Evaluation of The Effect of Market Mechanism to Promote the Renewable Energy Consumption

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Abstract. With the rapid development of renewable energy, there is a shortage of renewable energy consumption, resulting in serious waste of resources. Relying solely on technological improvement can no longer meet the large-scale consumption demand of renewable energy, and market-based measures are needed to further promote the consumption of renewable energy. Nowadays, China has established multiple market mechanisms. In order to measure the market mechanism's contribution to the renewable energy consumption effectively and guide the adjustment of the market mechanism, a comprehensive evaluation system needs to be constructed. Therefore, this paper first determines each evaluation index of the evaluation system from the three aspects of power generation side, power grid side and social side, and then proposes the concept of influence degree, which is used to form the evaluation index value. Then the evaluation is established based on the improved entropy method and ideal solution. Finally, taking the measures of developing auxiliary power service market in Fujian Province and other regions as an example to evaluate its impact on the renewable energy consumption, which proves that the method used in this paper has application value in evaluating the effect of the operation mechanism of the power market.

1. Introduction

Because of the environmental pollution problems caused by the use of traditional energy sources, the country has issued a series of related policies to promote national energy transformation. So far, renewable energy development and construction has begun to take shape. As of 2018, the consumption of hydropower, nuclear power and wind power accounted for 14.3%, and it has increased year by year. The annual output of wind power is 680 million tons of standard coal, which is greater than the total annual consumption of hydropower, nuclear power, and wind power of 660 million tons of standard coal. While the installed capacity of renewable energy power generation in China has ranked first in the world, serious wind abandonment and light abandonment have occurred, resulting in the loss of economic benefits. According to the "Renewable Energy Law", the National Development and Reform Commission, the National Energy Administration, and relevant departments have issued a number of research and release plans to address the issue of renewable energy consumption guarantees. The introduction of demand-side management can effectively improve the accuracy of power load
forecasting, reduce energy waste, and achieve efficient resource allocation [1,2]. Since 2017, the first batch of energy internet demonstration projects nationwide have been started. The energy internet can interconnect the power network composed of distributed energy storage and other devices to overcome the geographically fragmented and volatile deficiencies of renewable energy production and become a renewable energy source. Containment problems provide feasible solutions [3, 4, 5]. In 2019, China's wind and light abandonment rates have decreased. The average wind abandonment rate for that year was 4%, a year-on-year decrease of 3%; the average light abandonment rate was 2%, a year-on-year decrease of 1%. In May 2019, the National Energy Administration and the National Development and Reform Commission issued a notice to establish and improve a renewable energy power consumption guarantee mechanism. The mechanism is implemented in the way that provincial administrative regions determine the weight of responsibility for renewable energy consumption. It clarifies that each market subject is obliged to conduct renewable energy consumption [6]. Although the problem of insufficient renewable energy consumption is being improved, it is impossible to accurately determine the contribution of each market mechanism. Therefore, the objective and accurate evaluation of the effectiveness of the renewable energy consumption market system is important for improving the renewable energy consumption mechanism.

Domestic scholars have discussed the comprehensive measurement of renewable energy consumption. Literature [7] analyzes the interaction between factors affecting renewable energy consumption, and proposes an evaluation method for the contribution of renewable energy consumption influencing factors; literature [8] uses the entropy weight TOPSIS method to measure renewable energy consumption level. The influencing factors of fluctuating renewable energy consumption are given; literature [9] combined with big data analysis and other methods to construct a renewable energy policy effectiveness evaluation system that reflects the promotion of renewable energy development and environmental benefits; literature [10] AHP and entropy method are used to calculate the weight of the new energy consumption benefit evaluation index; the literature [11, 12] starts from multi-link factors to measure the power supply, power grid and demand side. The contribution of the resources to promote the integration and consumption of renewable energy; literature [13] uses policy effectiveness, cost effectiveness, technological progress and dynamic efficiency indicators to qualitatively analyze the effectiveness of China's renewable energy policy implementation, which shows the positive impact of energy policies on the development of renewable energy; literature [14] proposes a method for optimal allocation of complementary microgrids that include renewable energy by analyzing the complementarity between wind, light and water resources. An evaluation system that analyzes the impact of each complementary characteristic on the economic operation of the microgrid. Literature [15] combines the evaluation of sub-systems with the evaluation of combined power generation systems, and constructs an evaluation index framework of multi-energy complementary characteristics. The literature [16] adopts the analytic hierarchy process when determining the index weight, and introduces the entropy method to modify the weight, thus reducing the subjective influence.

This article first establishes an evaluation index system that promotes the effect of renewable energy consumption, and proposes a method for forming the evaluation index value of renewable energy consumption efficiency. The improved entropy value method is used to determine the weight of each evaluation index and then the ideal solution is used to calculate the comprehensive market. Mechanism efficiency value, so as to carry out comparison analysis and decision-making accordingly.

2. Evaluation System

Combined with the characteristics of China's renewable energy consumption, the relevant data of energy structure and power production consumption in the past five years are analyzed, and some literatures [17, 18] are used for reference to obtain a number of mechanisms for evaluating the effectiveness of the market mechanism for renewable energy consumption index.

In order to fully demonstrate the effects of different market mechanisms, it is necessary to examine from multiple angles. This paper selects three first-level indicators to build an effective evaluation
index system that includes 8 second-level indicators to promote the market mechanism of renewable energy consumption. As shown in Table 1, in the power generation link, increasing the amount of renewable energy consumption can replace some non-renewable energy generation, so the ratio of the traditional thermal power unit's power generation capacity to the total power generation energy storage capacity can measure the level of non-renewable energy consumption. On the grid side, select two indicators: wind curtailment and light curtailment rate index and flexibility resource participation. Renewable energy in China is mainly based on wind power and photovoltaic, so the rate of abandoned wind and light can more intuitively reflect the ability of a system to absorb renewable energy. Renewable energy power generation has a strong uncertainty, poor power balance capacity, and easy to impact the safety of power grid operation. Flexible resources can increase the flexibility of the system, and serve the dynamic supply and demand balance of energy-consuming systems. The participation of flexible resources in power grid regulation is an effective method to solve system fluctuations. In terms of social impact, the increased use of clean energy will reduce the consumption of fossil fuels and the emission of atmospheric pollutants. Therefore, we choose five indicators of carbon dioxide, sulfur dioxide, nitrogen oxides, PM2.5, and annual emissions of smoke to measure a market the contribution of the mechanism within a certain region.

Table 1. Evaluation index of market mechanism effect for promoting renewable energy consumption.

| Level 1 Index | Level 2 Index |
|---------------|---------------|
| Generating side | Traditional thermal power generating unit's power generation capacity / total power generation capacity |
| Grid side | Abandoned wind and abandoned light rate |
| | Flexible resource participation |
| Social side | CO2 emissions |
| | Sulfur dioxide emissions |
| | NOx emissions |
| | PM2.5 emissions |
| | Soot emissions |

3. Determination of indicator value

After the evaluation index is determined, the time series consisting of several years of historical data collected needs to be properly processed to calculate the value of each index.

First, suppose that before the implementation of a market mechanism, the value of each indicator increases or decreases with the passage of time. After the implementation of a market mechanism, the change rate of the time series and other parameters change, and then based on the changed parameter keeps increasing or decreasing regularly. If the obtained data does not satisfy this assumption, it is corrected by adjusting the data time span.

In order to effectively measure the degree of influence of the implementation of a market mechanism on a certain evaluation index, this paper proposes the concept of the degree of influence. The quantitative calculation of the degree of influence is the value of each evaluation index under the action of the market mechanism.

For an evaluation index $X$, before the market mechanism is effectively used, its time series model can be expressed as:

$$Y_0 = \alpha_0 + \beta_{0,1} t^x + \beta_{0,2} t^{x-1} + \ldots + \beta_{0,2} t$$  \hspace{1cm} (1)

Similarly, after the market mechanism comes into play, its time series model can be expressed as:

$$Y_1 = \alpha_1 + \beta_{1,1} t^x + \beta_{1,2} t^{x-1} + \ldots + \beta_{1,2} t$$  \hspace{1cm} (2)
In the formula, \( t \) represents time, and \( Y \) represents the value of the evaluation index at different times.

On this basis, the degree of influence \( IX \) is defined as:

\[
I_X = \frac{\int_{t_s}^{t_n} \left| Y_t - Y_0 \right| dt}{T}
\]  

(3)

In the formula, \( ts \) represents the data start year, \( tn \) represents the latest data year, and \( T \) represents the data year span. This value can reflect the degree of change of the index value, and is expressed as the ratio of the area between the evaluation index value function before and after the market mechanism function and the length of the market mechanism function, as shown in the yellow shaded part of Figure 1.

![Figure 1. Visual representation of the degree of influence.](image)

For example, when \( \chi = 1 \), \( I_X = \frac{1}{2} \left( \alpha_1 + \beta_1 t' - \alpha_0 - \beta_0 t' \right) = \frac{\alpha_1 - \alpha_0}{2} + \frac{\left( \beta_1 - \beta_0 \right) t'}{2} \). Where \( t' \) is the time when the mechanism starts to be implemented. At this time, the influence degree can be expressed as one-half of the difference between the latest year indicators in the two states, as shown in Figure 2. It is worth noting that the latest year indicator data in a state where a market mechanism has been established is obtained through statistics, while the latest year indicator data in an unadjusted state needs to be calculated based on real data before \( t' \) time.
4. Weighting method
One of the core problems in measuring the effect of renewable energy consumption lies in the determination of evaluation index weights. Traditional evaluation methods mostly use subjective weighting methods, which have a certain degree of subjective arbitrariness. Therefore, this article chooses the entropy method, which can effectively avoid the influence of subjective human factors. And considering that the entropy method can only compare the relative relationship between indicators [19], in order to meet the needs of management and decision-making, this paper gives changes to the k value.

4.1. Normalized processing index value
If \( x_{ij} \) is a maximal indicator, then:

\[
y_{ij} = \frac{\max \chi_i - x_{ij}}{\max \chi_i - \min \chi_i}
\]

If \( x_{ij} \) is a minimal indicator, then:

\[
y_{ij} = \frac{x_{ij} - \min \chi_i}{\max \chi_i - \min \chi_i}
\]

At this point, the standardized matrix \( Y_{ij} \) is obtained, where \( i (1 \leq i \leq m) \) represents the \( i \)-th market mechanism to be evaluated and \( j (1 \leq j \leq n) \) represents the \( j \)-th evaluation index.

4.2. Calculate entropy
For the matrix of the proportion of each market mechanism object under \( n \) indicators that have been standardized, the entropy value \( e_j \) of each indicator is calculated as follows:

\[
e_j = -k \sum_{i=1}^{n} y_{ij} \cdot \ln(y_{ij})
\]

Among them, the value of \( k \) is not a constant parameter, and its selection can adopt the subjective weighting method, which incorporates historical experience and expert opinions into the weight measurement. In this paper, the analytic hierarchy process is adopted, and the value of the scale \( k \) is
determined by comparing the two indexes. The intermediate transition parameters of the analytic hierarchy process are no longer given. The indicator considered to be very representative takes \( k = 0 \), the indicator considered to have no reference value takes \( k = 1 \), and the \( k \) value of the index between the two is selected between 0 and 1, the more important index has the \( k \) value closer to 0, as shown in Table 2. In this way, the advantages of quantitative and qualitative methods can be effectively combined and have been applied in many practices.

| Parameter k value | Meaning                      |
|------------------|------------------------------|
| 0                | Index j is extremely important |
| 0.3              | Index j is important          |
| 0.5              | The value of indicator j is obvious |
| 0.7              | Index j has certain reference value |
| 1                | Indicator j has no value      |

4.3. Calculating the difference coefficient and normalization

The index difference coefficient \( g_j \) can reflect the amount of information contained in the index value. After normalization, the weight of each evaluation index is finally obtained, which can be expressed as:

\[
g_j = \frac{1 - e_j}{\sum_{j=1}^{m} e_j} \quad (7)
\]

From this, the weight of each index to the target layer can be calculated.

5. Construction of comprehensive evaluation model of market mechanism for promoting renewable energy consumption

In this paper, the ideal solution method is used to construct the evaluation model. It inspects the close degree of the evaluation object and the ideal target value, and the distance degree of the evaluation object and the negative ideal target value, to evaluate objects. This method has no limit on the number of samples. The entire evaluation process eliminates the influence of subjective factors and improves the objectivity of decision analysis [20].

First standardize the decision matrix. The \( m \times n \)-order initial evaluation matrix \( x_{ij} \) is composed of \( m \) market mechanisms and an evaluation indicator (this paper proposes 8 second-level indicators), and the vector normalization formula is used:

\[
y_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^2}} \quad (1 \leq i \leq m, \quad 1 \leq j \leq n)
\]

\( (8) \)
Get a standardized evaluation matrix \( Y_j \). Calculate the weighted normalization matrix \( V \) with the determined weight \( g_j \) of each evaluation index:

\[
V = (v_{ij})_{mn} = (g_j \cdot Y_{ij})_{mn}
\]  

Determine positive and negative ideal solutions. Let \( v^* \) and \( v^- \) denote ideal and negative ideal solutions, respectively, \( J^+ \) and \( J^- \) denote positive index sets and negative index sets.

\[
\begin{align*}
    v^* &= \{(\max_{1 \leq i \leq m} v_{ij} | j \in J^+), (\min_{1 \leq i \leq m} v_{ij} | j \in J^-)\} \\
    &= \{v^*_1, v^*_2, \ldots, v^*_n\} \\
    v^- &= \{(\min_{1 \leq i \leq m} v_{ij} | j \in J^+), (\max_{1 \leq i \leq m} v_{ij} | j \in J^-)\} \\
    &= \{v^-_1, v^-_2, \ldots, v^-_n\}
\end{align*}
\]  

Calculate the distance \( s^* \) and \( s^- \) of each selected market mechanism to the ideal solution and the negative ideal solution.

\[
\begin{align*}
    S^*_i &= \sqrt{\sum_{j=1}^{n} (x_{ij} - x^*_j)^2} \\
    S^-_i &= \sqrt{\sum_{j=1}^{n} (x_{ij} - x^-_j)^2}
\end{align*}
\]  

Define the relative closeness \( C_i^* \) of each market mechanism to the ideal solution and the negative ideal solution as:

\[
C_i^* = \frac{S^-_i}{S^*_i + S^-_i} \quad (i = 1, 2, \ldots, m)
\]

After calculating the relative closeness of each scheme, the schemes are sorted according to the principle that the greater the relative closeness is the better and the smaller is the worse. The conclusions can be used to reversely analyze the rules of the contribution of each program with different mechanisms to the target layer, discuss the shortcomings of the under-performing programs, and thus guide the formulation of policy guidelines.

6. Example analysis
As one of the key points of the new round of power system reform, the establishment of an auxiliary power service market aims to ensure the safety of the power grid and improve the quality of power consumption. It is becoming more and more important in the reality of clean energy consumption that
needs to be solved. Fujian Province is one of the eight pilot provinces of the national power auxiliary service market. The “Notice of the Fujian Energy Regulatory Office on the official operation of the Fujian frequency modulation auxiliary service market” [21] clearly stipulated that the Fujian power auxiliary service market will be launched in 2020. It will be put into official operation from April 1st. The Shanxi Electric Power Frequency Modulation Auxiliary Service Market was officially launched on January 1st of the same year, involving an installed capacity of 45,660 MW. The province plans to establish an optimization mechanism of frequency modulation quotation sequencing to balance the price and quality factors to achieve economic and organic unity of security.

This article takes the five provincial capitals of Fujian Province and Shanxi Province as the research objects, and evaluates the effect of promoting the renewable energy consumption in the electric auxiliary service market that began to enter the trial run in sequence in 2018. In order to make the data change more smoothly, the dependent variable data in the model are all taken logarithmically.

Taking the ratio of the power generation capacity of the traditional thermal power generation unit index and the total power generation energy storage capacity as an example, after regression analysis, a linear regression model is selected to fit the evaluation index time series model according to the F test result. From the test results, the model coefficients have practical significance through statistical tests and econometric tests. Where * indicates that the parameter is within the confidence interval at the 5% significance level.

Table 3. Estimated results of time series models before and after the market mechanism.

|                              | Before the market mechanism works | After the market mechanism works |
|------------------------------|----------------------------------|----------------------------------|
| coefficient                  | 0.988                            | -0.045                           |
| Constant term                | -                                | 92.000                           |
| Adjust R²                    | 0.963                            | 0.988                            |
| F statistic                  | F (1,2) = 80.140, p = 0.012*     | F (1,1) = 162.360, p = 0.050*    |
| P statistic (coefficient)    | 0.012*                           | 0.050*                           |
| D-W value                    | 3.246                            | 3.000                            |

After using SPSS software to obtain the evaluation index value sequence model, according to the definition of the impact degree proposed in this article, the MATLAB software is used to calculate the impact degree. The radar chart of the operation result is shown in Figure 3, where S1 to S8 represent the above determined indicators, from traditional thermal power generating unit's power generation capacity / total power generation capacity to the soot emission.

Figure 3. Calculated results of the impact of secondary indicators.

The analysis and calculation results show that the establishment of an auxiliary service market in Fujian Province has excellent results in reducing the rate of abandoned wind and light, reducing the
use of fossil fuels and reducing carbon dioxide emissions. Consider taking relevant measures to make up for the deficiencies. After adding 4 provinces of renewable energy consumption data for comparison, and sequentially calculating the entropy value and closeness, the final evaluation results of each market mechanism for promoting renewable energy consumption are shown in Table 4 and Figure 4. Because the accuracy of some data is difficult to guarantee, it may cause some errors, and here the letters are used to replace the area names.

Table 4. Evaluation results of the promotion of renewable energy consumption in different regions.

| Area     | Overall score | Rating |
|----------|---------------|--------|
| Area A   | 0.593969696   | Good   |
| Area B   | 0.337506195   | Good   |
| Area C   | 0.200064224   | Poor   |
| Area D   | 0.761253451   | Excellent |
| Area E   | 0.153542854   | Poor   |

Figure 4. Calculated results of the impact of secondary indicators.

It can be obtained from Table 4 and Figure 4 that the comprehensive implementation effect of the establishment of the power peaking auxiliary service market in area D is the best, followed by area A and area B, and the comprehensive effect of area C and area D is average. Considering the short time for the establishment of power peaking auxiliary service markets in various regions, and the implementation of policies often have delays, the data currently collected can only reflect the consumption within a short period of time in a region, and cannot accurately reflect the rationality and effectiveness, if you want to improve the accuracy of the evaluation results, you need more data to test. Overall, the establishment of an electric power peaking auxiliary service market can expand the space for renewable energy consumption, increase system flexibility, and effectively reduce wind and light abandonment. In order to stimulate the new vitality of the electric power peaking auxiliary service market, it is necessary to fully grasp the characteristics of the power supply structure, load curve, economic level and other characteristics of each region, and make decisions based on the specific conditions of each region.

7. Conclusions
Aiming at the market mechanism for solving the problem of insufficient renewable energy consumption, this paper proposes an evaluation system based on improved entropy method and ideal solution to measure the market mechanism's effect on promoting renewable energy consumption. This article determines the eight secondary indicators that make up the evaluation system, proposes the concept of influence to quantitatively describe the influence of the market mechanism, and applies an improved entropy method to achieve the combination of subjective and objective evaluation methods. It can be seen from the analysis of the calculation examples that the establishment of the power peaking auxiliary service market is very effective in reducing wind and light abandonment, but it has little effect on encouraging the participation of flexible resources. Analysis of the evaluation results
calculated using the method proposed in this article can point out the shortcomings of the current mechanism and guide the formulation and implementation of new policies. The evaluation system for promoting renewable energy consumption proposed in this paper is expected to provide decision-making assistance for the selection and establishment of electricity market mechanisms.

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