Grey relational analysis for Energy Storage Service Provider Influencing Factors

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Abstract—China faces the problems of abandoning wind and light and environmental pollution. Energy conservation and emission reduction as a new technology can effectively solve the above problems. In the process of building a Energy Storage Services project, the issue of Influencing Factors is the focus of attention. Aiming at the problem of Influencing Factors in Energy Storage Services systems, a Influencing Factors method based on grey correlation analysis is proposed. Adopting this method, one can avoid the influence of subjective factors on weight assignment through grey correlation analysis. Gray relational analysis can objectively analyze the proportion of each index in supplier's production consideration.

1 Introduction

As China's economic development enters a new normal, there are problems such as low energy efficiency use of traditional energy and low level consumption of new energy. Simultaneously, there are problems such as smog and carbon emissions in environmental protection. Energy Storage Services system is a new technology that integrates new energy and traditional energy. By adopting a complementary energy supply mode between multiple energy sources, it can improve the efficiency of new energy utilization and alleviate the contradiction between energy supply and demand. Therefore, it is most important to choose the most suitable supply. Business becomes the focus of research on Energy Storage Services systems [1-3]. For the supplier's choice, we must establish a Energy Storage Services system evaluation index system; second, we should use the evaluation method to evaluate the candidate suppliers. The main contribution of this paper is to establish a set of Energy Storage Services system evaluation index system. In the evaluation process, in order to improve the objectivity of evaluation, the grey correlation degree method is used to calculate the weight, so as to avoid subjective evaluation.

Many researchers have devoted themselves to the issue of Influencing Factors. Xu et al.[4] proposed considering the diversity of different equipment parameters and investment costs, a Influencing Factors method based on the Analytic Hierarchy Process (AHP) weight calculation method to obtain the Comprehensive Evaluation Index (CEI) is proposed.; Seyedmohsen and Kash [5] proposed a Influencing Factors method based on a Bayesian Network (BN) in considering the elasticity of Influencing Factors criteria.; Under the background that multi-energy complementary systems are increasingly valued by governments and enterprises, there are few studies on Influencing Factors in the construction of multi-energy complementary systems in the existing literature.

From the perspective of Energy Storage Services system, this paper studies the optimal combination of wind, light, natural gas and energy storage equipment suppliers, and builds a Energy Storage Services system supplier evaluation index system. At the same time, in order to avoid the subjectivity of the evaluator, choose grey relational analysis. At last, The grey theory evaluate Energy Storage Services system vendors and to illustrate and validate them through specific examples.

2 Grey Relational Analysis for Selection of Evaluation Index and Determination of Weight

2.1 Grey Relational Analysis

Let the observation data \( x_i(k)(k = 1, z\ldots, n) \) is the vector for the evaluation index. [10] The steps of the gray correlation analysis method are as follows:

1) Let the reference vector is:

\[
X_0 = \{x_0(1), x_0(2),\ldots, x_0(m)\}
\]

2) The vector being compared is:

\[
X_i = \{x_i(1), x_i(2),\ldots, x_i(m)\}, \quad i = 1, 2, \ldots, n
\]

Two vectors of time series are described by X0 and Xi, respectively. Let the observation data \( x_i(k)(k = 1, 2, \ldots, n) \) be the vector for the evaluation index, and the vector for the evaluation index be \( X_0 = \{x_0(1), x_0(2), \ldots, x_0(n)\} \).

\[
X_0 = \{x_0(1), x_0(2), \ldots, x_0(n)\}
\]

(3) Through a series of calculations, the灰色相关矩阵Gray Correlation Matrix (GCM) can be obtained. The calculation process is as follows:

1) For each index, the original data is normalized, and the data before and after normalization are shown in Table 2.

| Index | Original Data | Normalized Data |
|-------|---------------|-----------------|
| Index 1 | 5.0           | 0.933           |
| Index 2 | 8.5           | 0.885           |
| Index 3 | 12.0          | 0.800           |

2) For each index, calculate the correlation coefficient between the reference vector and the observed index vector, and the correlation coefficients between the reference vector and the observed index vector are shown in Table 3.

| Index 1 | X_1(k) | X_2(k) | X_3(k) |
|---------|--------|--------|--------|
| Index 1 | 0.9   | 0.8   | 0.7   |
| Index 2 | 0.7   | 0.6   | 0.5   |
| Index 3 | 0.5   | 0.4   | 0.3   |

3) Calculate the average value of the correlation coefficient, and the average value of the correlation coefficient is shown in Table 4.

| Index | Average Correlation Coefficient |
|-------|---------------------------------|
| Index 1 | 0.85                           |
| Index 2 | 0.65                           |
| Index 3 | 0.45                           |

4) Calculate the normalized value of the average correlation coefficient, and the normalized value of the average correlation coefficient is shown in Table 5.

| Index | Normalized Average Correlation Coefficient |
|-------|--------------------------------------------|
| Index 1 | 0.95                                       |
| Index 2 | 0.80                                       |
| Index 3 | 0.65                                       |

5) The normalized correlation coefficient is obtained by subtracting the previous step from the normalized average correlation coefficient, and the normalized correlation coefficient is shown in Table 6.

| Index | Normalized Correlation Coefficient |
|-------|-----------------------------------|
| Index 1 | 0.90                              |
| Index 2 | 0.75                              |
| Index 3 | 0.50                              |

6) The grey correlation coefficient is obtained by normalizing the normalized correlation coefficient, and the grey correlation coefficient is shown in Table 7.

| Index | Grey Correlation Coefficient |
|-------|-------------------------------|
| Index 1 | 0.90                          |
| Index 2 | 0.75                          |
| Index 3 | 0.50                          |

7) The evaluation table is obtained by comparing the grey correlation coefficient of each index, and the evaluation table is shown in Table 8.

| Index | Evaluation |
|-------|------------|
| Index 1 | Good       |
| Index 2 | Good       |
| Index 3 | Good       |

The evaluation table shows the evaluation of each index. If the grey correlation coefficient of the index is large, the index is evaluated as good. According to the evaluation table, the final evaluation result is obtained.

\[
\begin{align*}
1 & \text{ Let the reference vector is:} \\
& X_0 = \{x_0(1), x_0(2), x_0(3), \ldots, x_0(m)\} \\
2 & \text{ The vector being compared is:} \\
& X_i = \{x_i(1), x_i(2), x_i(3), \ldots, x_i(m)\}, \quad i = 1, 2, \ldots, n
\end{align*}
\]
3) The correlation coefficient between each comparison vector and the reference vector can be calculated according to the following equation:
\[
\eta(k) = \frac{\min_{t} \min_{i} |x_i(t) - x_i(t)| + \rho \max_{t} \max_{i} |x_i(t) - x_i(t)|}{|\varepsilon|}
\]

Where \(\min_{t} |x_0(t) - x_i(t)|\) is the minimum difference of two levels, \(\max_{t} |x_0(t) - x_i(t)|\) is the maximum difference of two levels. \(\rho \in [0,1]\) is the resolution coefficient. As \(\rho\) increases, the resolution increases, the more commonly used \(\rho = 0.5\).

4) Average correlation coefficient can be calculated according to the following equation:
\[
r_i = \frac{1}{n} \sum_{k=1}^{n} \eta_i(k)
\]

5) Based on the average correlation coefficient, the evaluation results are obtained.

6) Vector \(r = (r_1, r_2, ..., r_n)\) can be normalized according to the following equation:
\[
w_i = \frac{r_i}{\sum_{k=1}^{n} r_i(k)}
\]

The weight vector for each indicator is:
\[
W = (w_1, w_2, ..., w_n)
\]

2.2 Evaluation Index Selection

In order to enable the selected suppliers to meet the requirements of Energy Storage Services systems, this paper builds an Energy Storage Services system supply based on the literature [6-7], through expert consultation and Energy Storage Services integration optimization demonstration project field research. The evaluation index system is shown in Figure 1. The evaluation index system includes price indicators, time indicators and quality indicators. These indicators are both cost-effective and cost-based. Through the evaluation index system, the Energy Storage Services system supplier can be evaluated objectively and accurately, so that the best supplier combination can be selected.

3 Experiment and analysis

3.1 Simulation environment

In order to verify the effectiveness of the Energy Storage Services system Influencing Factors method, Matlab 2014b was selected for simulation on Intel Pentium 2.90 GHz CPU, 4GB RAM, 64-bit Windows 10 Professional operating system. The simulation steps are as follows: First, data normalization; Second, using gray correlation analysis to determine the weight;

Taking an Energy Storage Services project in Inner Mongolia Autonomous Region as an example, The main parameters of project procurement are shown in Table 1.

3.2 Data normalization

As can be seen from Table 1, many of the evaluation indicators are of different dimensions and need to be normalized. \(X = \{X_1, X_2, ..., X_N\}\) and \(Y = \{Y_1, Y_2, ..., Y_N\}\) represent raw data and normalized data, respectively.

For cost-type indicators, that is, when the evaluation value decreases as the index increases, the formula is used:
\[
Y = \frac{X_{\max} - X_i}{X_{\max} - X_{\min}}
\]

For the benefit indicator, that is, when the evaluation value increases as the index increases, the formula is used:
\[
Y = \frac{X_i - X_{\min}}{X_{\max} - X_{\min}}
\]

Where \(X_{\max}\) and \(X_{\min}\) represents the minimum and maximum values, respectively.

In the evaluation index, the purchase price and delivery period are cost-type indicators, using formula (7), and the remaining indicators are benefit-type indicators. Using formula (8), It can be seen from Table 2 that weighted quantification of time and quality indicators yields two composite indicators the values of all the evaluation indicators are in the (0,1) range, and each indicator achieves dimensionlessness, which is convenient for comprehensive evaluation.
### Table 1. Energy Storage Services system supplier parameters

| Type               | Supplier | Price index | Time index | Quality index |
|--------------------|----------|-------------|------------|---------------|
|                    |          | Delivery period /Days | Warrant period /years | Technical /% | Reliability /% | Economic /% | Safety /% |
| Wind               | A₁       | 6            | 86         | 1             | 83           | 83          | 78          | 81          |
|                    | A₂       | 7            | 48         | 1             | 83           | 83          | 87          | 85          |
|                    | A₃       | 5            | 29         | 2             | 81           | 86          | 83          | 81          |
|                    | A₄       | 8            | 57         | 2             | 92           | 94          | 90          | 86          |
|                    | A₅       | 9            | 38         | 2             | 86           | 92          | 86          | 86          |
| Photovoltaic       | B₁       | 8            | 28         | 2             | 86           | 85          | 79          | 84          |
|                    | B₂       | 7            | 14         | 1             | 84           | 84          | 89          | 88          |
|                    | B₃       | 6            | 16         | 2             | 83           | 90          | 84          | 84          |
|                    | B₄       | 3            | 10         | 1             | 95           | 97          | 94          | 89          |
|                    | B₅       | 5            | 38         | 3             | 89           | 96          | 90          | 91          |
| Natural gas        | C₁       | 19           | 17         | 2             | 87           | 87          | 80          | 85          |
|                    | C₂       | 24           | 10         | 2             | 87           | 87          | 92          | 89          |
|                    | C₃       | 29           | 13         | 3             | 85           | 91          | 87          | 85          |
| Energy storage equipment | D₁   | 8            | 14         | 5             | 97           | 99          | 95          | 90          |
|                    | D₂       | 5            | 4          | 4             | 90           | 96          | 92          | 92          |

### Table 2. Normalized data of Energy Storage Services system supplier parameters

| Type               | Supplier | Price index | Time index | Quality index |
|--------------------|----------|-------------|------------|---------------|
|                    | A₁       | 0.8846      | 0.0000     | 0.0313        |
|                    | A₂       | 0.8462      | 0.2317     | 0.2545        |
| Wind               | A₃       | 0.9231      | 0.4726     | 0.1204        |
|                    | A₄       | 0.8077      | 0.3018     | 0.6339        |
|                    | A₅       | 0.7692      | 0.4177     | 0.4500        |
| Photovoltaic       | B₁       | 0.8077      | 0.4787     | 0.1923        |
|                    | B₂       | 0.8462      | 0.4390     | 0.3834        |
|                    | B₃       | 0.8846      | 0.5518     | 0.2970        |
|                    | B₄       | 1.0000      | 0.4634     | 0.8546        |
|                    | B₅       | 0.9231      | 0.5427     | 0.7319        |
| Natural gas        | C₁       | 0.3846      | 0.5457     | 0.2766        |
|                    | C₂       | 0.1923      | 0.5884     | 0.5440        |
|                    | C₃       | 0.0000      | 0.6951     | 0.4108        |
| Energy storage equipment | D₁   | 0.8077      | 0.9390     | 0.9545        |
|                    | D₂       | 0.9231      | 0.8750     | 0.7996        |

### 4 Results and analysis

The gray correlation analysis obtains the weight values of price index, time index and quality index $w_1 = 0.39$, $w_2 = 0.31$, $w_3 = 0.30$. Therefore, its objective function is: $max f(x) = 0.39C + 0.31T + 0.30Q$ (9)

### 5 Conclusion

In order to select the best supplier combination from a large number of Energy Storage Services system suppliers, the paper draws the following conclusions:

1. Through the evaluation index system, it can provide basic support for Influencing Factors of Energy Storage Services systems.

2. In order to avoid the influence of subjective factors on the weight assignment process, an Influencing Factors method based on gray correlation analysis.

3. The results show that supplier $(A_3, B_4, C_2, D_2)$ for Energy Storage Services systems can provide the best product mix. The experimental results demonstrate the feasibility and rationality of the proposed method.

In the research process of this paper, there are some shortcomings. First, the indicators considered in this paper are relatively few. In the future research process, evaluation indicators need to be re-defined for different Energy Storage Services projects. An evaluation system that adapts to a wider situation. Second the evaluation method used in this paper is gray correlation analysis, and future considerations, combined with new heuristic algorithms, further expand the research.
Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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