Comprehensive Benefit Evaluation of Electricity Substitution Projects Based on AHP-Grey Relational Degree Model

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Abstract. Electricity substitution has become a critical way to further promote the new energy consumption. This paper has established an AHP-Grey relational degree model to analyze the comprehensive benefit brought by electricity substitution projects. The index system of this model focuses on the carbon emission reduction and pollution emission reduction brought by electricity substitution projects through promoting new energy consumption. An example analysis was carried out to prove the practicability of the model and its result.

1. Introduction
Electricity is the key secondary energy to transform the new energy into an energy form, which users can use it directly. Along with the rapid development of UHV transmission network construction, a large amount of new energy can be transformed at generation side and transmitted from west China to east China. At the same time, electricity substitution at demand side is now in progress to further promote the consumption of new energy. However, how to select optimal project among electricity substitution projects and to achieve the maximum comprehensive benefit has become an urgent problem recently.

As concluded from domestic and foreign literatures, there is less research in the comprehensive benefit evaluation of electricity substitution projects. This paper has built a evaluation model based on AHP and grey relational degree theory to calculate the comprehensive benefit of several electricity substitution projects. An example analysis was carried out to verify the practicability and rationality of the model and method.

2. Index system establishment
The index system should be established according to the following principles:

   Authenticity. Index system should be established in accordance with the actual operation situation and the project’s internal and external environment. Field research result and literature review results should be taken into consideration as well.

   Comparability. Indexes should be able to perform horizontal comparison and vertical comparison. Horizontal comparison means index data can be compared among different companies, vertical comparison means index data can be compared among the different time periods within on company.
Operability. The difficulty during data collection and its integrity should be taken into consideration when establishing the index system in order to provide convenience for the comprehensive benefit calculation.

The index system should be separated into 3 categories, including finance, marketing and social benefit. This separation was made according to national policy, business operation and project situation. The energy efficiency and net present value rate is determined to be the core index. The comprehensive benefit evaluation index system is shown in Table 1.

Table 1. Comprehensive benefit evaluation index

| Categories         | Indexes                                      | Codes |
|--------------------|----------------------------------------------|-------|
| Core index         | Energy efficiency/Net present value rate     | X₀    |
| Finance            | Internal rate of return                      | X₁    |
|                    | Payback period                               | X₂    |
| Marketing          | Market share                                 | X₃    |
|                    | Customer satisfaction rate                   | X₄    |
|                    | Users’ energy utilization                    | X₅    |
|                    | Energy demand forecast accuracy              | X₆    |
| Social Benefits    | Dust pollution rate                          | X₇    |
|                    | SOx pollution rate                           | X₈    |
|                    | NOx pollution rate                           | X₉    |
|                    | COx pollution rate                           | X₁₀   |
|                    | Wind curtailment                             | X₁₁   |
|                    | Solar energy curtailment                    | X₁₂   |

3. Comprehensive benefit evaluation model

3.1. The AHP weighting method

The AHP weighting method is calculated as follows:

1) X represents the comprehensive benefit, which includes \( X = \{X₁, X₂, ..., X₃\} \), and their weight is \( W = \{W₁, W₂, ..., W₃\} \). \( j \) represents decision indexes and its number is \( m \), \( k \) represents evaluation objectives and its number is \( n \). The rest indexes can be done in the same manner.

2) AHP’s scale meaning Definition.

3) Judgement matrix establishment through pairwise comparison.

4) Weight calculation.

5) Consistency check.

3.2. The grey relational degree model

After the AHP weighting calculation, the grey relational degree model can be built using index data matrix:

\[
A = \begin{pmatrix}
X_{11} & X_{12} & \ldots & X_{1n} \\
X_{21} & X_{22} & \ldots & X_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
X_{m1} & X_{m2} & \ldots & X_{mn}
\end{pmatrix} \tag{1}
\]

The model can be calculated as follows:

1) Core index data collecting and form the core index data vector:

\[
X₀ = (X₀₁, X₀₂, ..., X₀ₙ)
\tag{2}
\]

2) Index data normalization:
The normalization process in this paper was carried out using averaging method to remove the dimensional difference between indexes:

\[ X'_{jk} = \frac{X_{jk}}{\frac{1}{m} \sum_{j=1}^{m} X_{jk}} \quad (3) \]

3) D-value calculation
D-value calculation between every index and core index:

\[ |X'_{j0} - X'_{jk}| \]

Maximum and minimum D-value calculation:

\[ \min_{j=1}^{m} \min_{k=1}^{n} |X'_{j0} - X'_{jk}| \quad (5) \]

\[ \max_{j=1}^{m} \max_{k=1}^{n} |X'_{j0} - X'_{jk}| \quad (6) \]

4) Grey relational degree calculation
The grey relational degree coefficient between every index and core index should be calculated using formula (7):

\[ \theta_{jk} = \frac{\min_{j} \min_{k} |X'_{j0} - X'_{jk}| + \lambda \max_{j} \max_{k} |X'_{j0} - X'_{jk}|}{|X'_{j0} - X'_{jk}| + \lambda \max_{j} \max_{k} |X'_{j0} - X'_{jk}|} \quad (7) \]

\( \lambda \) represents distinguishing coefficient, of which data range is (0,1). In this paper, we decide the value of \( \lambda \) is 0.5.

The average value of grey relational degree coefficient should be calculated using formula (8) and obtain the grey relational degree of each index:

\[ E = \frac{1}{n} \sum_{j=1}^{n} \theta_{jk} \quad (8) \]

4. Example analysis

| Table 2. Data |
|---------------|
| Indexes       | Project A | Project B | Project C |
| Energy efficiency/\% | 85.2      | 88.1      | 82.5      |
| Net present value rate | 0.85      | 1.22      | 0.75      |
| Internal rate of return/\% | 12.5      | 13.2      | 11.5      |
| Payback period/year | 7.4       | 6.9       | 7.8       |
| Market share/\% | 90.5      | 99.5      | 88.2      |
| Customer satisfaction rate/\% | 99.5      | 92.5      | 97.6      |
| Users’ energy utilization/\% | 98.2      | 95.4      | 97.6      |
| Energy demand forecast accuracy/\% | 99.9      | 95.6      | 99.9      |
| Dust pollution rate/(g/kWh) | 0.56      | 0.35      | 0.66      |
| SOx pollution rate/(g/kWh) | 2.10      | 2.00      | 1.90      |
| NOx pollution rate/(g/kWh) | 3.10      | 2.20      | 2.50      |
| COx pollution rate/(g/kWh) | 3.10      | 2.20      | 2.15      |
| Wind curtailment/\% | 20.4       | 18.5      | 18.9      |
| Solar energy curtailment/\% | 42.1      | 35.6      | 37.1      |
The model established in this paper will be used in the electricity substitution projects in North China. The data is shown in Table 2.

The weight of indexes can be obtained through AHP method, as it’s shown in Table 3.

Table 3. Weight of indexes

| Indexes                                | Weight |
|-----------------------------------------|--------|
| Internal rate of return                 | 0.06   |
| Payback period                          | 0.04   |
| Market share                            | 0.05   |
| Customer satisfaction rate              | 0.07   |
| Users’ energy utilization               | 0.05   |
| Energy demand forecast accuracy         | 0.11   |
| Dust pollution rate                     | 0.05   |
| SOx pollution rate                      | 0.11   |
| NOx pollution rate                      | 0.11   |
| COx pollution rate                      | 0.11   |
| Wind curtailment                        | 0.12   |
| Solar energy curtailment                | 0.12   |

After the normalization process, the D-value of different indexes can be obtained through the calculation of formula (4). In this paper, we selected 2 core indexes (energy efficiency and net present value rate), hence the grey relation degree of the 2 core indexes is demonstrated in Table 4.

Table 4. Grey relation indexes

| Projects          | Energy efficiency | Net present value rate |
|-------------------|-------------------|------------------------|
|                   | A     | B     | C     | A     | B     | C     |
| Indexes           |       |       |       |       |       |       |
| Internal rate of return | 0.850 | 0.843 | 0.861 | 1.981 | 1.976 | 1.988 |
| Payback period    | 0.897 | 0.903 | 0.891 | 1.952 | 1.960 | 1.946 |
| Market share      | 0.876 | 0.865 | 0.879 | 1.927 | 1.914 | 1.931 |
| Customer satisfaction rate | 0.825 | 0.836 | 0.828 | 1.863 | 1.877 | 1.867 |
| Users’ energy utilization | 0.872 | 0.875 | 0.873 | 1.922 | 1.926 | 1.923 |
| Energy demand forecast accuracy | 0.752 | 0.760 | 0.752 | 1.764 | 1.776 | 1.764 |
| Dust pollution rate | 0.866 | 0.913 | 0.844 | 1.828 | 1.914 | 1.790 |
| SOx pollution rate | 0.745 | 0.754 | 0.764 | 1.755 | 1.768 | 1.781 |
| NOx pollution rate | 0.720 | 0.784 | 0.762 | 1.719 | 1.809 | 1.778 |
| COx pollution rate | 0.710 | 0.776 | 0.780 | 1.705 | 1.799 | 1.804 |
| Wind curtailment  | 0.726 | 0.745 | 0.741 | 1.728 | 1.756 | 1.750 |
| Solar energy curtailment | 0.718 | 0.751 | 0.744 | 1.717 | 1.764 | 1.753 |

Using formula (8), the grey relation degree of every index is calculated and shown in Table 5.
Table 5. Grey relation degree calculation results

| Indexes                         | Energy efficiency | Net present value rate | Average |
|---------------------------------|-------------------|------------------------|---------|
| Internal rate of return         | 0.851             | 1.982                  | 1.417   |
| Payback period                  | 0.897             | 1.952                  | 1.425   |
| Market share                    | 0.874             | 1.924                  | 1.399   |
| Customer satisfaction rate      | 0.830             | 1.869                  | 1.350   |
| Users’ energy utilization       | 0.874             | 1.924                  | 1.399   |
| Energy demand forecast accuracy | 0.754             | 1.768                  | 1.261   |
| Dust pollution rate             | 0.874             | 1.844                  | 1.359   |
| SOx pollution rate              | 0.754             | 1.768                  | 1.261   |
| NOx pollution rate              | 0.755             | 1.769                  | 1.262   |
| COx pollution rate              | 0.756             | 1.769                  | 1.263   |
| Wind curtailment                | 0.738             | 1.745                  | 1.242   |
| Solar energy curtailment        | 0.738             | 1.745                  | 1.242   |

As the result shows, the grey relation degree of payback period, internal rate of return, market share and users’ energy utilization is higher than other indexes. In addition, grey relation degree of payback period payback period is 1.425, which is the highest among those. The result of the rest of indexes remains between (1.242, 1.359). Therefore, reducing cost and improving the income of each project is the key method to promote the comprehensive benefit of electricity substitution projects. Besides, advanced technologies should be applied to improve market share and users’ energy utilization.

5. Conclusion

Electricity substitution projects are able to transform several new energy into electricity, which is able to be used by the users directly. Hence electricity substitution is becoming a critical way to further improve new energy consumption.

This paper has built an AHP-Grey relational degree model to analyze the comprehensive benefit of electricity substitution projects. The rationality and applicability of present model was proved by example analysis. As the result shows, the payback period, internal rate of return, market share and users’ energy utilization are key factors which should be further improved when designing the project schemes.

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