Study on the comprehensive benefit evaluation model of energy storage for the development of clean energy city

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Abstract. The establishment of clean energy based power supply mode is an important direction of urban energy development in China. The realization of clean energy structure depends on large-scale energy storage technology, so reasonable evaluation of energy storage construction for the development of clean energy city has important practical significance. Under this background, this paper designs the comprehensive benefit index evaluation system of energy storage considering three dimensions of social benefit, economic benefit and environmental benefit; Secondly, TOPSIS evaluation method based on entropy weight method is used to build a comprehensive evaluation model of energy storage for clean energy city development; At last, Taking Urumqi City as an example, the validity of the model is verified.

1. Introduction

Comprehensive benefit evaluation refers to the quantitative analysis of project development through the construction of diversified evaluation index system and the comprehensive evaluation method, so as to provide important reference information for decision makers. Firstly, this paper selects indicators to construct the evaluation index system of urban energy storage development of clean energy. Secondly, entropy weight method is adopted to comprehensively weight the indicators, and TOPSIS comprehensive evaluation model based on entropy weight method is constructed. Finally, an example is given to verify the effectiveness of the proposed model, and to visually demonstrate the benefits brought by the development of clean energy cities and energy storage. This part, based on energy storage planning and construction, builds a comprehensive benefit evaluation index system for the development of clean energy cities, which can comprehensively evaluate the comprehensive benefit of energy storage development of clean energy cities in different regions from a macro perspective.

From the point of the current research situation, the literature [1] and the current status of energy storage technology of energy storage mainly application scenarios and requirements on comb, and puts forward several problems, mainly is the security problems such as electrochemical energy storage security accidents such as fire, some way of economy remain to be discussed and further optimize the business model and some of the scene still needs to explore. The important role of energy storage technology in improving the acceptance capacity of power grid to new energy, frequency modulation of power grid, peak load clipping, and improving power quality and power reliability has been recognized internationally. In recent years, with the continuous maturity of electrochemical energy storage technology and the rapid decline of cost, China's electrochemical energy storage has grown rapidly, with the total installed capacity increasing from 105MW in 2015 to 1.034gw in 2018, with an annual growth
of 114%. Energy storage from the time, the energy function of flexible handling can make more friendly, renewable energy power generation on power grid control, participate in power grid peaking and frequency modulation and other auxiliary services, to support the safety of power grid, the device can also be in the user side, to provide users with peak valley regulation, improving the capacity of power supply, improve power supply reliability, and other requirements, therefore, energy storage in the power generation side and grid side and user side has achieved rapid large-scale application, has become China's clean energy transformation and energy an important part and key support to the development of the Internet technology [2-8]. Literature [9] analyzes the alternative model of clean energy from the perspectives of the supply side and the consumption side, analyzes the influencing factors of the development of clean energy from the aspects of technology, economy and policy, and puts forward Suggestions to promote the development of clean energy [10, 11]. Through the analysis of the characteristics of China's energy structure and the situation of supply and demand, literature [12] points out that in the context of the global transition to a clean and low-carbon direction, the construction of clean energy cities is an important path to promote the optimization and adjustment of China's energy structure. Under the background of China's vigorous development and utilization of new energy, it is particularly important to improve the quality and efficiency of energy development. Therefore, in addition to unconventional oil and gas development, China should accelerate the clean use of traditional fossil energy, coordinate industrial layout, reform energy system, use various energy-saving technologies and clean alternative energy technologies, promote energy conservation, encourage scientific and technological innovation and strengthen international cooperation, and accelerate the pace of clean energy [13-15].

2. Establishment of comprehensive benefit evaluation index system for clean energy city and energy storage development

![Evaluation index system of comprehensive benefit of clean energy city and energy storage development](image)

Figure 1. Evaluation index system of comprehensive benefit of clean energy city and energy storage development

In this paper, through the establishment of social benefit, economic benefit and environmental benefit from three aspects of economic indicators, then the three major indicators divided into 17 small index
(as shown in figure 1-1), aims to index the establishment of the city for clean energy and energy storage of all kinds of benefits on economy can be quantified, quantity, intuitive performance all aspects of benefit, to provide clean energy and energy storage city areas intuitive guidance.

3. Comprehensive evaluation model based on entropy weight method and TOPSIS method

TOPSIS method, also known as ideal solution method, is an effective method for selecting, sorting, evaluating and making decisions in a multi-objective system. The basic principle of TOPSIS method is to order the solutions by means of the "ideal solution" and "negative ideal solution" of the multi-objective decision problem. The "ideal solution" is a best-conceived solution whose index values are the best of the other solutions, while the "negative ideal solution" is another worst-conceived solution whose index values are the worst of the alternative solutions. "Ideal solution" and "negative ideal solution" generally do not exist in the original solution set. Therefore, if there is a solution in the solution set that is closest to the "ideal solution" and at the same time farthest from the "negative ideal solution", the solution is the best solution in the solution set. Through the analysis of TOPSIS evaluation method principle, the entropy weight method is used to determine the weight, and the TOPSIS comprehensive evaluation model is used to evaluate the comprehensive benefits of clean energy city and energy storage. The application process and steps of the comprehensive evaluation model based on entropy weight method and TOPSIS evaluation method are as follows:

1. Forming a decision matrix
   With m evaluation objects and n decision indicators, the objective decision matrix can be obtained:
   \[ X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \] (1)

2. The data processing
   The dimensionless matrix Y is obtained by dimensionless processing of matrix x and forward processing of low optimal index and moderate (medium optimal) index.

\[ \text{Figure 2. Application flow of comprehensive evaluation model based on entropy weight method and TOPSIS evaluation method} \]
\[ Y_{\text{ma}} = X_{\text{ma}} / \sqrt{\sum_{j=1}^{m} X_{j}^2} \]  

\[
Y = \begin{bmatrix}
Y_{11} & Y_{12} & \cdots & Y_{1n} \\
Y_{21} & Y_{22} & \cdots & Y_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
Y_{m1} & Y_{m2} & \cdots & Y_{mn}
\end{bmatrix}
\]  

(3) Determine the weight

Entropy weight method is an objective weighting method. The entropy weight method analyzes the trend of the changes of each index, determines the entropy value of each index with the help of information entropy, and then modifies the weight of each index with the entropy weight, so as to obtain a more objective index weight. According to the definition of entropy, the entropy value of the index \( j \) is calculated as:

\[ Q_j = \frac{1}{\ln m} \sum_{i=1}^{m} P_{ij} \ln P_{ij} \]

(4)

Where,

\[ P_{ij} = \frac{(1+\hat{r}_{ij})}{\sum_{j=1}^{n}(1+\hat{r}_{ij})} \]

Thus, the entropy weight of the \( j \)th index is:

\[ w_j = \frac{(1-Q_j)}{\sum_{j=1}^{n}(1-Q_j)} \]

(5)

(4) Determine the ideal solution and the negative ideal solution

The optimal and worst vectors composed of the maximum and minimum values of the columns in the matrix are the ideal solution and the negative ideal solution. Denoted as:

\[ Y^+ = (\max Y_{11}, \max Y_{12}, \ldots, \max Y_{1n}) \quad (i = 1, 2, \ldots, m) \]

\[ Y^- = (\min Y_{11}, \min Y_{12}, \ldots, \min Y_{1n}) \quad (i = 1, 2, \ldots, m) \]

(7)

(8)

(5) Calculate the distance from the ideal solution

The distance between the \( i \)th evaluation object and the ideal solution and the negative ideal solution is as follows:

\[ D^+_i = \sqrt{\sum_{j=1}^{n} \left[ W_j (Y_{ij} - Y_{ij}^+) \right]^2} \quad (i = 1, 2, \ldots, m) \]

\[ D^-_i = \sqrt{\sum_{j=1}^{n} \left[ W_j (Y_{ij} - Y_{ij}^-) \right]^2} \quad (i = 1, 2, \ldots, m) \]

(9)

(10)

Where, the weight vector of the index: \( W = (W_1, W_2, \ldots, W_n) \).

(6) Calculate the closeness to the ideal solution

The closeness of the \( i \)th evaluation object to the ideal solution is:

\[ C_i = \frac{D^-_i}{(D^+_i + D^-_i)} \]

(11)

The final result is sorted according to the size of \( a \). Because a comprehensively considers the distances between the indicators of the evaluated solution to the positive ideal solution and the negative ideal solution, it indicates that the ratio of the distance from the index value to the negative ideal solution is on the line between the ideal solution and the negative ideal solution. So the larger \( a \) is, the farther the distance from the negative ideal solution to the evaluated object is, the closer the evaluated object is to the ideal solution and the higher the ranking.
4. Empirical analysis
This article takes Urumqi as an empirical analysis object, and uses Urumqi three-year forecast data to verify the above comprehensive evaluation model based on the entropy weight method and TOPSIS evaluation method.

4.1. Basic data

| Table 1. Basic data. | First, secondary indicators | Third indicators | 2021   | 2023   | 2025   |
|----------------------|-----------------------------|-----------------|--------|--------|--------|
| Social benefits \(U_1\) | Increase in GDP (Ten thousand yuan) \(U_{11}\) | 520.63 | 612.0585 | 709.167 |
| | The proportion of increased secondary GDP \(U_{12}\) | 0.52 | 0.55 | 0.57 |
| | Increase employment \(U_{13}\) | 0.027 | 0.033 | 0.034 |
| | Reduce network loss (Ten thousand yuan) \(U_{21}^a\) | 6609.3 | 7305.4 | 12304.7 |
| The grid side \(U_2^a\) | Low reserves high arbitrage (Ten thousand yuan) \(U_{22}^a\) | 122134.6 | 174924 | 334072.3 |
| | Save grid reliability cost (Ten thousand yuan) \(U_{23}^a\) | 2203.1 | 3101.8 | 4101.6 |
| The power supply side \(U_2^\beta\) | Delay the construction of peak-regulating units (Ten thousand yuan) \(U_{21}^\beta\) | 121750 | 188750 | 393750 |
| | Increase clean energy bill revenue (Ten thousand yuan) \(U_{22}^\beta\) | 7833.3 | 10062.4 | 21294.9 |
| | Delay the expansion of customer distribution stations (Ten thousand yuan) \(U_{23}^\beta\) | 30397 | 58995 | 108157.5 |
| The user side \(U_2^\gamma\) | Reduce the cost of electricity for capacity (Ten thousand yuan) \(U_{21}^\gamma\) | 21.4 | 38.6 | 71.6 |
| | Reduce the cost of distribution loss (Ten thousand yuan) \(U_{23}^\gamma\) | 4609.3 | 9305.4 | 12304.7 |
| | Reduce the cost of power outages (Ten thousand yuan) \(U_{24}^\gamma\) | 423 | 595.5 | 787.5 |
| Environmental benefits \(U_3\) | Emission reduction of CO2 (kg) \(U_{31}\) | 63372787.75 | 78328286.43 | 96816143.69 |
| | Emission reduction of SO2 (kg) \(U_{32}\) | 2210678.64 | 2732382.08 | 3377307.33 |
| | Emission reduction of NOX (kg) \(U_{33}\) | 1105339.32 | 1366191.04 | 1688653.66 |
| | Smoke reduction (kg) \(U_{34}\) | 20043486.36 | 24773597.57 | 30620919.87 |
| | Emission reduction of PM2.5 (kg) \(U_{35}\) | 294757.15 | 364317.61 | 450307.64 |
4.2. Determination of indicator weights
First normalize the data. Take the index value of each scheme into equation (3-2) for normalization. The specific results are shown in the following table:

**Table 2.** Normalized index values of each scheme.

| Evaluation indicator | 2021          | 2023          | 2025          |
|-----------------------|---------------|---------------|---------------|
| \( U_1 \)            |               |               |               |
| \( U_{11} \)         | 0             | 0.484927      | 1             |
| \( U_{12} \)         | 0             | 0.591236      | 1             |
| \( U_{13} \)         | 0             | 0.855425      | 1             |
| \( U_{21}^\alpha \)  | 0             | 0.239784      | 1             |
| \( U_{22}^\alpha \)  | 0             | 0.324324      | 1             |
| \( U_{23}^\alpha \)  | 0             | 0.324324      | 1             |
| \( U_{21}^\beta \)   | 0             | 0.375000      | 1             |
| \( U_{22}^\beta \)   | 0             | 0.537018      | 1             |
| \( U_{23}^\beta \)   | 0             | 0.325000      | 1             |
| \( U_{21}^\gamma \)  | 0             | 0.400781      | 0             |
| \( U_{22}^\gamma \)  | 0             | 0.447189      | 1             |
| \( U_{23}^\gamma \)  | 0             | 0.447189      | 1             |
| \( U_{24}^\gamma \)  | 0             | 0.447189      | 1             |
| \( U_{31} \)         | 0             | 0.447189      | 1             |
| \( U_{32} \)         | 0             | 0.447189      | 1             |
| \( U_{33} \)         | 0             | 0.447189      | 1             |
| \( U_{34} \)         | 0             | 0.447189      | 1             |
| \( U_{35} \)         | 0             | 0.447189      | 1             |

According to equations (2-4) to (2-6), the entropy weight vectors are as follows:

**Table 3.** Index weights based on entropy weight method.

| First indicators | First indicator weight | Third indicators | Third indicator weight |
|------------------|------------------------|------------------|------------------------|
| U1               | 0.1560                 | \( U_{11} \)     | 0.3553                 |
|                  |                         | \( U_{12} \)     | 0.3339                 |
|                  |                         | \( U_{13} \)     | 0.3108                 |
|                  |                         | \( U_{21}^\gamma \) | 0.1290                 |
|                  |                         | \( U_{22}^\gamma \) | 0.1151                 |
|                  |                         | \( U_{23}^\gamma \) | 0.1090                 |
|                  |                         | \( U_{21}^\beta \) | 0.0959                 |
|                  |                         | \( U_{22}^\beta \) | 0.1547                 |
|                  |                         | \( U_{23}^\beta \) | 0.1151                 |
|                  |                         | \( U_{24}^\beta \) | 0.0995                 |
|                  |                         | \( U_{31}^\gamma \) | 0.1150                 |
|                  |                         | \( U_{32}^\gamma \) | 0.1062                 |
|                  |                         | \( U_{33}^\gamma \) | 0.2000                 |
|                  |                         | \( U_{34}^\gamma \) | 0.2000                 |
|                  |                         | \( U_{35}^\gamma \) | 0.2000                 |
| U2               | 0.5589                 | \( U_{21}^\gamma \) | 0.1151                 |
|                  |                         | \( U_{22}^\gamma \) | 0.1150                 |
|                  |                         | \( U_{23}^\gamma \) | 0.0995                 |
|                  |                         | \( U_{24}^\gamma \) | 0.1062                 |
|                  |                         | \( U_{31}^\gamma \) | 0.2000                 |
|                  |                         | \( U_{32}^\gamma \) | 0.2000                 |
|                  |                         | \( U_{33}^\gamma \) | 0.2000                 |
|                  |                         | \( U_{34}^\gamma \) | 0.2000                 |
|                  |                         | \( U_{35}^\gamma \) | 0.2000                 |
| U3               | 0.2851                 | \( U_{31}^\gamma \) | 0.1151                 |
|                  |                         | \( U_{32}^\gamma \) | 0.1150                 |
|                  |                         | \( U_{33}^\gamma \) | 0.0995                 |
|                  |                         | \( U_{34}^\gamma \) | 0.1062                 |
|                  |                         | \( U_{35}^\gamma \) | 0.2000                 |
4.3. TOPSIS Evaluation

Dimensionless basic data according to formula (3-6) gives Table 4-4.

**Table 4. Processed data.**

| First, secondary indicators | Third indicators | 2021       | 2023       | 2025       |
|-----------------------------|-----------------|-----------|-----------|-----------|
| $U_1$                       |                 |           |           |           |
| $U_{11}$                    |                 | 0.485790577 | 0.571097  | 0.661706644 |
| $U_{12}$                    |                 | 0.549685569 | 0.580092  | 0.601114596 |
| $U_{13}$                    |                 | 0.49623998  | 0.604669  | 0.622994163 |
| $U_2$                       |                 |           |           |           |
| $U_{21}^\alpha$             |                 |           |           |           |
| $U_{22}^\alpha$             |                 | 0.276139885 | 0.460233  | 0.84376076  |
| $U_{23}^\alpha$             |                 | 0.276139885 | 0.460233  | 0.84376076  |
| $U_2^\beta$                 |                 |           |           |           |
| $U_{21}^\beta$              |                 | 0.244847579 | 0.470861  | 0.847549312 |
| $U_{22}^\beta$              |                 | 0.225894617 | 0.435654  | 0.871307809 |
| $U_2^\gamma$                |                 |           |           |           |
| $U_{21}^\gamma$             |                 | 0.276139885 | 0.460233  | 0.84376076  |
| $U_{22}^\gamma$             |                 | 0.34469851  | 0.546188  | 0.763453623 |
| $U_{23}^\gamma$             |                 |           |           |           |
| $U_3$                       |                 |           |           |           |
| $U_{31}$                    |                 | 0.453533692 | 0.560564  | 0.692874413 |
| $U_{32}$                    |                 | 0.453533692 | 0.560564  | 0.692874413 |
| $U_{33}$                    |                 | 0.453533692 | 0.560564  | 0.692874413 |
| $U_{34}$                    |                 | 0.453533692 | 0.560564  | 0.692874413 |
| $U_{35}$                    |                 | 0.453533692 | 0.560564  | 0.692874413 |

Get the weight of each indicator from Figure 4-3:

\[ W = (0.3553, 0.3339, 0.3108, 0.1290, 0.1151, 0.1090, 0.0959, 0.1547, 0.1151, 0.1150, 0.0995, 0.1062, 0.2000, 0.2000, 0.2000, 0.2000) \]

The positive and negative ideal points calculated according to equations (3-7) and (3-8) are as follows.

In this article, each indicator is a benefit indicator. The larger the indicator attribute value, the better.

\[ Y^+ = (0.661706644, 0.601114596, 0.622994163, 0.594684047, 0.84376076, 0.84376076, 0.847549312, 0.871307809, 0.763453623, 0.655054507, 0.692874413, 0.692874413, 0.692874413, 0.692874413) \]

\[ Y^- = (0.485790577, 0.549685569, 0.49623998, 0.560564, 0.276139885, 0.276139885, 0.276139885, 0.276139885, 0.225894617, 0.34469851, 0.502920082, 0.453533692, 0.453533692, 0.453533692, 0.453533692) \]

Then calculate the distance from the positive and negative ideal points in each year according to equations (3-9) and (3-10), and the results are as follows:
Table 5. Proximity of positive and negative ideal points.

| Item                      | Year | 2021            | 2023            | 2025            |
|---------------------------|------|-----------------|-----------------|-----------------|
| Negative ideal point closeness |     | 0.209383037     | 0.125357577     | 0.016159119     |
| Positive ideal point closeness |     | 0.016159119     | 0.089872903     | 0.209383037     |

Finally, the relative closeness is calculated according to formula (3-11) as shown in Table 4-6, and the comprehensive benefits of each year are finally ranked.

Table 6. Relative closeness.

| Year | 2021 | 2023 | 2025 |
|------|------|------|------|
| Closeness | 0.071646 | 0.417566 | 0.928354 |

4.4. Result analysis

Combined with the evaluation results of TOPSIS, this paper analyzes the comprehensive benefits of energy storage planning in the target year to the development of Urumqi clean energy city from both horizontal and vertical perspectives.

(1) Horizontal analysis

Since the type of energy storage actually configured may be personalized according to different geographical conditions and user needs, this part assumes that all the energy storage configured are large lithium ion batteries in order to preliminarily calculate the cost and benefit of energy storage. According to the article "analysis on the kilowatt-hour cost and mileage cost of energy storage" published in the journal of new electric energy technology in 2019, it can be seen that the kilowatt-hour cost of lithium iron phosphate energy storage power station is currently 1000-1700 yuan/kWh. Combined with the basic data in Table 5-2, this paper takes 1500 yuan/kWh for the preliminary calculation of the economy of the energy storage scheme of Urumqi configuration. It can be obtained as follows:

The energy storage system configured in 2021 will bring a total revenue of 349.8 million yuan to various entities, including 305.62 million yuan on the grid side, 24.29 million yuan on the power side and 1989.90 million yuan on the user side.

The total revenue generated by the energy storage system configured in 2023 is 1005.78 million yuan for various subjects, including 493.67 million yuan for the grid side, 275.98 million yuan for the power side and 23,613 yuan for the user side.

In 2035, the energy storage system configured can bring a total revenue of 1773.45 million yuan for various subjects, including 759.56 million yuan for the grid side, 684.81 million yuan for the power side and 301.78 million yuan for the user side.

(2) Longitudinal analysis

According to the results of relative closeness in Table 3-6, it can be seen that energy storage configuration brings comprehensive benefits to Urumqi clean energy city, including social benefits, economic benefits and environmental benefits, gradually approaching the ideal solution. Therefore, it can be seen that the planned energy storage configuration scheme can effectively support the construction of Urumqi clean energy city.

5. Conclusion

By using TOPSIS evaluation method based on entropy weight method, this paper evaluated the comprehensive benefits of clean energy city and energy storage development, and intuitively demonstrated the significant benefits brought by clean energy city and energy storage development to the region through case analysis of Urumqi. This paper focuses on the reasonable establishment of the evaluation system, the analysis of the weight of each index and the analysis of the closeness degree, quantifies the benefits of all aspects, intuitively shows the considerable benefits brought by the development of clean energy cities and energy storage, and provides reference for the active development of clean energy cities and energy storage in various regions. Therefore, under the current
energy background, actively developing energy storage and gradually transitioning to clean energy cities are important directions for energy development and transformation in various regions. However, under the background of ubiquitous electric Internet of things, a series of issues such as how to realize efficient energy storage and effectively promote the transformation to clean energy cities need to be further studied.

Acknowledgments
This work was financially supported by Research on Urumqi clean energy city and energy storage development.

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