Research on multi-level index evaluation method of Coal-to-Electricity Project

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Abstract. According to the actual characteristics of "coal to electricity" project, the comprehensive benefit evaluation index system of "coal to electricity" project was established from three dimensions of social benefit, economic benefit and distribution network operation. This paper proposed a combination weighting method combining the entropy weight method and the analytic hierarchy process, which made up for the shortcomings of the single valuation method. It selected three different "coal to electricity" projects in Shanxi Province as examples, scored and compared their comprehensive benefits and proposed improvement and treatment plans for the problems existing in the project, which was conducive to the further implementation and promotion of the "coal to electricity" project.

1. Introduction
With the acceleration of industrialization and urbanization, the haze weather has increased significantly in recent years. Among them, Shaanxi Province is particularly severe. It is a region with high smog, which poses a great threat to the health and life of people in this area [1]. In 2013, the Shaanxi People's Government promulgated the “Shaanxi Provincial Five-Year Action Plan for “Pollution Control, Haze Reduction, and Blue Sky Protection” (2013-2017)”, which clearly proposed the annual average concentration of fine particulate matter (PM2.5) and respirable particulate matter (PM10) The decline indicator [2]. In June 2015, the Shaanxi Development and Reform Commission issued the Implementation Plan for Substituting Coal-fired Consumption Reduction in the Guanzhong Region from 2015 to 2017, proposing a comprehensive control plan for the total consumption of coal-fired consumption and the completion of the replacement of coal with electricity [3]. As one of the main causes of air pollution in winter in Shaanxi, the pollution of scattered coal heating in some rural areas in Shaanxi has been paid attention to. The "coal to electricity" project for winter heating is gradually being implemented in some areas [4].

At present, domestic work has been carried out on the actual benefit evaluation of the "electric heating" project. Literature [5] analyzed the prospects of electric energy substitution technology in the end user market, systematically introduced the application advantages of electrical heating technology from the aspects of applicability and economy; literature [6] based on the “coal to electricity” project in Mentougou District, Beijing The monitoring data of environmental quality has obtained the contribution of the "coal to electricity" project to the treatment of air pollution; the literature [7-8] analyzed the heating load of the "coal to electricity" project for the change in the proportion of heating energy; Reference [9] takes the “coal to electricity” project in Liaoning as an example, analyzes and calculates the impact of the project’s marginal cost on the province’s GDP, and proves that the implementation of the “coal to electricity” project is conducive to regional economic growth; literature
On the basis of summarizing a variety of heating methods, the evaluation indicators for comparison of various heating methods are proposed from different dimensions such as pollution emissions, energy consumption, and economy. However, the research work at this stage only involves a certain aspect of the "coal to electricity" project. It does not comprehensively analyze the comprehensive benefits of the "coal to electricity" project, and its evaluation index system and benefit evaluation method are not perfect.

This article establishes a comprehensive benefit evaluation index system for the "coal to electricity" project, which can comprehensively evaluate the actual benefits of the project, and its evaluation results can provide guidance and suggestions for the implementation of the "coal to electricity" project to avoid similar problems in the "coal to electricity" project of other regions.

2. Determine the evaluation index

2.1. Social Benefit Index

Toxic gases such as NOx, SOx, and CO emitted during incomplete combustion using small, old boilers for coal-fired heating will greatly exceed national standards, and coal-fired heating without purification treatment will generate a large amount of smoke and dust, which will cause serious pollution air.

a) Calculation of pollutant emission reduction. The implementation of the "coal to electricity" project can greatly reduce the emissions of soot and pollutants from the burning of bulk coal, and the increase in electricity consumption is converted accordingly by the increment of coal burning in power plants. The emission factors listed in Table 1 can be used to calculate the reduction of NOx, SO2, CO and soot [11].

The calculation formula of pollutant emission reduction is:

$$
\Delta m_i = K_i \times T - k_i \times t
$$

Where $\Delta m_i$ is the emission reduction of pollutants, $K_i$ and $k_i$ are the emission factors of the $i$-th pollutant of bulk burning coal and coal for power generation, $T$ is the place where "coal to electricity" is implemented. Reduced amount of bulk coal burned, kg,$t$ is the increment of coal burning in power plants converted by increased power consumption. According to the latest statistical data from the National Bureau of Statistics, the power plant requires about 360 g of standard coal per kilowatt-hour of electricity generation.

Table 1. Pollutant emission factor table

| Category               | NOx emission factor | SO2 emission factor | CO emission factor | Soot emission factor |
|------------------------|---------------------|---------------------|--------------------|----------------------|
| Bulk coal              | 2.81                | 17.11               | 65.14              | 6.26                 |
| Coal for power generation | 0.79               | 0.37                | 0.01               | 0.15                 |

b) Environmental value factor. The severity of the environment affected by different pollutants varies and can be calculated in a unified amount of environmental value. The common environmental value factors of common pollutants in the power industry are shown in Table 2 [12].

Table 2. Pollutant emission factor table

| Category | NOx emission factor | SO2 emission factor | CO emission factor | Soot emission factor |
|----------|---------------------|---------------------|--------------------|----------------------|
| Universal | 7.95                | 6.07                | 1.00               | 2.20                 |

According to the calculated NOx, SO2, CO and soot emission reductions in Table 1, the total environmental value of pollutant emission reductions after the implementation of the "coal to electricity" project in the region can be calculated:

$$
V_e = \sum \Delta m_i \times V_i
$$
Where $V_m$ is the total environmental value of pollutant emission reduction after the implementation of the "coal to electricity" project in the region, and $V_i$ is the environmental value factor of the $i$-th pollutant.

Through the investigation of typical users in the area where the "coal to electricity" project is implemented, the effect of the implementation of the transformation is evaluated from the user's side, and the result analysis is then carried out.

a) Room temperature pass rate. The actual measurement of the room temperature is collected, and the heating effect of the "coal to electricity" electric heating equipment is evaluated according to the heating demand on the user side. The standard of heating temperature in the winter in Shaanxi is 16 ℃~24 ℃, the actual room temperature of a certain percentage of typical users is collected, and the greenhouse qualification rate on the user side is statistically obtained.

b) User satisfaction. User satisfaction is a comprehensive subjective indicator, mainly covering the following factors: the comfort level of heating effect, the convenience of electric heating operation and the presence or absence of noise interference of equipment, etc. Each influencing factor can have different emphasis according to the actual situation;

c) User economic indicators. In view of the cost economy considered by the user, the user economic index refers to whether the electric heating cost paid by the user after the implementation of the "coal to electricity" electric heating equipment project has economic advantages compared with the cost of the coal-fired heating, which is qualitative. Evaluation indicators.

2.2. Economic benefit index

The "coal to electricity" project needs to be completed by the power supply department in the area where it is located. The general life cycle of the distribution network transformation is set to 25 a.

a) Internal rate of return IRR. The internal rate of return in this paper specifically refers to the discount rate index corresponding to the cumulative net cash flow of the "coal to electricity" project during the life cycle, and the calculation formula is as follows:

$$\sum_{t=1}^{z} (M_f - M_o) (1 + I_{IR})^{-t} = 0$$  \hspace{1cm} (3)

Where $M_f$ is the number of cash inflows, $M_o$ is the number of cash outflows, $t$ is the number of periods, $z$ is the number of life-cycle calculation periods.

b) Net present value NPV. The net present value of the "coal to electricity" project refers to the sum of the present value of the discounted annual net cash flow during the life of the project to the beginning of the project implementation based on the discount rate set by the power industry or its benchmark rate of return. The dynamic indicator of profitability during the life of the "coal to electricity" project, where $\lambda$ is the discount rate.

$$NPV = \sum \frac{M_f - M_o}{(1 + \lambda)^t}$$ \hspace{1cm} (4)

c) Payback period PP. The investment recovery period of the "coal to electricity" project refers to the time required by the project’s net income to repay the total investment of all expansion and reconstruction, and is the main static indicator for financial evaluation of the investment recovery capacity of the power grid reconstruction project.

$$P_c = t_0 - 1 + \frac{\sum (M_f - M_o)}{M_f - M_o}$$ \hspace{1cm} (5)

Where $t_0$ is the number of years when the cumulative cash flow is positive for the first time, $T$ is the total number of years of investment.

d) The total return on investment $ROI$. The total investment rate of return in this paper specifically refers to the ratio of the annual average pre-tax profit before the normal operation of the "coal to
electricity" project or the ratio of the annual pre-interest-tax profit to the total investment of the project, which is the assessment of the life of the "coal to electricity" project Indicators of internal profitability.

\[ R_{\text{oi}} = \frac{E_{\text{bi}}}{T_I} \times 100\% \]  

(6)

Where \( E_{\text{bi}} \) is the annual average pre-tax profit, \( T_I \) is the total investment of the project.

The cost control index refers to the rate of change of the actual input cost of the project compared to the planned input cost, and can reflect the cost control of the "coal to electricity" project.

2.3. Operation status of distribution network

a) Voltage qualification rate. After the implementation of the "coal to electricity" project, the total power consumption in the heating season in rural areas will increase significantly, and there is a high probability that the rural distribution network will have low voltage problems. The voltage detection points are reasonably distributed according to the distribution network in the area. The allowable deviation of the power supply voltage of the low-voltage distribution network is -10% to 7% of the standard voltage, and the interval score can be set according to this standard.

b) Harmonic distortion rate. Electric heating equipment often contains non-linear loads and is a common source of harmonics. The switching process will cause the current or voltage distortion rate to increase and generate harmonics, affecting the normal operation of harmonic-sensitive equipment, such as a heat storage. When the electric boiler is switched on and off, the harmonic current distortion rate can be up to 70% \[15\]. This article selects the harmonic current distortion rate to evaluate the harmonic effects caused by the "coal to electricity" project.

\[ T_{\text{HD}} = \sqrt{\frac{\sum_{k=1}^{M} I_k^2}{I_0^2}} \times 100\% \]  

(7)

Where \( T_{\text{HD}} \) is the total harmonic current distortion rate, \( I_0 \) is the effective value of the fundamental current, \( I_k \) is the effective value of the k-th harmonic current, \( M \) is the harmonic order.

c) Frequency of voltage sag. After the implementation of the "coal to electricity" project, the use of electric heating equipment will be higher at the same time, and the startup time will be more concentrated, which will often cause large startup currents and cause voltage sags. In this paper, the system average root mean square value SARFI variation frequency is used to evaluate the voltage sag impact caused by the "coal to electricity" project.

\[ S_{\text{SARFI}} = \frac{\sum N_i}{N_v} \]  

(8)

Where \( S_{\text{SARFI}} \) is the frequency of voltage sag events in a system or a single measurement point when the voltage rms is at the threshold; \( H \) is the voltage rms threshold, generally 90; \( N_v \) is The total number of users of the evaluation sample; \( N_i \) is the number of users affected by the i-th voltage sag event.

d) Reliability of power supply. The power supply reliability rate is one of the basic indicators that characterize the power supply level of the power grid. In order to reflect the possible impact of the "coal to electricity" project, the statistical time is selected as the duration of the entire heating season.

3. simulation examples

3.1. Basic situation of the project

This paper selects three completed “coal to electricity” projects in rural areas of the suburbs of Weinan City, Shanxi Province for case analysis.
a) Item 1. The “coal to electricity” project 1 is implemented in a village in the suburbs of the plains. A total of 703 households in the village were “coal to electricity” and the electric heating equipment was an air source heat pump. The project was completed in September 2017;
b) Project 2. The “coal to electricity” project 2 is implemented in a village in the outer suburbs of the mountain range. As a pilot area of “coal to electricity”, the village completed the transformation of 503 households in 2014. The electric heating equipment is mainly electric boilers and heat pumps;
c) Item 3. "coal to electricity" project 3 is implemented in a village in the far suburbs of the valley. A total of 196 households have completed the "coal to electricity" transformation, of which 180 use regenerative electric boilers as electric heating equipment, and the rest use Thermal electric boiler.

3.2. Index weight determination
The entropy weight method is used to weight each index, the initial data matrix is constructed for the actual data of the 3 projects, and the standardization processing is performed, and then the information entropy of each index is obtained, and the objective weights are solved, as shown in Table 3.

| First-level indicators | Second-level indicators classification | Second-level indicators | Objective weights | Subjective weights | Combined weights |
|------------------------|---------------------------------------|-------------------------|------------------|-------------------|-----------------|
| Social benefit 0.333   | Environmental Benefit Index           | Environmental emission reduction value 0.145 0.370 0.302 | Room temperature pass rate 0.127 0.110 0.115 | User satisfaction 0.345 0.205 0.247 | Per capita cost change 0.127 0.110 0.115 |
| User side situation    | Household electricity consumption increment 0.256 0.205 0.221 |
| Power supply side      | Internal Rate of Return 0.197 0.200 0.199 |
|                        | Net present value 0.197 0.200 0.199 |
|                        | Payback period 0.198 0.200 0.199 |
|                        | Total return on investment 0.200 0.200 0.200 |
| Economic benefit 0.333 | Cost control index                   | Change rate of total investment 0.208 0.200 0.203 |
|                        | Voltage pass rate 0.163 0.135 0.143 |
|                        | Harmonic distortion rate 0.141 0.345 0.284 |
|                        | SA RFI(90%) 0.253 0.295 0.281 |
|                        | Power supply reliability rate 0.152 0.135 0.140 |
| Distribution network operation 0.333 | Power quality index                | Peak shift valley filling effect 0.139 0.050 0.078 |
|                        | User side situation                  | Load rate of main transformer in low season 0.152 0.040 0.074 |

b) Secondly, establish a discriminant matrix according to the analytic hierarchy process, and obtain the discriminant matrix of the index by weighing the importance of the index by the expert group. For example, in this paper, the discriminant matrix $P$ of three first-level indicators of social benefit index, economic benefit index and distribution network operation status is:

$$P = \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

(9)
Find the maximum feature $QI=(0.57, 0.57, 0.57)$ of the discriminant matrix, derive the feature vectors in turn and normalize them to obtain the subjective weight. The subjective weights of the three first-level indicators in this paper are all 0.333. According to this method, the subjective weights of the lower-level indicators are continuously solved to obtain the subjective weight values of each layer of the total evaluation system, as shown in the subjective weight column in Table 3.

c) Finally, the combined weights are assigned to each index and calculated, and the final combined weights can be obtained, as shown in Table 3.

3.3. Evaluation of indicators at all levels
According to the social benefits, economic benefits and distribution network operation of the three projects, each index is scored item by item. The indicators of social benefits and economic benefits are evaluated by the expert scoring method. The distribution network operation indicators are based on the relevant national standards, and the standard range value is 60 points, and the scores are reasonable and evenly distributed. In combination with the weight values given in Table 3, the higher-level indicator scores are obtained. The final evaluation results are shown in Table 4.

| Indicator item                                   | Item 1 | Item 2 | Item3 |
|-------------------------------------------------|--------|--------|-------|
| Environmental emission reduction value          | 90.0   | 70.0   | 80.0  |
| Room temperature pass rate                      | 100.0  | 80.0   | 100.0 |
| User satisfaction                               | 85.0   | 70.0   | 70.0  |
| Household economy                               | 85.0   | 85.0   | 85.0  |
| Household electricity consumption increment     | 90.0   | 70.0   | 85.0  |
| Internal rate of return                         | 85.0   | 70.0   | 85.0  |
| Net present value                               | 70.0   | 60.0   | 70.0  |
| Investment recovery period                      | 85.0   | 70.0   | 85.0  |
| Total return on investment                      | 90.0   | 70.0   | 85.0  |
| Change rate of total investment                 | 78.0   | 60.0   | 75.0  |
| Voltage pass rate                               | 90.0   | 78.7   | 69.3  |
| Harmonic distortion rate                        | 60.0   | 40.0   | 86.4  |
| SARFI                                           | 90.0   | 85.0   | 70.0  |
| Power supply reliability rate                   | 72.4   | 87.2   | 81.5  |
| Peak shift valley filling effect                | 90.0   | 85.0   | 90.0  |
| Load rate of main transformer in low season     | 85.0   | 80.0   | 80.0  |
| Total social benefits                           | 89.3   | 72.9   | 79.9  |
| Total economic benefit                          | 81.6   | 66.0   | 78.0  |
| Distribution network operation status total score| 78.6   | 71.2   | 78.5  |
| Total comprehensive benefit score               | 83.1   | 70.0   | 78.8  |

Judging from the results, the social benefits of Project 1 are almost extremely successful, the economic benefits are successful, the distribution network operation status is basically successful, and the overall comprehensive benefits belong to success; the social benefits of Project 2 are basically successful, and the economic benefits are poor only Partial success is achieved, the distribution network operation status is basically successful, and the overall comprehensive benefit has just reached the basic success level; the social benefits, economic benefits, and distribution network operation status of Project 3 are basically successful, and the overall comprehensive benefit is also at a successful level.

4. Conclusion
An index system for comprehensive benefit evaluation of the "coal to electricity" project was established, and the distribution network operation status indicators were innovatively added to the index system to make the evaluation system more comprehensive. Combining the entropy weight method and the analytic hierarchy process to weight the indicators at all levels, a comprehensive
benefit evaluation process for the "coal to electricity" project was proposed. Finally, a comprehensive benefit evaluation was carried out based on the case of the “coal to electricity” project in three types of rural areas in Shaanxi, and the governance methods and measures were given for low sub-items, which is important for the future implementation and promotion of the “coal to electricity” project.

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