalize x'_{ij}; let

$$x^*_{ij} = \frac{x'_{ij}}{\sum_{i=1}^{m} x'_{ij}} \tag{5}$$

It requires $\sum_{i=1}^{m} x_{ij} > 0$. When $x_{ij} > 0$, $x^*_{ij} \in (0, 1)$ and $\sum_i x^*_{ij} = 1$.

(2) Standardization Method

$$x^*_{ij} = \frac{\left(x_{ij} - \overline{x_j}\right)}{s_j} \tag{6}$$

where $\overline{x_j}$ is the sample average of the j-th index data; s_j is the sample standard deviation of the j-th index data; x^*_{ij} is the standardize value.

(3) Linear Proportionality Method. For the evaluation index x_{ij}, in order to eliminate the 0 value in x_{ij}, a suitable positive number a can be added to translate the data. Let

$$x'_{ij} = a + x_{ij} \tag{7}$$

Then, let

$$x^*_{ij} = \frac{x'_{ij}}{x^s_j} \tag{8}$$

where x^s_j is the minimum value of the index; x^*_{ij} is the value with dimensionless.

It is known that the value range of x^*_{ij} is $[1, +\infty]$ through the linear proportionality method.

(4) Extremum Method. Through the conformance process, each index data is converted into a maximal index, so the extremum dimensionless method is shown as (9).

$$x^*_{ij} = \frac{x_{ij} - m_j}{M_j - m_j} \tag{9}$$

where $M_j = \max_i\{x_{ij}\}$ and $m_j = \min_i\{x_{ij}\}$.

4.2.2. Calculation of Multiple Objective Weight Methods for Clean Energy Development Level Indexes. According to the four dimensionless results, the objective weights are calculated by entropy weight method, mean square weight method, the variance weight method, and the variation coefficient weight method.

(1) Entropy Weight Method. The steps of the entropy weighting method are as follows:

(1) Calculating the proportion of the i-th country in the j-th index.

$$y_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad \left(0 \le y_{ij} \le 1\right) \tag{10}$$

where y_{ij} represents the contribution of the i-th sample under the j-th index attribute.

(2) Calculating the entropy of the j-th index

$$e_j = -K \times \sum_{i=1}^{m} \left(y_{ij} \times \ln y_{ij}\right) \tag{11}$$

where the constant k generally takes $K = 1/\ln m$, which guarantees $0< e_j <1$.

(3) Calculating information entropy redundancy

$$d_j = 1 - e_j \tag{12}$$

where d_j represents the difference coefficient, indicating inconsistency degree of each project contribution about the j-th index.

(4) Calculating the weights of each index

$$w_j = \frac{d_j}{\sum_{i=1}^{m} d_j} \tag{13}$$

where w_j represents the normalized weight coefficient.

(2) Mean Square Weight Method. The mean square weight w_j is calculated by (14).

$$w_j = \frac{s_j}{\sum_{k=1}^{m} s_k} \tag{14}$$

where s_j is calculated by equation (15) and $\overline{x}_j$ is shown as (16).

$$s_j^2 = \frac{1}{n}\sum_{i=1}^{m}\left(x_{ij} - \overline{x}_j\right)^2 \tag{15}$$

$$\overline{x}_j = \frac{1}{n}\sum_{i=1}^{n} x_{ij} \tag{16}$$

(3) Variance Weight Method. The variance weights w_j is calculated by (17).

$$w_j = \frac{r_j}{\sum_{k=1}^{m} r_k} \tag{17}$$

where r_j is the variance of j-th index, and determined by (18).

$$r_j = \max_{i,k=1,\ldots;i\neq k}\left\{\left|x_{ij} - x_{kj}\right|\right\} \quad (j = 1, 2, \ldots, m) \tag{18}$$

(4) Variation Coefficient Weight Method. The steps of the variation coefficient weight method are as follows:

(1) Calculating the standard deviation σ_k of each index by (19).

$$\sigma_k = \sqrt{\sum_{i=1}^{n}\frac{\left(x_{ik} - \overline{x_k}\right)^2}{n}} \quad (k = 1, 2, \ldots, m) \tag{19}$$

where $\overline{x_k}$ represents the mean of the k-th index.

(2) Calculating the coefficient of variation c_k of each index by (20).

$$c_k = \frac{\sigma_k}{\overline{x_k}} \tag{20}$$

(3) Calculating the weight of each index

$$w_j = \frac{c_j}{\sum_{k=1}^{m} c_k} \tag{21}$$

4.2.3. The Objective Weight Optimization Model Based on Variance Minimal. The weight results of various combination schemes are optimized using the variance minimal optimization weight method. And the combination scheme with the smallest relative variance is chosen as the objective weight of the global clean energy development level.

Suppose there are l combination schemes of dimensionless and weight, p indexes. And the weight of the corresponding index for each combination scheme is represented by w_{jk}. Then k represents the number of evaluation indexes, and j represents the number of dimensionless and weight combination schemes. The variance of each combination scheme can be calculated by (22).

$$D_j = \frac{\sum_{k=1}^{p}\left(w_{jk} - \overline{w_k}\right)^2}{l} \tag{22}$$

where $k = 1, 2, \cdots, p$, $j = 1, 2, \cdots, l$, D_j is the variance of the j-th dimensionless and weight combination scheme. The combination scheme with the smallest variance D is the optimal scheme. The weight of this combination scheme is the objective weight of the global clean energy development level.

4.3. Additive Integration Weight Method for Global Clean Energy Development Level. The additive integration weight method reflects the idea of the composite integration weighting method, namely, organically combines the above two types of weighting methods to determining weight values. The model can simultaneously reflect subjective and objective information. This core idea of the method is to determine the proportion of the weights of different types weights, then calculating the comprehensive weight value based on integrating the different types of weights. The steps of this method are as follows:

Suppose p_j and q_j are the objective and subjective weights of the global clean energy development level. Then, w_j is the comprehensive weight that simultaneously reflects the characteristics of subjective and objective information integration. w_j is determined by (23).

$$w_j = k_1 p_j + k_2 q_j \quad (j = 1, 2, \ldots, n) \tag{23}$$

where k_1, k_2 are undetermined constant, $k_1+k_2=1$ and $k_1 >0$, $k_2 >0$. When the values of k_1 and k_2 make the maximum of $\sum_{i=1}^{m} y_i$, the values of k_1 and k_2 are needed. $\sum_{i=1}^{m} y_i$ is determined by (24).

$$\sum_{i=1}^{m} y_i = \sum_{i=1}^{m}\sum_{j=1}^{n}\left(k_1 p_j + k_2 q_j\right) x_{ij} \tag{24}$$

where m and n represent the number of samples and evaluation indexes, respectively.

5. Comprehensive Evaluation Model of Global Clean Energy Development Level

In the comprehensive evaluation of the clean energy development level, it is necessary to establish a scientific and reasonable comprehensive evaluation model conduct reasonable evaluation. In the construction of the comprehensive evaluation model, considering the characteristics of the evaluation index system covering a wide range and the number of evaluation objects, this paper proposes the following principles for the comprehensive evaluation model of clean energy development level:

(1) Applicability principle: the model should be applied to a large number of evaluation objects and evaluation indexes to meet the requirements of global evaluation. And it can comprehensively carry out analysis and calculation about every characteristics of each index, and achieve balanced evaluation of all indexes in the global clean energy development level index system, and the comprehensive evaluation process is also convenient to calculate.

(2) Measurable principle: the model should be able to measure the level of clean energy development among countries to output scores to rank countries, so that the differences between countries can be visualized.

Based on those principles, the grey relational analysis method and the logarithm range method are chosen to evaluate the global clean energy development level. And the comprehensive evaluation model of global clean energy development level is established using compatibility degree maximization and difference degree minimize model through integrating the advantages of these two evaluation results based on above model.

5.1. Comprehensive Evaluation Model of Clean Energy Development Level Based on Grey Relational Degree Method. While satisfying the principle of evaluation model, the grey correlation degree model uses the grey correlation degree as a theoretical tool to measure the degree of correlation between each evaluation object and the ideal level of global clean energy development. The clean energy development level is better with higher grey relation degree. The grey relational analysis method can effectively solve the problem caused by the grey system attribute of the global clean energy development level. The total character of grey relational analysis method breaks through the frame of contrast between nationals which is commonly used in general system analysis. Instead, all factors are unified in one whole for comparison and analysis, so it has more extensive practical value.

The steps of grey relational model are as follows [22, 23].

First, the optimal value of each index is selected as the reference sequence C_0.

Then, the optimal indexes set and national indexes data are dealt with dimensionless so as to reduce the interference of random factors.

Finally, the correlation coefficient of clean energy development level comparison sequence C_i for reference sequence C_0 on indexes $C_i(j)$ is calculated:

$$\xi i(j) = \frac{\min_i \min_j \left|x_0(j) - x_i(j)\right| + \rho \max_i \max_j \left|x_0(j) - x_i(j)\right|}{\left|x_0(j) - x_i(j)\right| + \rho \max_i \max_j \left|x_0(j) - x_i(j)\right|} \quad (25)$$

where, i=1,2,. . .,n are countries number; j=1,2,. . .,m are the number of evaluation indexes. ρ is resolution coefficient, and its function is to improve the difference between the correlation coefficients. The value of ρ is usually 0.5.

To compare with the overall, it is necessary to focus the correlation coefficient of each index into a value, that is, to calculate its weighted average value, as the quantity of correlation degree. The correlation degree is r_i; it is shown as (26).

$$r_i = \frac{1}{n}\sum_{j=1}^{m} \xi_i(j) \quad (26)$$

Obviously, when r_i is higher, its global clean energy development level is better.

5.2. Comprehensive Evaluation Model of Clean Energy Development Level Based on Logarithmic Range Method. In the meantime of satisfying the principle of evaluation model, the logarithmic range model deals with no difference processing to consistent indexes by introducing magnification factor according to the mathematical theory and then carries on the linear weighted comprehensive evaluation. The logarithmic range method can reduce the excessive difference of evaluation result caused by the excessive peak value of some data in the evaluation object. At the same time, the global clean energy development level of each country can be judged from whole angles to reflect the overall evaluation results.

The steps of the logarithmic range model are as follows:

First, Logarithmic Range Method is performed using (27) and (28) for the benefit type index and cost type index, respectively, and the logarithmic range matrix $[X]_{mn}$ is obtained.

$$x_{mi} = 100 \times \frac{\log\left[C \times I_{mi} + a\right] - \log\left[C \times \min\left(I_i\right) + a\right]}{\log\left[C \times \max\left(I_i\right) + a\right] - \log\left[C \times \min\left(I_i\right) + a\right]} \quad (27)$$

$$x_{mi} = 100 \times \frac{\log\left[C \times \max\left(I_i\right) + a\right] - \log\left[C \times I_{mi} + a\right]}{\log\left[C \times \max\left(I_i\right) + a\right] - \log\left[C \times \min\left(I_i\right) + a\right]} \quad (28)$$

$$[X]_{mn} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & \cdots & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (29)$$

where x_{mi} is the score of the i-th index of country m-th; I_{mi} is the original data of i-th index of country m-th; $\min(I_i)$ is the minimum of countries data; $\max(I_i)$ is the maximum of countries data; C is the amplification coefficient of the original data of indexes; a is the translation coefficient.

The global clean energy development indexes $[D]_{n1}$ are calculated according to the logarithmic range matrix $[X]_{mn}$

TABLE 2: Evaluation object selection table.

continent	country
North America	United States (1#), Canada (2#), Mexico (3#)
Oceania	New Zealand (4#), Australia (5#)
Africa	Tanzania (6#), Nigeria (7#), South Africa (8#), Mozambique (9#), Morocco (10#), Kenya (11#), Ghana (12#), Angola (13#), Egypt (14#), Algeria (15#)
South America	Chile (16#), Venezuela (17#), Peru (18#), Colombia (19#), Brazil (20#), Argentina (21#)
Europe	United Kingdom (22#), Italy (23#), Greece (24#), Spain (25#), Ukraine (26#), Slovenia (27#), Slovakia (28#), Switzerland (29#), Sweden (30#), Portugal (31#), Norway (32#), Romania (33#), Croatia (34#), Czech Republic (35#), Netherlands (36#), Finland (37#), France (38#), Germany (39#), Denmark (40#), Poland (41#), Belgium (42#), Bulgaria (43#), Austria (44#), Ireland (45#)
Asia	China (46#), Vietnam (47#), Indonesia (48#), India (49#), Israel (50#), Iran (51#), Iraq (52#), Syria (53#), Singapore (54#), Turkey (55#), Thailand (56#), Saudi Arabia (57#), Japan (58#), Malaysia (59#), Qatar (60#), Korea (61#), Kazakhstan (62#), Philippines (63#), Russia (64#), Pakistan (65#), United Arab Emirates (66#)

and evaluation indexes weight matrix $[W]_{\mathrm{n1}}$. The equation is as follows:

$$[D]_{\mathrm{m1}} = [X]_{\mathrm{mn}} \times [W]_{\mathrm{n1}} \tag{30}$$

5.3. Comprehensive Evaluation Model of Clean Energy Development Level Based on Compatibility Degree Maximization and Difference Degree Minimize Method. The compatibility degree maximization and difference degree minimize model could provide optimized integration scheme from multiple evaluation scheme. It can make the comprehensive evaluation model more scientific, fair, and reasonable and more in line with the requirements of modern scientific decision-making.

First, the compatibility degree and difference degree of h-1 evaluation schemes are defined; the equations are as shown in (30) and (31):

$$r_{\mathrm{k}} = \sum_{\mathrm{j=1}}^{\mathrm{h}} \left(w_{\mathrm{j}} \times ri_{\mathrm{j}}\right) \tag{31}$$

$$d_{\mathrm{y}} = \frac{1}{h}\sum_{\mathrm{j=1}}^{\mathrm{h}} d_{\mathrm{yj}} \tag{32}$$

where, $\sum_{\mathrm{j=1}}^{\mathrm{h}} w_{\mathrm{j}} = 1, w_{\mathrm{j}} > 0$ are the weight of the j evaluation scheme, the value usually is $1/h$. d_y is the difference degree between a multiattribute evaluation scheme and other h multiattribute evaluation; d_{yj} is the number of countries whose multiattribute evaluation schemes in a certain number range, and the number of countries exceed the number range in the j multiattribute evaluation schemes. r_{ij} is the rank correlation coefficient of each evaluation scheme and can be calculated by the equation (33).

$$r_{\mathrm{ij}} = 1 - \frac{6}{n\left(n^2-1\right)} \sum_{\mathrm{k=1}}^{\mathrm{n}} \left(a_{\mathrm{k}}^{(\mathrm{i})} - a_{\mathrm{k}}^{(\mathrm{j})}\right)^2 \qquad (i, j = 1, 2, \ldots, h+1) \tag{33}$$

where $a_{\mathrm{k}}^{(\mathrm{i})}, a_{\mathrm{k}}^{(\mathrm{j})}$ represent the index of the k-th country in the i and j schemes.

Then, the index of compatibility degree maximization and difference degree minimize method is calculated. Setting a new evaluation scheme x=x_t, according to the scope of each classification, the difference degree is minimized, and the compatibility degree is great. That is shown as (34).

$$\max_{\{x_{\mathrm{t}} \mid t \in D_{\mathrm{xk}}\}} r_{\mathrm{x}}^{(\mathrm{k})} = \left[\min_{\{x_{\mathrm{t}} \mid t \in \bigcup_{\mathrm{i=0}}^{\mathrm{k-1}} D_{\mathrm{i}}\}} d_{\mathrm{xk}}\right], \quad k = 1, 2, \ldots L \tag{34}$$

where d_{xk} is the difference degree of x_{t} in class k, $r_{\mathrm{x}}^{(\mathrm{k})}$ is the compatibility degree of x_{t} in class k, D_{xk} is the candidate set of D_{k}, and L is the number of evaluation scheme classification. So the serial number range is $(M_{\mathrm{k-1}}, M_{\mathrm{k}}]$, k=1,2,. . .,L, M_0=0, M_{L}=n. $D_{\mathrm{k}} = \{t \mid M_{\mathrm{k-1}} < t \leq M_{\mathrm{k}}\}$; D_0=Φ is the set of object numbers in class k when x_{t} is the benchmark scheme.

Finally, the compatibility degree and the difference degree of various evaluation schemes are obtained, and the scheme with the maximal compatibility degree and the least difference degree is chosen as the final evaluation scheme.

6. Empirical Analysis

6.1. Basic Data. To drop the relevance among indexes and elevate the scientificity of index system and the accuracy of evaluation, this paper establishes the questionnaire rely on the index system shown in Section 2. And conduct survey to 37 experts in clean energy sector using Delphi method. Then delete the indexes having little effect on comprehensive evaluation result according to the consequence of Delphi method.

Using subjective filtering methods, the filtered comprehensive evaluation index system of global clean energy development level is obtained, as is shown in Figure 5.

This paper selects 66 representative countries in the world according to the situation of national economic development and the availability of index data. The specific country selection and continent classification are shown in Table 2. Obtain the corresponding index data in the way that search and collect data of these countries in the IEA (international Energy Agency) database and global energy research unified platform database of State Grid.

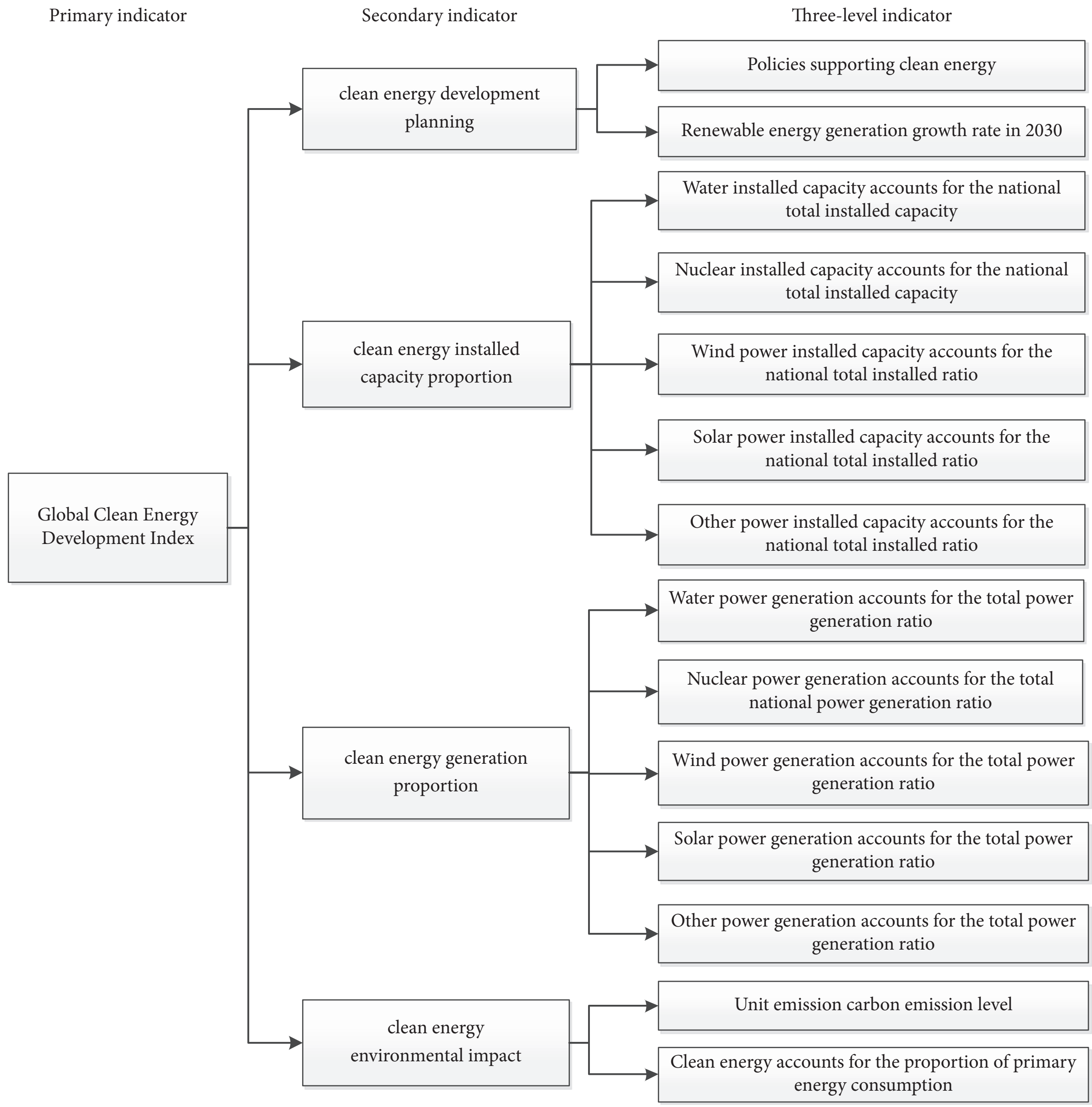

Figure 5: Filtered comprehensive evaluation index system of global clean energy development level.

6.2. Comprehensive Evaluation Results and Analysis

6.2.1. Comprehensive Evaluation Model Results of Global Clean Energy Development Level

(1) Application of Weight Model. In terms of subjective weight, this paper is based on the weight model constructed in Section 3, aiming at selected index systems to establish questionnaire, calculating the scores of clean energy experts with G1-method to conduct index subjective weight amount.

In terms of objective weight, the text adopts variance minimal optimization weighting method to obtain the variance from the weights of 10 combined methods calculated by dimensionless and weight method. Then rank the combined schemes with the variance from big to small. The ranking is shown as Table 3.

As is shown in the table, standardization-variance scheme conduct minimizes variance, which means the objective weight's difference degree is minimized in frequently used dimensionless method and weighted method. It also means the weighted result is more objective and representative. So it uses this combined method's weight to be the objective weight of global clean energy development level.

Finally, using the additive integration weight method to calculate comprehensive weight by carrying out the percent subjective weight accounts for comprehensive weight and the percent of subjective weight accounts for comprehensive weight. Then make the integration of weights to obtain the

Table 3: Variance of dimensionless and weight combination scheme.

Combination Scheme	Variance	Ranking
Normalization-mean square	0.004	2
Normalization-variance	0.011	8
Normalization-variation coefficient	0.008	4
Normalization-entropy	0.025	9
Standardization-variance	0.004	1
Linear proportionality-mean square	0.009	6
Linear proportionality-variance	0.026	10
Linear proportionality-variation coefficient	0.005	3
Extremum-mean square	0.010	7
Extremum-variation coefficient	0.008	5

Table 4: Weight of global clean energy development level evaluation indexes.

Index	Weight
Policies supporting clean energy	0.053
Renewable energy generation growth rate in 2030	0.077
Water installed capacity accounts for the national total installed capacity	0.057
Nuclear installed capacity accounts for the national total installed capacity	0.071
Wind power installed capacity accounts for the national total installed ratio	0.069
Solar power installed capacity accounts for the national total installed ratio	0.063
Other power installed capacity accounts for the national total installed ratio	0.099
Water power generation accounts for the total power generation ratio	0.057
Nuclear power generation accounts for the total national power generation ratio	0.062
Wind power generation accounts for the total power generation ratio	0.082
Solar power generation accounts for the total power generation ratio	0.061
Other power generation accounts for the total power generation ratio	0.081
Unit emission carbon emission level	0.112
Clean energy accounts for the proportion of primary energy consumption	0.054

Table 5: Compatibility degree and difference degree of evaluation models' results.

Method	Compatibility Degree	Ranking	Difference Degree	Ranking
Grey Relational Degree Method	0.615	3	1.667	1
Logarithmic Range Method	0.712	2	1.333	2
Compatibility Degree Maximization and Difference Degree Minimize Method	0.879	1	1	3

comprehensive weight of clean energy development level, as shown in Table 4.

(2) Application of Comprehensive Evaluation Model. Use selected index system to do the calculation of weighted model and comprehensive evaluation model, and obtain the counties index of Grey Correlation Degree Methodfbfhlog-arithmic range method and compatibility degree maximize range method. Then calculate the compatibility degree and difference degree from the index results of three models; the result is shown as in Table 5.

Through the calculation of the weighted model and the comprehensive evaluation model, the maximization compatibility and minimization difference degree model has the largest compatibility and the smallest difference and thus the final global clean energy development level index. The indexes of clean energy development levels in each country are classified and compared according to continents. The global clean energy development level of the countries in Europe and America is shown in Figure 6. The global clean energy development levels of the countries in Asia, Africa, and Oceania are shown in Figure 7.

6.2.2. Spatial Distribution of Global Clean Energy Development Level. Due to the different distribution of resources in various countries and different economic development conditions, the development level of clean energy varies greatly from country to country. After obtaining the indexes

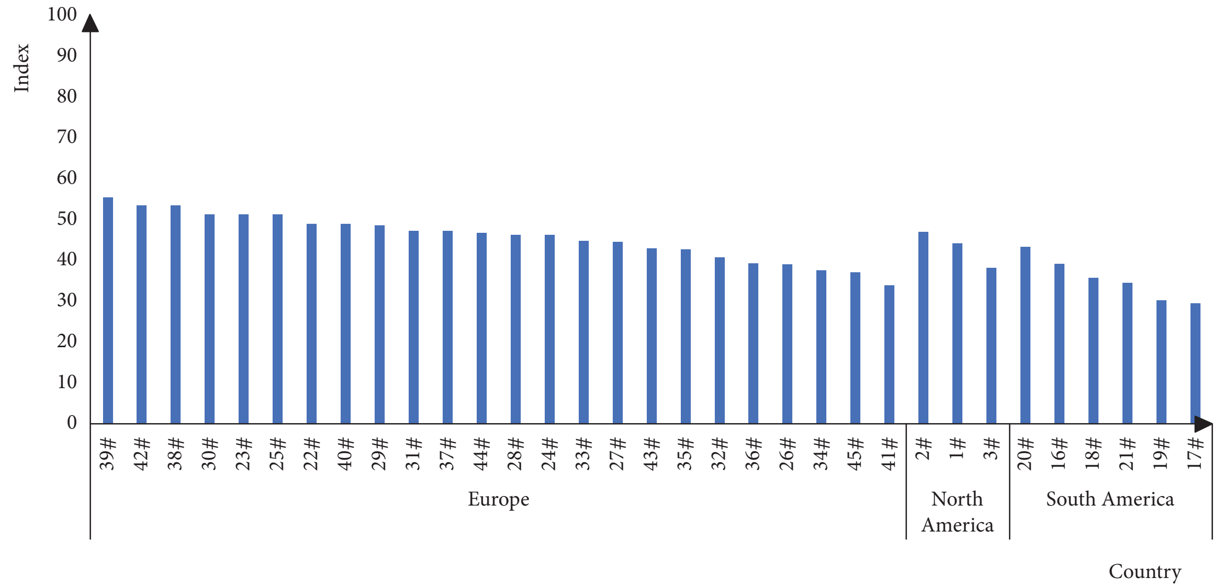

Figure 6: Global clean energy development level of European American countries.

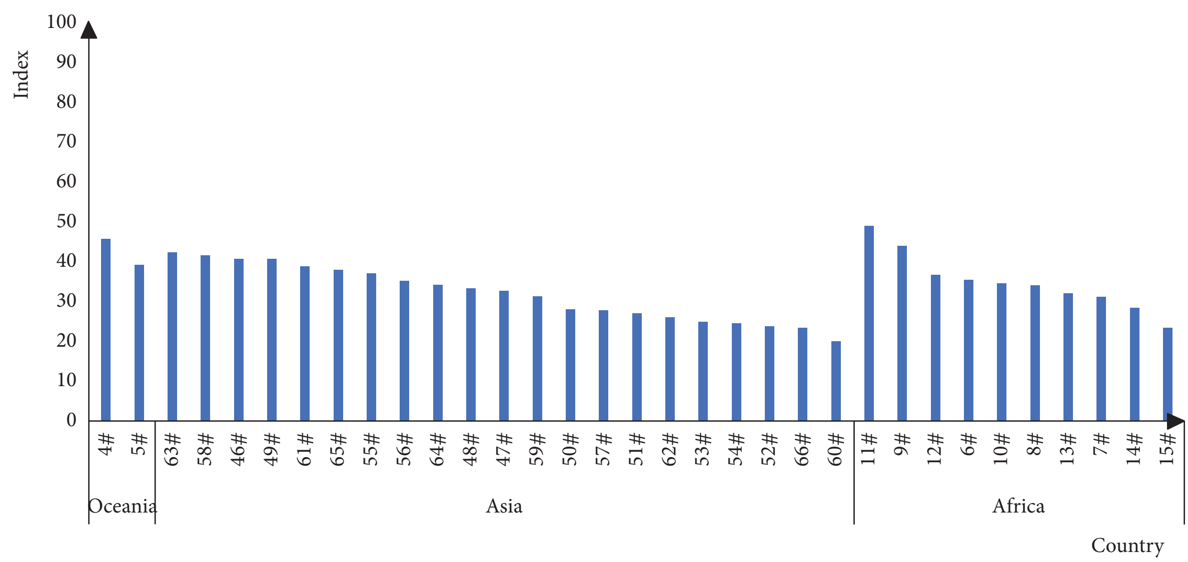

Figure 7: Global clean energy development level of Oceanian, Asian, and African countries.

of clean energy development levels in each country, the spatial distribution of the global clean energy development level is expressed by color in order to visually show the differences of clean energy development levels in various countries around the world. The higher level of country's clean energy development, the darker the country's map color, and vice versa. It is shown in Figure 8.

From the intercontinental point of view, countries with dark blue colors are mainly concentrated in Europe, while parts of the Americas and parts of Oceania have relatively high levels of clean energy development, while the overall level of clean energy development in Asia and Africa is relatively low.

Countries in Europe have a high clean energy development index. The average score of Europe is 46 points, the highest score of 39# in Europe is 55 points, and the difference between the highest index country and the lowest index country is 22 points. North America has a good level of clean energy development, with an average score of 43 in North America and North America's best-developed 2# gets 47 points which higher 8 points than the lowest country. The development index of clean energy in three North American countries is higher than 38 points. Oceania also has a good level of clean energy development, with an overall average score of 42, and the highest index 4#country has a score of 45, which is 7 points different from the second country–5#.

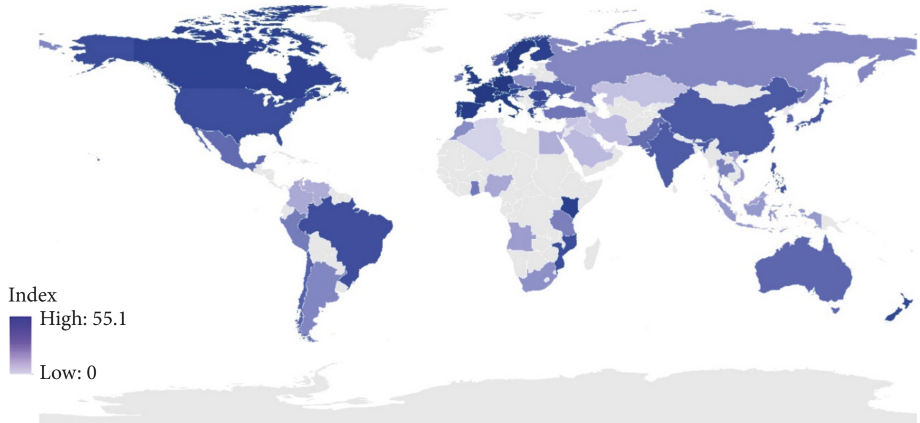

Figure 8: Spatial distribution map of the global clean energy development level.

The clean energy development index in Oceania countries is above 39 points. South America has a general index of clean energy development, with an overall average score of 35, and the best-developed country 20# has a score of 43, 14 points higher than the lowest index country. The development index of clean energy in Africa is general, with an average score of 35 totally. The index score of country 11# is 48, which is 25 points above that of the countries with the lowest index score. There is a big difference in the development level of clean energy between countries. The level of clean energy development in Asia is general, with an overall average score of 32 points, countries 46 #, 49 #, and 58 # ranking first and scoring 41 points, which are 22 points different from the lowest score countries, and the level of clean energy development among countries is quite different.

6.2.3. Regional Evaluation of Global Clean Energy Development Level. The clean energy development level in each country is evaluated. Then, based on the classification of countries by continent, the indexes of clean energy development in all continents are ranked in Europe, America, Oceania, Africa, and Asia.

Europe has a relatively developed economic level and a better regional integration. European infrastructure of energy and electric is good. And in recent years, Europe has been promoting energy transformation, energy conservation, and emission reduction related policies and measures, so Europe ranks first in the global clean energy development level of continents.

America has abundant clean energy resources and a high level of clean energy development, but it still has huge spaces to development clean energy. The clean energy development in North America started earlier and the clean energy generation proportion of South America is relatively high, so America ranks second in the global clean energy development level of continents.

Oceania has a relatively developed economy, abundant clean energy resources, and complete electric power infrastructure. Countries in Oceania have a good fundamental condition for clean energy development, so Oceania ranks third in the global clean energy development level of continents.

There are many countries in Africa; some of them have complete electric power infrastructure, but many regions in Africa have not yet been connected to electricity, so Africa ranks fourth in the global clean energy development level of continents.

Asia is a vast region with a large number of countries. There are obvious differences in geographic morphology and resource storage among different countries, and the characteristics of energy structure are quite different. Among Asia, the electric power infrastructure of East and West Asian countries is relatively better and electricity consumption is increasing rapidly. Although the power demand of most countries is booming, these countries are still committed to promoting the development of clean energy. The level of clean energy development in East Asia is high, while the power infrastructure of Southeast Asian countries is relatively backward. With the economy growing in these countries rapidly, the demand for electric power grows quickly that caused great dependence on fossil energy consumption; as a result, the development of clean energy in Southeast Asia is slow. In Central and South Asia, there are huge resources of oil, gas, and solar energy, but most countries still rely on fossil energy so the clean energy development level of these regions is relatively backward. Therefore, Asia ranks the fifth in the global clean energy development level of continents.

7. Conclusions and Suggestions

Under the context of rapidly global clean energy development, the paper proposes the comprehensive evaluation model based on the maximization compatibility and minimization difference degree model. And the related conclusion and suggestions are as follows.

(1) About the evaluation indexes system, this paper innovatively established the principle that construct the index system of clean energy development level through combining with the SMART principle and the development characteristics of clean energy. Based on those principles, this paper sets four secondary indexes for clean energy development level and 21 three-level indexes. The four secondary indexes are clean energy development planning, clean energy installed

capacity proportion, clean energy generation proportion, and environmental impact.

(2) Regarding the indexes weight model of clean energy development level, the conclusion is drawn: in the dimensionless and objective weight method combination schemes, the dispersion degree of standardization-variance scheme is the smallest in combination schemes, and it can represent the stable weighted level of clean energy development level in each index.

(3) About the comprehensive evaluation model, this paper uses the compatibility maximization and difference minimization degree model innovatively which different from the previous study, and gets the index which has the maximal compatibility degree and the least difference degree among the four evaluation results, so choosing this result as the index of the global clean energy development level. Then the feasibility of this method is verified through practical examples to make evaluation results more accord with the actual. It provides a novel method for comprehensively evaluating the development level of clean energy.

(4) From the results of empirical analysis, we can see that global energy consumption has entered a new stage of transformation and development, and clean energy is an important way to promote low-carbon clean energy development and achieve energy transformation and upgrading. At present, the development of clean energy is not balanced on all continents, and the level is uneven in different countries. Most developing countries have a generally low awareness of environmental protection. Due to the rapid development of the national economy and the need for a large amount of energy investment, energy consumption tends to be fossil energy sources with lower economic cost and higher availability. As a result, the investment in renewable energy research is low; hence the level is poor.

(5) By combining the characteristics of global energy Internet and clean energy development, this paper establishes a comprehensive evaluation model of clean energy development level, and then conducts a comprehensive and systematic evaluation of clean energy development level. It enables the government, enterprises, the public, and other social entities to more fully and correctly understand the economic, social, and ecological benefits of clean energy development and help people grasp the development direction of the world's clean energy, scientific research, and the world's clean energy development pattern and correctly determine the clean energy development route. And it is of great theoretical and practical significance for promoting the development of the Belt and Road and the construction of the global energy Internet.

In the future research, the calculation of weight method can combine more kinds of dimensionless methods and objective weighting methods based on variance minimal optimization weighting method, which can make the objective weight more reliable. In the comprehensive evaluation, with the further development of scientific research, the index data will be more complete and more accurate, which can make the results of the research model more objective and the evaluation results more practical.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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