Key Indicators Analysis Approach for Green Power Considering Contributed Characteristics

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Abstract. Key green power indicators are information which can intuitively reflect the status of green power construction in a region. Selecting reasonable key indicators will help to identify weak link the development of green power, and promote the development of clean energy and power systems. A multi-dimensional quantitative analysis method for key green power indicators is proposed in this paper. First of all, this paper designed a set of indicators starting from the different links of power supply, grid and load. The indicator set includes three dimensions: green power development, green energy sharing and green power living, and the selecting method key green power indicators is established. Then, from the aspects of indicator score and indicator weight, a model for quantitatively evaluating the development level of green power was constructed to analyze the development week link of green power. Finally, the effectiveness and feasibility of the proposed method are verified by using the indicator data of Qinghai Province. Qinghai's green power development level and development trend are quantified. The development balance of different links of green power was analyzed, and the constructed indicators are used to obtain the weak links of Qinghai's green power development. The calculation examples show that the evaluation and analysis method proposed in this paper can help to quantify the level of green power development and guide the coordinated development of various construction parts.

1. Introduction
Under increasingly serious environmental issues and the energy crisis, vigorously developing renewable energy represented by wind power and solar power, and achieving a low-carbon and sustainable energy supply and energy consumption system is the effective way for China and the world to transition from green to low-carbon energy. It can be seen that the transition from energy to green and low-carbon has become an inevitable trend [1-2]. It is important for promoting the large-scale development of renewable energy and building a more reasonable national energy system to actively consume clean energy and increase the proportion of clean energy. Therefore, it is necessary to take the green and low-carbon research of electricity as an entry point to measure the level of clean energy transformation and investigate the situation of green sustainable development [3-4]. Research on green and low carbon is mainly focused on three aspects. Firstly, the evaluation of green and low carbon development is studied in the national or regional. In
[5-6], a provincial green development level indicator system is built, and the green development level of Hubei Province and Qinghai Province are measured. Secondly, the evaluation of green development in the industry is proposed. In [7], a green development evaluation indicators system is established by Naiming Zhang in the agricultural field, the evaluation indicator system was verified and applied by using the 2014 data of five counties (cities and districts) for Baoshan City. Finally, green development in the energy sector is studied. In [8], it builds an indicator model covering the three dimensions of energy, resources, and environment, and evaluate the green development of different power generation methods in the power system. Green development level evaluations method are mainly concentrated at the regional and industry.

Above all, the current green development level research basically maintain in the field and industry level, and the evaluation of green energy is still at the exploring stage. In [9], a green hydropower indicator evaluation system is established, including hydrological characteristics, river water environment, river shape, and river connectivity. The characteristics of green development of hydropower station are obtained by analytic hierarchy process and fuzzy synthetic evaluation method. In [10], the urban green power indicator system has been established from energy interconnection. A comprehensive evaluation of the green degree of electrical energy was carried out by taking a city as an example. The above studies are mostly focused on single-indicator evaluation and analysis of power production, transmission, or consumption, and rarely take into account the power source and grid load. At the same time, the selection of key green power indicators can have an important guiding in the promotion of clean energy consumption and changes in public consumption habits. In [11], affect the decision-making of construction and the evaluation model of decision-making is built, the key indicator that satisfies the decision maker was obtained by the theory of bilayer interactive finite rational decision. The above-mentioned literature provides ideas for selecting key indicators of distributed wind power development and construction, but we can less attention to information that the public is more concerned about and can more intuitively reflect the key green power indicators under different links.

Therefore, this paper proposed a key green power indicator quantitative evaluation analysis method. The indicator set includes three dimensions: green power development, green energy sharing and green power living. On this basis, a quantitative evaluation method for key green power indicators is established, and then a quantitative model of the development level of green power is built. Finally, the weak links in the development of clean energy is obtained by using the proposed method, and then we can provide references for green power improvement.

This paper is organized as follows: The Green Power Index System is presented in Section II. The Evaluation Method of Green Power Indicator is discussed in Section III. In Section IV, the effectiveness and feasibility performance of the proposed method is examined in the indicator data of Qinghai Province for 2015, 2016, 2017, 2018, and 2019. Section VI is the conclusion.

2. Green Power Index System

2.1. Green power index system architecture

The core indicator of the green power indicator system is the green power index, which comprehensively reflects the overall level of green power development, covering the entire process of power production, transmission, and consumption, including thirty-four basic indicators of the three dimensions of green power development, green energy sharing, and Green power living. The green power indicator framework is shown in figure 1.

Green power development reflects the energy structure optimization and the technical level of power production. Green energy sharing reflects the improvement of the technical level of power transmission, the improvement of consumption level, and the optimization of the grid structure. Green power living reflects the improvement of technology level, optimization of energy consumption structure, the rise of consumption level.
2.2. Key indicator evaluation
The key indicators are third-level indicators is making downward on the overall development level of green power and restricting the rise of the green power indicator. To quantify the restrictive effect of the indicator on the green power indicator, the contribution of the indicator to the green power index within time is used. Therefore, the contribution of the indicator to the green power indicator is obtained from the change of the indicator score and the third-level weight and the second-level weight of the indicator. The expression is as follows:

\[ \Delta S_i = (s_{2019} - s_{2015}) \cdot c_i \cdot w_j \]  \hspace{1cm} (1)

where, \( \Delta S_i \) is the contribution to the green power indicator within the time range specified by the \( i \)th third-level indicators. In this paper, the indicator whose contribution value is less than -0.5 is selected as the key indicator; \( c_i \) is the combined weight of the indicator; \( w_j \) is the weight of the secondary indicator.

3. Evaluation Method of Green Power index

3.1. Green power index scoring method
In the green power indicator system, the connotation, dimension, and nature (positive and negative) of each indicator are different. Under different backgrounds of each indicator, the same value may also represent different levels of development. Therefore, the double-benchmark progressive method is used.

The double-benchmark progressive method sets two (A, C) benchmark values of the indicator. The A is generally one hundred points when the indicator is standardized, and the C is sixty points after the indicator is standardized. Then the score expression corresponding to indicator value \( x_i \) is as follows:

\[ S_i = (X_i - C) \times \frac{S_A - S_C}{A - C} + S_C \]  \hspace{1cm} (2)

where, \( X_i \) is an indicator value; \( S_A \) and \( S_C \) are the score values of of indicator normalized, respectively.

3.2. Weighting method of Green power indicator

Weighting method of third-level indicator
To make the evaluation results of the third-level indicators more in line with subjective expectations, the assignment method combining the maximum deviation method and the expert evaluation method
(Delphi method) is used as the third-level indicator weighting method. Then the combined weight \( W_j \) is calculated as follows:

\[
W_j = \frac{\alpha \cdot \gamma_j + (1-\alpha) \cdot \hat{W}_j}{\sum_{j=1}^{n} [\alpha \cdot \gamma_j + (1-\alpha) \cdot \hat{W}_j^*]}
\]

where, \( \hat{W}_j^* \) is the weight of the dispersion maximization method; \( \gamma_j \) is the weight of the expert evaluation method; \( \alpha \) is the subjective bias coefficient, which describes the combination of the two evaluation methods. When \( \alpha=1 \) or \( \alpha=0 \) are the expert evaluation method and the dispersion maximization method, respectively.

**Weighting method of Second-level indicator**

The number of secondary-level indicators is small and belongs to qualitative indicators. The consistency is obvious when the analytic hierarchy process is used in this paper. The analytic hierarchy process includes three calculation: establishing a hierarchical structure model, constructing the judgment matrix and checking consistency.

1. Establishing a hierarchical structure model
   According to the relationship between them, the objectives, factors (decision criteria), and decision objects of decision-making are divided into the highest layer, the middle layer, and the lowest layer, and a hierarchical structure diagram is drawn.

2. Constructing the judgment matrix
   The judgment matrix can be obtained by ranking their importance which can compare each program in pairs. The judgment matrix has the following properties:

\[
a_{ij} = \frac{1}{a_{ij}}
\]

where, \( a_{ij} \) is the comparison result of the importance of element \( i \) and \( j \).

3. Checking consistency
   The hierarchical single ranking is based on the judgment matrix \( A \), the ranking weight of the relative importance of the factors of the same level to the factors of the previous level. The largest characteristic root of the positive reciprocal matrix \( A \) of order \( n \) is \( \lambda \) (\( \lambda \geq n \)). If \( \lambda = n \), \( A \) is a consistent matrix. The consistency indicator \( CI \) is used to measure the inconsistency of matrix \( A \). To measure the size of \( CI \), the random consistency indicator \( RI \) is introduced as follow:

\[
RI = \frac{CI_1 + CI_2 + ... + CI_n}{n}
\]

Second, the test coefficient \( CR \) can be obtained by comparing \( CI \) with the random consistency indicator \( RI \). If \( CR < 0.1 \), the judgment matrix is considered to satisfactory consistency, otherwise it will not satisfy consistency.

**4. Example analysis**

Qinghai’s renewable energy resources are endowed with abundant clean energy resources such as solar energy, water energy, and wind energy. Qinghai Energy’s green and low-carbon transformation have complete policy, adheres to the priority of ecological protection, leads the development of green power, refreshes the duration of fully clean energy power supply, and forms a Chinese sample of green power development. Based on this, the effectiveness and feasibility of the proposed method are verified by using the indicator data of Qinghai Province for 2015, 2016, 2017, 2018, and 2019.

**4.1. Green power development balance**

The second-level index score and the green power index score are obtained by used the combination assignment method to obtain, as shown in figures 2 and 3.

As can be seen from Figure 2, the development level of green power development, green energy sharing, and Green power living in Qinghai Province have been improved. Green power development
indicators have the highest overall score. The green energy sharing indicator scored the second-highest, it obtains 73.27 points in 2019, the average annual growth rate is 5.39%, the green energy sharing still has great potential for improvement. The overall score of the green power living Indicator is the lowest, the average annual growth rate is 2.60%, the score shows a steady growth trend. In summary, the changes in secondary-level indicators can be summarized as follows: Green power development indicators have increased significantly, and green energy sharing and Green power living indicators are continuing to rise. In summary, the changes in secondary-level indicators can be summarized as follows: Green power development indicators have increased significantly, green energy sharing and Green power living indicators have been continuing to rise.

As can be seen from figure 3, according to the development of the five-year green power index, it can be seen that during the "13th Five-Year Plan" period, the green power index in Qinghai Province has been steadily increasing year by year. The level of green power development has gradually improved, it increased from 63.48 points in 2015 to 68.01 points in 2019. The growth rate is 7.14%. In 2017 and 2018, Qinghai launched the "Green Power 7th day" and "Green Power 9th day" all clean energy (solar, wind, and hydropower) power supply activities to achieve zero electricity consumption. At the same time, according to the changing trend of the green power index obtained by the evaluation model, it can be seen that this model can effectively reflect the positive accumulation of clean energy development in Qinghai in recent years. Therefore, the combined assignment method is more in line with the situation, reflecting the development level of green power in Qinghai.

It can be seen from figure 4, the green development of the three links of power production, transmission, and consumption is highly uneven. Clean and efficient power production and reduced pollutant emissions have enabled green power development to get the highest score. The increased proportion of clean power and the application of flexible and intelligent control of the grid side has enabled green energy sharing to obtain a higher score. The lowest score for Green power living is the weak link in the development of green power in Qinghai. In the future, Qinghai Province should vigorously develop green power living and increase the overall score of the green power index.
4.2. Analysis of key green power indicators
The negative contribution increment of the third-level index to the green power index for Qinghai obtained by Equation (1), The negative contribution increment is shown in Table 1. It can be seen from Table 1 that the contribution of a total of 8 third-level indicators is negative. The sum of the negative increments for Solar energy utilization efficiency, water energy utilization efficiency, and wind energy utilization efficiency is -2.363 points and accounts for 92.9% of the total negative contribution. It can be seen that these three indicators play a major role in restricting the scores of the green energy sharing indicator and the green power index. Therefore, the three indicators of solar energy utilization efficiency, water energy utilization efficiency and wind energy utilization efficiency can be regarded as key indicators. At the same time, the problem of wind power, photovoltaic power and hydropower curtailment in Qinghai Province has not been effectively resolved, that is, the local consumption capacity is insufficient.

Table 1. The negative contribution Incremental to the green power index in the third-level indicators.

| secondary-level indicators | third-level indicators                      | increment |
|---------------------------|--------------------------------------------|-----------|
| Green power development   | Wind power production ratio                | -0.004    |
|                           | Solar production ratio                      | -0.003    |
|                           | Wind energy efficiency                      | -0.186    |
| Green energy sharing      | Solar energy efficiency                     | -1.275    |
|                           | Water energy efficiency                     | -0.902    |
|                           | Comprehensive line loss rate of the power grid | -0.075  |
|                           | The demand-side response load ratio         | -0.017    |
| Green power living        | Electricity consumption per unit of GDP     | -0.081    |

4.3. Analysis of the influencing factors of key indicators
The development trend of new energy indicators, change of the wind power curtailment, photovoltaic power curtailment and hydropower curtailment indicators, and the ratio of total installed power to maximum load power are shown in figure 5, figure 6 and figure 7, respectively.

Figure 5. Development trend of new energy indicators
Figure 6. Change of wind, photovoltaic and hydropower curtailment
Figure 7. Ratio of total installed power supply to the maximum load power
It can be seen from Figure 5 that Qinghai renewable energy has shown a rapid growth trend, which is consistent with the continuous investment of renewable energy in Qinghai. It can be seen from Figure 6 that the "the wind power curtailment, photovoltaic power curtailment and hydropower curtailment" indicators show an increasing trend. The wind abandonment rate has increased slightly, and the abandonment rate and water abandonment rate have increased significantly. It can be seen from Figure 7 that the growth rate of power installed capacity is significantly faster than the growth rate of the load power. Due to the lack of space for the consumption of renewable energy in Qinghai, the " the wind power curtailment, photovoltaic power curtailment and hydropower curtailment" indicators show an increasing trend. Secondly, the insufficient transmission capacity of Qinghai's new energy and the weak peak-shaving capacity of Qinghai Power Grid can also make the wind power curtailment, photovoltaic power curtailment and hydropower curtailment indicators show an increasing trend.

5. Conclusion
Considering contributed characteristics of green power index, key indicators analysis approach for green power is proposed. A three-dimensional indicator set was designed from the power supply, grid and load including green power development, green energy sharing, and Green power living. A quantitative evaluation method for key green power indicators was established. And then, the development level model of green power was constructed by indicator scores and indicator weights. The level of clean energy development was analysed by using the model of green power. Finally, Qinghai Province was used as an example to quantitatively analyse the development level. we can obtain the following conclusions:
(1) The increasing trend of the green power indicator effectively reflects the positive accumulation of clean energy development in Qinghai in recent years, which shows that the development of green power in Qinghai Province is at a relatively high level. At the same time, Green power living is the weak link in the development of green power in Qinghai. Qinghai needs to strengthen the construction of Green power living to improve the level of green power development.
(2) Solar energy utilization efficiency, water energy utilization efficiency, and wind energy utilization efficiency accounted for 92.9% of the negative increase in contribution, which greatly restricted the scores of green energy sharing and green power index. It can be seen that the wind power curtailment, photovoltaic power curtailment and hydropower curtailment problem in Qinghai Province has not been effectively resolved.

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