Benefit evaluation of power substitute project for industrial users

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Abstract. Power substitution in industrial field is an important measure for Chinese government to control air pollution, and how to evaluate the benefit of electric energy substitute project effectively is related to the effectiveness of this measure. In this paper, the Comprehensive Benefit evaluation index system of industrial electric energy substitution project is constructed from three dimensions of economy, environment and society, and in order to avoid the deficiency of single comprehensive evaluation method, a combinatorial model based on anp-entropy method and improved TOPSIS method is established. Finally, the rationality of the evaluation method is verified by an example.

1. Introduction

For a long time, due to the industrial structure dominated by industry and the energy consumption structure dominated by coal, China is facing severe environmental and energy constraints. The Chinese government has used electric energy substitution as an important measure to control air pollution, and has made the field of industrial manufacturing as one of the key promotion fields of electric energy substitution. At present, China's power substitution projects in the industrial field of the promotion of a series of difficulties, such as unclear project benefits, financing difficulties and investment risks, they seriously hinder the application of power substitution. Therefore, under the premise of satisfying the basic energy demand of users, how to reasonably optimize the power replacement project has become an important subject of electric energy substitution. On the basis of the existing research, this paper constructs the benefit evaluation Index system of industrial user electric energy substitute project, applies the anp-entropy method and the combination model of improving TOPSIS method, and evaluates the benefit of industrial user's electric energy substitution project.

2. Benefit evaluation Index system of electric energy substitute project for industrial users

According to the characteristics of electric energy substitution project in China, this paper analyzes the influencing factors of project benefit from three dimensions of economic benefit, environmental benefit and social benefit, and constructs the benefit evaluation Index system of electric energy substitute project including 3 dimensions and 14 three level indexes, as shown in Figure 1:
2.1. Economic benefits

The economic benefit embodies the profitability and operation condition of the project, which is the premise of whether the project can be implemented normally and sustainable development. This paper reflects the economic benefits of the project from two aspects of profitability and operational ability.

![Benefit evaluation Index system of electric energy substitute project for industrial users](image)

Figure 1. Evaluation system of benefit index of power substitute project for industrial users.

1) Profitability: Refers to the ability of a project to obtain profits for a certain period of time after it has been put into operation. In this paper, the financial internal rate of return, financial net present value, investment payback period, total investment rate of return of four indicators, the calculation formula is as follows:

\[ \frac{\sum_{t=1}^{n} (CI - CO) t}{(1 + FIRR)^t} = 0 \]  \hspace{1cm} (1)

\[ FNPV = \sum_{t=1}^{n} (CI - CO) t (1 + i_c)^{-t} \]  \hspace{1cm} (2)

\[ P_t = T - 1 + \left[ \frac{\sum_{i=1}^{T} (CI - CO) i}{(CI - CO)T} \right] \]  \hspace{1cm} (3)

\[ ROI = \frac{EBIT}{TI} \times 100\% \]  \hspace{1cm} (4)

Where, \( CI \) is the cash inflow; \( CO \) is the cash outflow; \( n \) is the project life; \( i_c \) is the discount rate set; \( T \) is the number of years in which the cumulative net cash flow of each year is positive or zero for the
first time; $ROI$ is the total investment rate of return; $EBIT$ is the annual profit before interest and tax of the operating period; $TI$ represents the total investment for the project.

(2) Operational capability: refers to the ability of a project to use various assets to earn profits. In this paper, the total asset turnover rate and current Assets turnover index are selected, the calculation formula is as follows:

$$Total\ asset\ turnover = \frac{Operating\ income}{average\ total\ assets} \times 100\%$$  \hspace{1cm} (5)$$

$$Current\ liquidity\ turnover = \frac{average\ balance\ of\ operating\ income}{current\ assets} \times 100\%$$  \hspace{1cm} (6)$$

2.2. Environmental benefits

The environmental benefit of electric power substitution project refers to the impact of project construction on the environmental improvement of the project location. Due to the space problem, this paper focuses on calculating the emission reduction value of $CO_2$, $SO_2$ and $NO_x$. As the implementation of electric power substitution project can increase the proportion of clean energy, it can partially replace the effect of thermal power generation. Therefore, if the proportion of clean energy in the project location is assumed to be $\alpha$, the effective annual replacement electric quantity is considered to be $\alpha$ times the annual replacement electric quantity of the project, and the effective replacement electric quantity of the electric energy replacing project is used as the electric quantity of replacing thermal power generation. According to the annual development report of China electric power (2017), the emission coefficients of $CO_2$, $SO_2$ and $NO_x$ of China's thermal power generation air pollutants are respectively 822g/kWh, 0.39g/kWh and 0.36g/kWh. According to the research results of the report "the amount of major pollutants discharged from 1t coal fired by thermal power plants", the emission reduction values of $CO_2$, $SO_2$ and $NO_x$ are 130 yuan /t, 6,000 yuan /t and 8,000 yuan /t respectively. The calculation formula of its emission reduction value is:

$$Q = Q^* \times \alpha$$ \hspace{1cm} (7)$$

$$V_C = Q \times \rho_{CO_2} \times N_{CO_2}$$ \hspace{1cm} (8)$$

$$V_S = Q \times \rho_{SO_2} \times N_{SO_2}$$ \hspace{1cm} (9)$$

$$V_N = Q \times \rho_{NO_x} \times N_{NO_x}$$ \hspace{1cm} (10)$$

Where, $Q^*$ is the annual replacement electric power of the electric power replacement project, $Q$ is the effective replacement electric power, and $\alpha$ is the proportion of clean energy in the project location; $V$ represents the total emission value of each gas; $N$ represents the unit emission reduction value of each gas, and $\rho$ represents the emission reduction coefficient of each gas.

2.3. Social benefits

Social benefits usually refer to measuring the benefits of a project from the standpoint of the state and society. The application and popularization of electric energy substitution project put forward the requirement for electric power construction, especially the construction of transmission and distribution link, which can promote the development of related industries. And the implementation of the Power replacement project will bring more high quality work environment to employees, so that users feel the benefits of environmental improvement, so as to improve the recognition of energy saving and emission reduction by industrial users and industrial users awareness of energy conservation. Therefore, the social benefits of the project can be measured from promoting the development of related industries, the recognition of energy saving and emission reduction by industrial users, and the awareness of energy conservation of industrial users.
3. Construction of benefit evaluation model for power substitute project of industrial users
According to the evaluation index system constructed, this paper uses the subjective empowerment model based on ANP method and the objective empowerment model based on entropy method to form the combination empowerment, and constructs the anp-entropy method and the combined evaluation model of TOPSIS method in combination with the improved TOPSIS method.

3.1. Combination empowerment model based on subjective and objective integration weights
(1) Determination of subjective weight based on ANP method
Analytic network process (ANP) is different from the simple hierarchical structure of AHP method, and it uses similar network structure to represent the mutual relationship between various elements in a complex system. It is more reasonable to reflect the functional characteristics of complex systems and the interdependence among the elements of the system. The weight steps are calculated as follows:

① Based on the evaluation index system given in figure 1, the above indexes are divided into control layer and network layer through expert evaluation. Then, the criterion relative to the target layer in the control layer is expressed with $P_1, P_2, \ldots, P_n$, and the set of network layer elements is set as $C_1, C_2, \ldots, C_N$. Control layer element $P_k \{s=1,2,\ldots,m\}$ is the criterion, and the element $e_{1j}$ in $C_j$ is set as the sub-criterion. The element in element group $C_j$ is compared with its indirect dominance over $e_{1j}$ according to its influence on $e_{1j}$, and the judgment matrix $W_{ij} = [w_{ij}]$ can be obtained.

② The column vectors of $W_j$ are the order vectors for the degree to which $\{e_{1j}, e_{2j}, \ldots, e_{nj}\}$ in $C_i$ affects $\{e_{1j}, e_{2j}, \ldots, e_{nj}\}$ in $C_j$. If the elements of $C_j$ are not affected by the elements of $C_i$, then $W_{ij} = 0$. In this way, the supermatrix $W$ under $P_S$ control layer can be obtained finally. Taking the control element $P_S$ as the criterion, the importance of each element group in the control element $P_S$ to each element group $C_j$ was compared, and the weighted matrix $A$ was obtained to represent the relationship between the elements in $P_S$. On this basis, the weighted hypermatrix $\overline{W}_{ij} = a_{ij}W_{ij}$ can be obtained.

③ Weighted super matrix $\overline{W}$ limit relative ranking vector $\overline{W}^\omega = \lim_{k \to \infty} \overline{W}^k$. The jth column of $\overline{W}^\omega$ is the weight of each element.

(2) Determination of objective weight based on entropy right method
Entropy method is an objective empowerment method, which embodies the evaluation effect of index in objective information. The more dispersed the data distribution of the index, the greater its inaccuracy, the greater the amount of information it contains, the higher the importance, its weight should also be larger; on the contrary, it shows that the index is of low importance and its weight is small. The calculation steps of the entropy method are as follows:

① It is assumed that there are m evaluation samples and n evaluation indexes for each sample. According to the evaluation index system of industrial users’ electricity substitution project benefit, multiple raw data of indicators are collected to obtain the original data matrix $X = [x_{ij}]$ of indicators. Then, the index is divided into benefit index and cost index, which are dimensionless respectively, and a new decision matrix $Y = [y_{ij}]$ is obtained.

② Based on the decision matrix $Y$, the index is normalized by formula $h_{ij} = \frac{y_{ij}}{\sum_{i=1}^{n} y_{ij}}$ and the entropy value $e_{ij} = -k \sum_{i=1}^{n} h_{ij} \ln h_{ij}$ is calculated, where, $k = \frac{n}{\ln n}$.

③ The indicator of the weight is calculated by formula $w_t = \frac{(1-e_{ij})}{\sum_{i=1}^{m}(1-e_{ij})}$.

(3) Combination empowerment to determine weights
Considering two kinds of empowerment methods, the weight coefficients determined by the subjective and objective empowerment method are multiplied, and then normalized, combined weights $\omega^* = \frac{\sum_{i=1}^{n} w_i w_t}{\sum_{i=1}^{n} w_i w_t}$.
3.2. Benefit evaluation model of electric energy substitute project based on improved TOPSIS model

TOPSIS method is a kind of multi-objective multi-attribute decision method in system engineering, which is based on the standardization matrix after the original data standardization, and selects the optimal and the worst solutions as positive and negative ideal points respectively, and calculates the distance from each evaluation object to positive and negative ideal points respectively. Finally, the evaluation results of each evaluation object are calculated and sorted according to the formula of relative closeness degree, and the advantages and disadvantages are judged. In order to make the evaluation result more scientific and accurate, this paper introduces the variable weight theory to improve the traditional TOPSIS model. The main steps are as follows:

Step 1: Set indexes to evaluate n attributes to evaluate the advantages and disadvantages of m samples. The evaluation value of plan $M_j$ on index $C_i$ is $r_{ij}$ ($i = 1, 2, \ldots, m; j = 1, 2, \ldots, n$), then the multi-objective decision matrix $X$ can be obtained, and the $X$ matrix elements can be standardized to obtain the matrix $Z$.

Step 2: Calculate the weight of variable weights

1) Using combinatorial empowerment method to determine the basic weight vector of each index $W = (w_1, w_2, \ldots, w_m)$.

2) Calculating variable weights by using variable weight model

In variable weight theory, $Z = (z_1, z_2, \ldots, z_m)$ is set as the factor state variable, $W = (w_1, w_2, \ldots, w_m)$ as the factor constant weight variable, and $S(Z) = (S_1(Z), S_2(Z), \ldots, S_m(Z))$ as the state variable weight vector, then the variable weight vector $W(Z) = (W_1(Z), W_2(Z), \ldots, W_m(Z))$ can be expressed by the normalized hadamard product of $W$ and $S(Z)$, that is:

$$W_i(Y) = \frac{W_iS(Z)}{\sum_{i=1}^{m}W_iS(Z)}$$

where: $S_i(Z) = e^{a(z_i - \bar{Z})}$ and $a$ are variable weight factors.

Step 3: Calculate the ideal point separately $z_i^+ = \max(z_{i1^+}, z_{i2^+}, \ldots, z_{im^+})$, negative ideal points $z_i^- = \min(z_{i1^-}, z_{i2^-}, \ldots, z_{im^-})$.

Step 4: Calculate the weighted distance between each evaluation item and the positive ideal solution and the negative ideal solution $D_i^{++}, D_i^{--}, D_i^{+-}, D_i^{-+}$, where:

$$D_i^{+-} = (\sum_{j=1}^{m}[W_i(z_{ij} - z_{i^-})]^2)^{\frac{1}{2}}$$

$$D_i^{-+} = (\sum_{j=1}^{m}[W_i(z_{ij} - z_{i^+})]^2)^{\frac{1}{2}}$$

Step 5: Calculate the relative sticker progress of the evaluation object and the positive ideal solution $C_i' = \frac{D_{i^-}}{D_{i^+} + D_{i^-}}$, the greater the $C_i'$, indicating the greater the overall efficiency of the project.

4. The example analysis

This paper investigates three power substitution projects of an iron and steel group in Shijiazhuang City, Hebei Province: Metallurgical electric furnace replacement coal-fired cupola project, industrial electric boiler replacement coal-fired boiler project, electric kiln replacement coal-fired cupola project. Taking these three industrial power substitution projects as an example, this paper verifies the rationality and scientific nature of the evaluation model constructed in this paper. Based on the annual management summary of each purpose and the combing of the financial statements, this paper gets the quantitative index data according to the formula of the 2nd chapter. And the use of Delphi method, relying on experts rich experience and theoretical knowledge, the importance of qualitative indicators to judge the score, its assignment rules for {Excellent, good, poor, poor, poor}, the corresponding score is {90, 80, 70, 60, 50}. The underlying data of the indicator system is thus obtained, as shown in table 1:

| Index layer | Power replacement project to be evaluated |
|-------------|------------------------------------------|
|             | Metallurgical Electric Furnace Replacement Project | Industrial Electric Boiler Replacement Project | Electric Kiln Replacement Project |
| Table 1: Basic data of benefit index of industrial user electric energy substitute project |
According to the combinatorial Empowerment model in the 3rd chapter, the combined weights of 3 industrial power substitution projects are calculated respectively, which is limited to the space problem, and only the final weight calculation results are listed in this paper, as shown in table 2:

| The serial number | Index                                | Objective weight | Subjective weight | Combination weights |
|-------------------|--------------------------------------|------------------|-------------------|---------------------|
| 1                 | Financial internal rate of return  
(%)                       | 0.201            | 0.174             | 0.348               |
| 2                 | Net present value of finance  
(ten thousand)           | 0.111            | 0.082             | 0.091               |
| 3                 | Payback period of investment  
(year)                    | 0.062            | 0.037             | 0.023               |
| 4                 | Total investment rate of return  
(%)                       | 0.036            | 0.056             | 0.020               |
| 5                 | Total asset turnover             | 0.095            | 0.115             | 0.109               |

Table 2. Combined weight calculation results
Then according to the improved TOPSIS model calculation steps, the similar proximity of three items is obtained, and the scheme is sorted, as shown in Table 3.

Table 3. Weighted distance and relative proximity calculation

| Power replacement project | Weighted positive distance | Weighted negative distance | Relative proximity $C_j$ | Ranking |
|---------------------------|---------------------------|---------------------------|--------------------------|---------|
| Metallurgical Electric Furnace Replacement Project | 0.2077 | 0.1990 | 0.4893 | 2 |
| Industrial Electric Boiler Replacement Project | 0.1193 | 0.2056 | 0.6329 | 1 |
| Electric Kiln Replacement Project | 0.2083 | 0.1846 | 0.4698 | 3 |

From table 3, we know that the relative closeness of 3 electric energy substitution projects is sorted by: industrial Electric boiler substitution project > Metallurgical electric furnace substitution project > Electric kiln replacement project, which shows that the comprehensive benefit of industrial electric boiler replacement project is the best, followed by metallurgical electric Furnace project, electric kiln replacement project benefit is the least. After analysis, it can be seen that all aspects of industrial electric boiler replacement project indicators are relatively excellent, especially in terms of economic and environmental benefits, while metallurgical furnace replacement project Although the economic efficiency indicators are very good, but the environmental benefits of the indicators are poor, the results of the comprehensive evaluation of its benefits have a greater impact. Among them, the total asset turnover rate of industrial electric boiler replacement project is the lowest, and there is also a big gap in its CO$_2$ emission reduction index. Therefore, through contract energy management, financial leasing and other investment models to improve the turnover of total project assets, reduce business risk, and speed up the development of new technologies and equipment, further improve the energy efficiency of electric boilers, reduce the cost of projects, and further improve the efficiency of industrial electric boiler projects.

5. Conclusion
Based on the principle of Evaluation Index system construction, this paper constructs the comprehensive Benefit evaluation index system of industrial electric energy substitute project from three dimensions of economy, environment and society, establishes the combination evaluation model based on anp-entropy method and improved TOPSIS method, and finally verifies the scientific and rationality of the whole evaluation Index system and evaluation method by an example. The comprehensive benefit evaluation method of industrial electric energy substitute project proposed in
this paper can provide reference basis for industrial users to follow up investment decision and choose electric energy Substitute project, which is beneficial to project promotion and implementation.

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