Energy Efficiency Assessment of Industrial Users Based on Improved TOPSIS Grey Correlation Analysis

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Abstract. In order to improve the energy efficiency of industrial users and evaluate the energy efficiency level before optimizing the energy efficiency of enterprises, an energy efficiency evaluation method based on improved TOPSIS grey relational analysis was proposed to find the weak links in energy use. Firstly, three indexes of energy stability, energy consumption per unit output and carbon emission per unit output are selected to construct the energy efficiency index system. Secondly, the index weights are calculated by entropy weight method, and the energy efficiency levels of industrial users are classified, which can be used by the power grid to implement differentiated electricity prices for high-energy consumption enterprises. Last example city 10 typical energy-intensive enterprise users used improved TOPSIS grey correlation analysis method for evaluation of energy efficiency, energy consumption per unit output value is obtained by analysis of the index weight is the largest, the better the performance of the index, the higher the comprehensive evaluation results of energy efficiency, and finally the method compared with other evaluation methods to verify the effectiveness of the proposed method in this paper.

Keywords: Improved TOPSIS; Energy efficiency indicator system; Entropy weight method; The evaluation of energy efficiency.

1. Introduction

The energy consumption situation of industrial enterprises is complex, and different enterprises have different ways and conditions of energy consumption, which has certain potential for energy efficiency improvement [1-2]. Energy efficiency suggestions for each type of enterprise should be made after completing the energy efficiency evaluation of the enterprise. Relevant methods have been proposed for energy efficiency evaluation. According to the relevant characteristics of the integrated energy system, literature [3] proposes an energy efficiency evaluation model based on the cross-super-efficiency CCR model. Literature [4] proposed the comprehensive energy efficiency evaluation index of offshore oil and gas engineering micro-energy system by using the energy hub matrix modeling method. Literature [5] constructed the energy efficiency evaluation index system of power users based on PSR, and used the combination of intuitionistic fuzzy entropy method and DEA to evaluate and analyze the energy efficiency. However, the above literatures mainly studied the construction of energy efficiency indicators and the selection of methods, and did not consider the energy efficiency evaluation of typical industrial users.

Aiming at the above problems, this paper proposes an energy efficiency evaluation method based on improved grey TOPSIS [6]. For industrial users, it first proposes three indexes, namely, energy stability, energy consumption per unit output value and carbon emission per unit output value, to construct an energy efficiency index system. Secondly, it calculates the index weight by entropy weight method [7], and obtains the final score of the enterprise through calculation. The industrial enterprises were classified according to the final score of energy efficiency. In the last example, 10 typical industrial enterprises in a city were used to evaluate their energy efficiency level, and the final analysis showed that the enterprises with better energy consumption performance per unit output value had higher comprehensive energy efficiency evaluation results. And the effectiveness of the proposed method can be verified by comparing the evaluation results with other methods.

2. Improved TOPSIS grey correlation analysis

The section headings are in boldface capital and lowercase letters. Second level headings are typed as part of the succeeding paragraph (like the subsection heading of this paragraph). All manuscripts must be in English, also the table and figure texts, otherwise $_s w$ we cannot publish your paper. Please keep a second copy of your manuscript in your office.

TOPSIS method is a multi-objective decision evaluation method, which generally evaluates the evaluation object according to the distance of calculating the ideal solution, and can intuitively analyze the overall situation of the evaluated object. However, in the traditional TOPSIS method, Euclidean distance is used to calculate and evaluate the distance between the customer and the positive and negative ideal solutions. Considering the linear relationship between evaluation indexes, Euclidean distance will affect the accuracy of evaluation results to a certain extent, thus reducing the credibility of evaluation results. In ORDER TO solve this problem, BY IMPROVING THE GREY TOPSIS METHOD, THE WEIGHTED GREY correlation degree between indicators is used as the distance measure, replacing the original Euclidean distance measure, which makes up for the shortage of Euclidean criterion and improves the evaluation accuracy.

(1) Data preprocessing

The evaluation index data matrix Y is obtained by calculating the established energy efficiency evaluation index:

$$Y=\begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ \vdots & \vdots & & \vdots \\ y_{p1} & y_{p2} & \cdots & y_{pn} \end{bmatrix} \tag{1}$$

The evaluation indicators are generally divided into positive indicators (the bigger the indicator is, the better) and negative indicators (the smaller the indicator is, the better). Considering the difference of the two indicators, the two indicators are processed in the same direction and dimensionality:

$$y'_{ij}=\begin{cases} \dfrac{1}{k+max\left|Y_i\right|+y_{ij}} & y_{ij} \text{ is a negative indicator} \\ y_{ij} & y_{ij} \text{ is a positive indicator} \end{cases} \tag{2}$$

In the formula, $\max\left|Y_i\right|$ represents the maximum value of the element in the row where the evaluation index belongs. In the formula, k is generally taken as 0.1 as a conventional coefficient. The homotropization of index data is completed through Equation (2).

Equation (3) is used to de-dimensionalize Y':

$$y''_{ij}=\frac{y_{ij}}{\sqrt{\sum_{i=1}^{p} y_{ij}^2}} \tag{3}$$

(2) Find the maximum and minimum reference vector

The data matrix after forward normalization is $Y=\left(y_{ij}\right)_{p\times n}$, and its maximum reference vector is composed of the maximum value of each index

$$V_{\max}=\left\{\max(y_{1j}),\max(y_{2j}),\cdots,\max(y_{pj})\right\} \tag{4}$$

The minimum reference vector consists of the minimum value of each index:

$$V_{\min}=\left\{\min(y_{1j}),\min(y_{2j}),\cdots,\min(y_{pj})\right\} \tag{5}$$

(3) Positive and negative grey incidence matrix

Where, the gray incidence matrix of the ith evaluation sample and the positive ideal sample (negative ideal sample) is R^{+} （R^{-}）, and the element r_{ij}^{+} （r_{ij}^{-}）in the matrix is:

$$r_{ij}^{+(-)}=\frac{\min\limits_{p}\min\limits_{n}\left|y_{j}^{+(-)}-y_{ij}\right|+\rho\max\limits_{p}\max\limits_{n}\left|y_{j}^{+(-)}-y_{ij}\right|}{\left|y_{j}^{+(-)}-y_{ij}\right|+\rho\max\limits_{p}\max\limits_{n}\left|y_{j}^{+(-)}-y_{ij}\right|} \tag{6}$$

In the formula, ρ is the discrimination coefficient, which is generally taken as 0.5; r_{ij} superscript "+" is the value of positive incidence matrix; otherwise, it is the value of negative incidence matrix.

(5) Calculate the grey correlation degree

$$\xi_{j}=\frac{\sum_{i=1}^{p}R_{ij}}{p} \tag{7}$$

The final score of the object can be obtained by solving the grey correlation degree.

(6) Calculate the score

$$Score_{j}=\frac{1}{1+\left(\xi_{j}^{(\min)}/\xi_{j}^{(\max)}\right)^{2}} \tag{8}$$

Where $Score_{j}$ is the score of the desired object, $\xi_{j}^{(\min)}$ is the correlation coefficient between the data matrix and the minimum reference vector, and $\xi_{j}^{(\max)}$ is the correlation coefficient between the data matrix and the maximum reference vector.

3. Index weight calculation based on entropy weight method

Before the evaluation of energy efficiency, the weight of indicators has a great influence on the evaluation results, and the subjective weighting method is easy to cause subjective preferences to affect the evaluation results. In addition, the subjective weighting method is susceptible to the influence of expert experience, so the entropy weighting method in the objective weighting method is chosen in this paper to calculate the weight of the established index.

Entropy weight method is an objective method to calculate the weight of the index, and the entropy weight method mainly calculates the weight of the evaluation index according to the given energy efficiency evaluation matrix. According to Equation (9), the entropy of the first evaluation index is defined as:

$$H_{ij}^{*}=-k\sum_{i=1}^{p}f_{ij}\ln f_{ij},\ j=1,2,\cdots,n \tag{9}$$

Where $f_{ij}=y_{ij}/\sum_{i=1}^{p}z_{ij},k=1/\ln m$

The entropy weight of the JTH index can be defined as:

$$w_{j}=\frac{1-H_{j}}{q-\sum_{j=1}^{q}H_{j}} \tag{10}$$

Where $:0 \le w_j \le 1, \sum_{j=1}^{q} w_j = 1, W = \left[w_1, w_2, \cdots, w_q \right]$ Is the index weight vector.

4. Comprehensive evaluation index system

Comprehensive energy efficiency evaluation index is an important tool and means of comprehensive energy efficiency evaluation of enterprises. Establishing a scientific and reasonable evaluation index system is one of the core work of comprehensive energy efficiency evaluation. There are some differences in energy use behavior and characteristics of various industries. In this paper, according to the energy use characteristics of various industries, the energy use of various industries is uniformly transformed into the data of standard coal ton, and then indicators are selected for evaluation.

In this paper, the stability of energy consumption, energy consumption per unit output value and carbon emission per unit output value are selected as indicators to evaluate the comprehensive energy efficiency of high-energy-consuming enterprises.

Energy stability is used to reflect the abnormal energy consumption of the enterprise during the stage time, and the calculation of this index is displayed by using the average of the number of abnormal energy consumption of the enterprise in a certain month.

Energy consumption per unit output value is used to reflect energy consumption level and energy saving and consumption reduction. Energy consumption per unit output value can be calculated by energy consumption (ton standard coal) and gross product of the enterprise. The calculation formula is as follows:

$$\text{Energy consumption per unit output}=\frac{\text{Total energy consumption}}{\text{Gross enterprise product}} \tag{11}$$

Carbon emission per unit of output value is used to reflect the energy saving and consumption reduction level of the enterprise. The carbon emission level of the enterprise is observed and combined with the energy consumption level of the enterprise to give a reasonable energy efficiency score. The calculation of carbon emission can be referred to the literature [8].

$$\text{Carbon emission per unit of output}=\frac{\text{Enterprise carbon emission}}{\text{Gross enterprise product}} \tag{12}$$

5. The example analysis

10 typical high energy consumption enterprises in a city are selected as examples to evaluate and analyze their energy efficiency. The selected index system includes three indexes: energy stability, energy consumption per unit output value, and carbon emission per unit output value. The established indexes are shown in Table 1:

Table 1. Evaluation Index

Specific indicators	Fiducial value	Benchmark values
Energy stability (times /m)	10	3
Energy consumption per unit output (kgcl/t)	117	100
Carbon emission per unit of production (tco2/t)	0.905	0.845

The benchmark value and benchmark value of each indicator in the table are defined according to the relevant characteristics of high energy consumption enterprises, which can facilitate the implementation of differential electricity price for corresponding enterprises in the subsequent classification of industrial enterprises.

The energy efficiency index data of industrial users are shown in Table 2:

Table 2. Customer energy efficiency index data

The customer	Energy stability (times /m)	Energy consumption per unit output (kgcl/t)	Carbon emission per unit of production (tco2/t)
1	2	95	0.833
2	3	95	0.841
3	2	93	0.833
4	1	90	0.853
5	5	110	0.865
6	7	111	0.874
7	10	120	0.9
8	15	125	0.912
9	16	122	0.925
10	16	120	0.922

After obtaining each data of customer energy efficiency index, entropy weight method can be used to calculate the weight of energy efficiency index. The weight and type of each indicator are shown in the following table:

Table 3. Weight of evaluation index

Specific indicators	Index weight	The index type
Energy stability (times /m)	0.2591	Smallest
Energy consumption per unit output (kgcl/t)	0.4131	Smallest
Carbon emission per unit of production (tco$_2$/t)	0.3278	Smallest

It can be seen from Table 3 that the weight of energy consumption per unit of output value for industrial users is the largest, followed by carbon emission per unit of output value, and the weight of energy use stability is the smallest. By analyzing the weight of indicators, it can be further concluded that the types of indicators are extremely small, that is, the smaller the indicator, the better. Calculate the positive and negative grey correlation matrix values according to the above data

Table 4. Positive and negative grey correlation matrix values

The customer	Positive implicative	Negative correlation
1	0.951	0.715
2	0.915	0.720
3	0.950	0.715
4	1	0.711
5	0.878	0.727
6	0.846	0.736
7	0.818	0.747
8	0.786	0.769
9	0.779	0.775
10	0.778	0.777
Fiducial value	0.816	0.748
Benchmark values	0.919	0.719

Finally, according to the correlation matrix values obtained in Table 4, energy efficiency evaluation and analysis were conducted for these 10 high-energy consuming enterprises and the reference and benchmark values given. After the index weight is obtained, the energy efficiency level of 10 customers is analyzed, as shown in Figure 1:

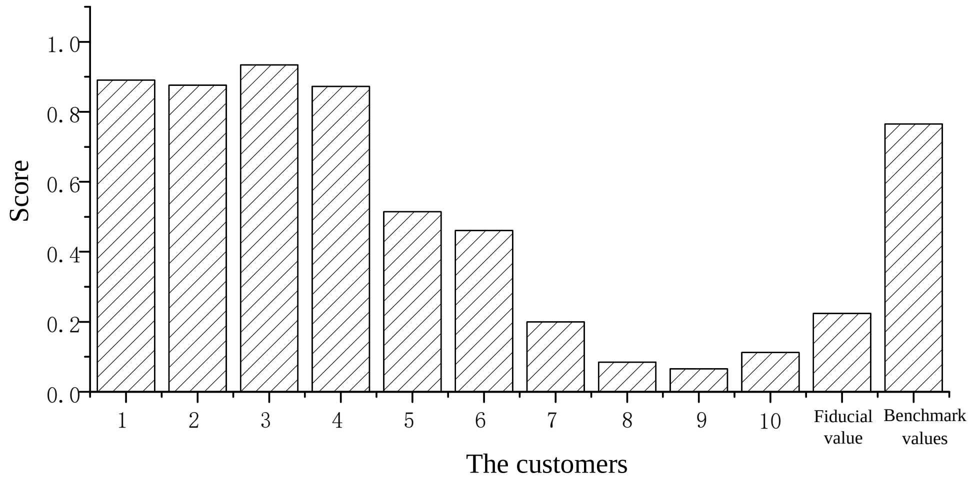

Fig. 1 User final score

From the analysis of figure 1. The end result can be customer 3 levels of energy efficiency highest (0.9339), the client 9 the energy efficiency level of the lowest (0.0661), the customer 3 of the indicators have reached a good level, customer 9 various energy efficiency indexes, so on the company's efforts in energy conservation measures, and the need to pay close attention to the level of energy efficiency, From the final scores of each customer, it can be seen that the customers with lower energy consumption per unit of output value have higher comprehensive final scores, that is, the users with better performance of energy consumption per unit of output value have higher comprehensive energy efficiency evaluation results.

According to the scores and rankings, the energy efficiency levels of enterprises are divided into three grades: eliminated, restricted and permitted. The differentiated electricity price policy is implemented by dividing the energy consumption levels of enterprises.

Table 5. User energy efficiency level

Obsolete Enterprises	Restricted Enterprises	Permitted Enterprises
Customer 7	Customer 5	Customer 3
Customer 10	Customer 6	Customer 1
Customer 8		Customer 2
Customer 9		Customer 4

It can be seen from Table 5 that the ranking of enterprises with comprehensive energy efficiency less than the benchmark value shall implement differential electricity price according to the eliminated enterprises; the ranking of enterprises with comprehensive energy efficiency greater than the benchmark value shall implement differential electricity price according to the restricted category; the ranking of enterprises with comprehensive energy efficiency greater than the benchmark value shall implement differential electricity price according to the permitted category.

In order to analyze the effectiveness of the improved grey TOPSIS method, different evaluation methods were adopted to evaluate the energy efficiency of 10 typical customers as well as the benchmark and benchmark values according to the original data and the weight data of indicators. The results can be seen in the following table:

Table 6. Comparison of different evaluation results

Evaluation method	Customer ranking											
	1	2	3	4	5	6	7	8	9	10	Fiducial value	Benchmark values
Fuzzy evaluation method [9]	2	3	4	1	6	7	9	11	12	10	8	5
Analytic hierarchy process [10]	2	3	1	4	6	7	9	12	11	10	8	5
TOPSIS	2	3	4	1	6	7	9	12	11	10	8	5
Improved grayTOPSIS	2	3	1	4	6	7	9	11	12	10	8	5

It can be seen from the above table that the three different evaluation models have basically the same evaluation ranking of industrial customers, which can verify the effectiveness of the model in this paper. Moreover, compared with the traditional TOPSIS method, the improved grey TOPSIS method differs in the ranking of energy efficiency for customer 3 and customer 4. Since the traditional TOPSIS method has the defect that the single Euclidean distance cannot accurately reflect the position of each scheme when calculating the distance of positive and negative ideal solutions, the improved grey TOPSIS proposed in this paper can accurately reflect the measurement relationship between the energy efficiency evaluation of each user and the optimal scheme, and the evaluation results are more accurate. In addition, analytic hierarchy process (AHP) and fuzzy evaluation methods are more dependent on subjective experience, while the method proposed in this paper makes full use of fewer subjective preference factors in the index data, further improving the objectivity of the evaluation results, and the reliability of the final energy efficiency evaluation ranking is higher than other methods.

6. Summary

In order to promote the efficiency of industrial users in this paper, the proposed based on improved grey TOSIS energy efficiency evaluation method through the establishment of comprehensive evaluation index of enterprise use of energy, and through the entropy weight method to calculate index weight, get the user efficiency score, and according to eliminate, restrictions, it allows class division differentiation of electricity power grid enterprise, The real energy consumption data of 10 typical high-energy consumption enterprises in a city were used as an example to verify the effectiveness of the proposed energy efficiency evaluation method. According to the analysis of the final results, the better the performance of the energy consumption index per unit of output value, the higher the final energy efficiency score. According to the evaluation results, the power grid can implement differentiated electricity price for enterprises with high energy consumption and adjust their own energy consumption to provide reference for further optimization of energy efficiency level. In this paper, only the entropy weight method is considered to determine the index weight results are easily affected by the data scale, and the shortcomings of subjective and objective methods can be avoided in the subsequent improved methods.

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