Multi-dimensional Benefit Evaluation of Wind-Solar-Storage Integration Based on Game Theory Combination Weighting

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Abstract. The purpose of this study is to establish a comprehensive and reasonable evaluation system, and to provide a scientific and effective weighting method for the indicators in the evaluation system. To sum up, this paper selects 9 low-carbon factors among 64 influencing factors, including energy efficiency, economy, society, low carbon and enterprise development, as evaluation indicators, and builds corresponding evaluation index system. At the same time, intuitionistic fuzzy analytic hierarchy process (AHP) is used for subjective empowerment to effectively improve the fuzziness and repeatability of evaluation empowerment. Entropy weight method gives weight objectively, so that the correlation and difference between indicators are taken into account. In addition, based on the basic idea of improving the combinatorial weights of game theory, we find the consistency or compromise between different index weights to obtain a more scientific comprehensive optimal weight distribution coefficient, which solves the limitations of traditional combinatorial weights to a certain extent.

Keywords: Game Theory Combinatorial Empowerment; AHP; Entropy weight method

1. Introduction

In recent years, China's economy has entered a period of high-quality development, and people's demand for energy has been increasing. With the emergence and development of a large number of new power equipment, the diversity of electric energy changes in the power system has been increased. The structural changes on both sides of supply and demand and the sharp changes of load bring severe challenges to the safe operation of power grid. In order to accurately evaluate power quality, improve power consumption quality and guide power quality management, it is of great practical significance to establish a multi-dimensional benefit evaluation system. The selection and determination of the evaluation method of benefit are mainly reflected in the selection and application of index weight and the comprehensive evaluation of index results[1-3]. Generally speaking, the methods to determine the weight of indicators can be analytic hierarchy process, entropy weight method, scheme preference

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weighting method, etc. These methods are generally evaluated according to the knowledge and experience of the evaluator, and the results may be somewhat subjective and arbitrary. Objective weighting methods, such as principal component analysis, entropy weight method, etc., such methods avoid subjectivity, but may lack subjective qualitative analysis in certain types of evaluation[4]. There are also some researchers using the above methods to combine empowerment and reduce the loss of information. An AHP-fuzzy comprehensive evaluation model based on analytic hierarchy process (AHP) and entropy method is established. The selected method combines the advantages of subjective and objective weights to reflect the information more comprehensively and objectively. The research of the above scholars did not take into account the differences among various methods. The integrated operation efficiency of landscape and storage is a complex of multiple indicators, and a single evaluation cannot see the inextricative links among the indicators. Therefore, how to comprehensively evaluate the integrated operation efficiency of landscape and storage through the combination of weights is a problem that technicians in this field need to solve[5].

2. Construction of integrated evaluation model of landscape and storage

2.1 Establish the index system results

Selecting reasonable and effective evaluation indicators and constructing an evaluation index system is the basis for risk assessment research. Firstly, based on the previous research on the multi-dimensional benefit evaluation of the integrated wind-solar-storage operation system, starting from the cluster analysis theory, five first-level evaluation indicators of multi-dimensional benefit evaluation were carried out: energy efficiency benefit factors, economic benefit factors, social benefit factors, low-carbon benefit factors, and enterprise development benefit factors. To construct a multi-dimensional benefit evaluation index system[6], since there are many multi-dimensional benefit evaluation index systems for the integrated operation of wind, solar, and storage, the low-carbon benefit index is selected to verify the method of this paper. The data comes from the data of the integrated operation system of wind, solar and storage of a power company in Jilin Province and the data of other power companies. This is shown in Table 1.

Table 1 Low-carbon indicators

low carbon benefit		
CO2 emission reduction completion rate	SO2 emission reduction completion rate	Nox emission reduction completion rate
CO emission reduction completion rate	Completion rate of soot emission reduction	Energy conservation and emission reduction rate
New energy consumption change value	Ecological environment impact rate	Proportion of new energy installed capacity

2.2 Evaluation process

The multi-dimensional benefit evaluation of wind-solar-storage integration plays an important role in the integrated operation of wind-solar-storage combining wind power, photovoltaic, energy storage and hydrogen storage. In order to ensure the rationality and effectiveness of risk assessment research, this paper conducts evaluation research based on the theory and ideas of systems engineering. The weights obtained by AHP and entropy weight method are combined by game theory to build a new weighting model and get the final weights. and the evaluation process is shown in Figure 1.

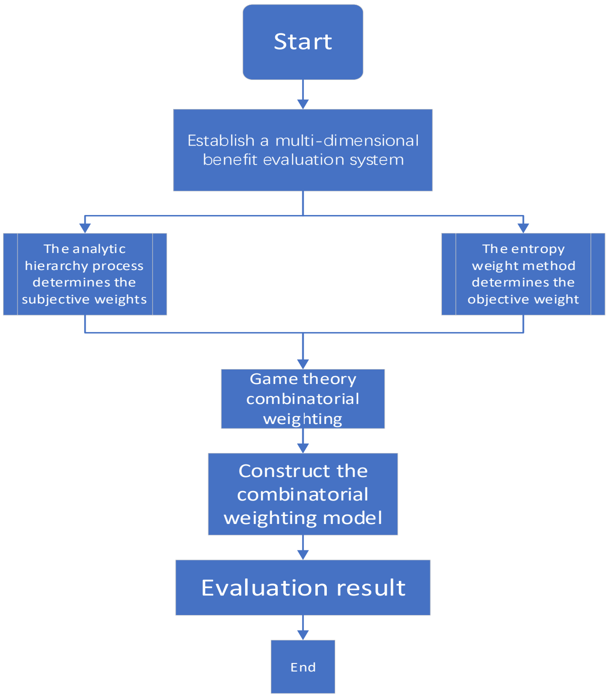

Figure 1. Flow chart.

3. Combinatorial weighting based on game theory

3.1. Analytic hierarchy Process subjective empowerment

Construct judgment matrix A

By comparing the importance of the risk assessment factors of the criterion layer with that of the target layer, the criterion layer judgment matrix A is constructed (see Equation (1)). Similarly, the judgment matrix of the index layer can be determined[7].

$$A = (a_{ij})_{m\times n} = \begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{pmatrix} \quad (1)$$

$$a_{ij} = \begin{cases} 0, The\ i\ element\ is\ less\ important\ than\ the\ j\ element \\ 1,\ The\ i\ element\ is\ as\ important\ as\ the\ j\ element \\ 2,\ i\ element\ is\ more\ important\ than\ j\ element \end{cases} \quad (2)$$

Calculate the judgment matrix B

$$B = \left(b_{ij}\right)_{mn} \tag{3}$$

$$b_{ij} = \begin{cases} \frac{r_i - r_j}{r_{max} - r_{min}}(b_m - 1) + 1, r_i > r_j \\ 1, r_i = r_j \\ \left(\frac{r_i - r_j}{r_{max} - r_{min}}(b_m - 1)\right)^{-1} + 1, r_i < r_j \end{cases} \tag{4}$$

Where r_i is the sum of the elements in row i of matrix . $r_i = \sum_{j=1}^{n} a_{ij}$, r_{max}, r_{min} is the largest and smallest value of the element in row i of the matrix A. b_m is the ratio of the largest and smallest values of the elements in row $i$of the matrix A.

Determine the optimal transfer matrix$C$

$$C = \left(C_{ij}\right)_{m\times n} \tag{5}$$

Where: $C_{ij}$is the element value in the optimal transfer matrix C , $C_{ij} = \frac{1}{n}\sum_{n=1}^{n} log \frac{b_{ik}}{b_{jk}}$

Compute the quasi-optimal uniform matrix$D$

$$D = \left(d_{ij}\right)_{m\times n} \tag{6}$$

Where: $d_{ij}$is the element value in the optimal transfer matrix D, $d_{ij} = 10^{c_{ij}}$

Calculate index weight.

The index weight is obtained by the eigenvector of the quasi-optimal uniform matrix D, and the eigenvector set is obtained by geometric average method $\overline{W} = \{\overline{W_1}, \overline{W_2}, \dots, \overline{W_n}\}$,The eigenvector set $\overline{W}$ is normalized to obtain the eigenvector set $W = \{w_1, w_2 \dots, w_n\}$ is the evaluation index weight of the criterion layer**.**

$$\overline{w_k} = \left(\prod_{i=1}^{n} d_{ki}\right)^{\frac{1}{n}} \tag{7}$$

Where d_{ki} is the element value of the quasi-optimal uniform matrix, k is the number of matrix rows, and i is the number of matrix columns.

$$w_k = \overline{w_k} \Big/ \sum_{k=1}^{n} \overline{w_k} \tag{8}$$

Where $\overline{w_k}$is the eigenvector value calculated by the geometric average method, w_k is the eigenvector value after normalization, and n is the number of indicators.

3.2. The entropy weight method gives weight objectively

The objective weighting method mainly starts from the relationship between the original data and uses certain mathematical methods to determine the weight of the index. Common objective weighting methods include factor analysis method, entropy weight method and CRITIC method. Entropy weight method is the change degree of the main evaluation indicators, and the information entropy value is used to calculate the weight of each evaluation index to obtain the objective weight that conforms to the actual situation[8].

Construct the original data matrix

The original data matrix was constructed with m samples of evaluation (expert scores) and n evaluation risk factors $D = \left(d_{ij}\right)_{m\times n}(i = 1,2 \dots, n; j = 1,2 \dots, n)$.

Data standardization processing

Not all analysis and evaluation indicators are benefit indicators, so it is necessary to conduct standardized data processing, which is as follows:

$$r_{ij} = \frac{d_{ij} - min_j d_{ij}}{max_j d_{ij} - min_j d_{ij}} \quad (9)$$

$$r_{ij} = \frac{max_j d_{ij} - d_{ij}}{max_j d_{ij} - min_j d_{ij}} \quad (10)$$

Where d_{ij} is the original data of the index, r_{ij} is the value of each index after standardized processing, $max_j d_{ij}$, $min_j d_{ij}$ is the maximum and minimum value of the j index.

Calculate the information entropy of the evaluation index e_j

$$e_j = -\frac{1}{lnm}\sum_{i=1}^{m} p_{ij} \cdot lnp_{ij} \quad (11)$$

Type of $p_{ij} = {r_{ij}}\Big/{\sum_{i=1}^{m} r_{ij}}$, if $r_{ij} = 0$, $p_{ij} = 0$, $p_{ij} \cdot lnp_{ij}$ have no sense of mathematics. Therefore, the proportion of the modified index value is defined as:

$$p_{ij} = \frac{r_{ij} + 10^{-4}}{\sum_{i=1}^{m}\left(r_{ij} + 10^{-4}\right)} \quad (12)$$

Calculate the objective weights of evaluation indicators ω_j

$$\omega_j = \frac{1 - e_j}{\sum_{j=1}^{n}\left(1 - e_j\right)} \quad (13)$$

Where $0 \le \omega_j \le 1$, and $\sum_{j=1}^{n} \omega_j = 1$

3.3. Combinatorial weighting based on game theory

In order to reduce the one-sidedness of weights in subjective and objective weighting, the subjective weight ω_1 determined by AHP and the objective weight ω_2 determined by entropy weight[9]. Based on the thought of game theory, the optimal comprehensive weight ω^* is calculated. The specific steps are as follows

Linear combination of subjective and objective weights

$$\omega^* = \beta_1 {\omega_1}^T + \beta_2 {\omega_2}^T \quad (14)$$

Where ω^* is the combined weight vector; β_1 and β_2 are the weight coefficients and $\beta_1 > 0$, $\beta_2 > 0$, $\beta_3 > 0$.

Optimize the combination

Based on game theory, the weight coefficients β_1, β_2 and β_3 of linear combination are optimized to minimize the deviation sum between ω^* and subjective and objective weights ω_1, ω_2 and ω_3. The game model for obtaining the optimal combination coefficient is $min(\|\omega^* - \omega_1\|_2 + \|\omega^* - \omega_2\|_2)$.

Solve the optimization combination coefficient

According to the principle of matrix differentiation, the first order derivatives of equations (14) and $min(\|\omega^* - \omega_1\|_2 + \|\omega^* - \omega_2\|_2)$ are obtained, and the derivative conditions are as follows

$$\begin{cases} \beta_1 \omega_1 {\omega_1}^T + \beta_2 \omega_1 {\omega_2}^T = \omega_1 {\omega_1}^T \\ \beta_1 \omega_2 {\omega_1}^T + \beta_2 \omega_2 {\omega_2}^T = \omega_2 {\omega_2}^T \end{cases} \quad (15)$$

According to equation (15), the coefficients $\beta_1, \beta_2, \beta_3$ are obtained.

Calculate the optimal comprehensive weight

The obtained $\beta_1, \beta_2, \beta_3$ are normalized, and the optimal combination coefficients ${\beta_1}^*, {\beta_2}^*, {\beta_3}^*$ are obtained, and the optimal comprehensive weight ω^* is obtained by substitution into equation (14) .

$$\omega^* = {\beta_1}^* {\omega_1}^T + {\beta_2}^* {\omega_2}^T \quad (16)$$

4. Computational analysis

According to equations (14) ~ (16), the calculated subjective and objective weights are combined and weighted, and the combined weights based on game theory are obtained[10], as shown in Table 2 and the line chart of the three methods is shown in Figure 2.

Table 2 Comparison results of various indicators

index	AHP	Entropy weight method	Game theory combination
CO2 emission reduction completion rate	0.1419	0.2481	0.1597
SO2 emission reduction completion rate	0.1240	0.1378	0.1248
Nox emission reduction completion rate	0.2237	0.1896	0.1096
CO Emission Reduction target completion rate	0.1562	0.0874	0.0138
Soot reduction target achievement Rate	0.1090	0.0266	0.1853
Energy saving and emission reduction achievement rate	0.0752	0.1605	0.1565
New energy consumption change value	0.0578	0.0303	0.0218
Ecological environment impact rate	0.0691	0.0193	0.0793
Proportion of new energy installed capacity	0.0430	0.1004	0.1492

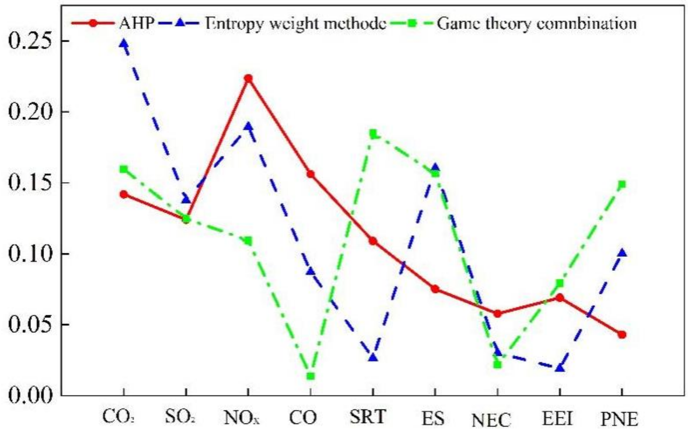

Figure 2. Weight analysis.

Through the analysis of the chart, we can get:

The subjective fluctuation of entropy weight method is large, which is not completely consistent with the result of game theory, but the result of entropy weight method is completely consistent with the trend of the weight value of the combination of game theory, indicating that game theory can be used to calculate the weight. The AHP method is relatively soft and has little difference with some points of the game theory combinatorial weighting method, which indicates that the AHP method is balanced after the game. Most of the weight values calculated based on the game theory combination weighting are between the results of two single evaluation weights, and the combined weight coefficient improves the problem of the high frequency extreme value span of the weight results of the objective method. At the same time, the subjective evaluation results are flexible, and the subjective influence brought by external factors is taken into account, so that the evaluation results are more accurate and reasonable. The dominant role of a single evaluation is avoided to the greatest extent.

5. Conclusion

Based on the thought of game theory, the subjective weights calculated by analytic hierarchy process and objective weights calculated by entropy weight method are combined to calculate the comprehensive weights of evaluation indicators, which avoids the influence of subjective or objective factors caused by the calculation of weights by a single method, and is conducive to the accurate determination of weights in the evaluation index system.

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