Study on Regional Comprehensive Energy Efficiency Evaluation Method

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Abstract. Integrated energy service is a new type of energy service to meet the diversified energy production and consumption of end customers, covering energy planning and design, engineering investment construction, multi-energy operation services and investment and financing services. This paper considers the energy input-output ratio, energy thermal efficiency and pollution gas emissions of the park, and comprehensively constructs an indicator system for the comprehensive energy park, which can provide guidance for the evaluation of comprehensive energy parks in the future.

1. Construction of the indicator system

With the continuous development of energy markets around the world, integrated energy service providers are gradually becoming a new type of interest in the energy market. In China, with the national energy revolution, especially the power system reform measures represented by the incremental power distribution business reform and the power market construction, the regional integrated energy service providers have invested in the park to provide multiple energy supplies to the park. The model already has the conditions for its formation. In this context, the traditional single energy supplier structure is gradually being broken. In recent years, major energy companies have also proposed new strategies for transforming from single energy suppliers to integrated energy service providers.

1.1. Indicator construction ideas

According to the focus of comprehensive energy service providers, the comprehensive energy efficiency evaluation index system is constructed from four dimensions of economy, physical efficiency, environment and safety. In terms of economic efficiency, consider using the existing resources of the park as much as possible, reducing the dependence on purchased energy by improving the efficiency of energy use, and reducing the investment of funds as much as possible on the basis of meeting the safe operation of the park; In terms of physical efficiency, consider improving the energy efficiency of integrated energy systems, reducing energy losses in integrated energy systems, and improving the efficiency of equipment utilization in integrated energy systems. In terms of environmental efficiency, it is mainly concerned with reducing greenhouse gas emissions, reducing emissions from three wastes, and improving clean energy supply. In terms of energy security, consider ensuring the safety of electric power supply, reducing the risk of insufficient energy supply, and reducing the failure rate of equipment. Based on this, the equipment has no failure rate, comprehensive voltage qualification rate, load level,
energy supply shortage rate, power supply reliability, thermal parameters pass rate and other indicators. The indicators are constructed as follows:

The energy efficiency influencing factors and quantitative indicators of this paper are shown in the following table.

| Indicator system                  | Evaluation dimension | Overall indicator | Supportive indicator |
|-----------------------------------|----------------------|------------------|----------------------|
| Comprehensive energy efficiency   |                      |                  |                      |
| evaluation index system           |                      |                  |                      |
| Comprehensive energy efficiency   |                      |                  |                      |
| evaluation index system           |                      |                  |                      |
| Energy system physical efficiency |                      | Energy system    | User load rate       |
| energy efficiency                 |                      | thermal efficiency| Power line loss rate |
|                                  |                      |                  | Heating pipe network |
|                                  |                      |                  | conveying efficiency |
| Energy system eco-efficiency      |                      | Unit output CO₂  | Combined output value |
| emissions                        |                      | emissions        | of cogeneration unit  |
|                                  |                      |                  | CO₂                   |
|                                  |                      |                  | Cooling, heat and power |
|                                  |                      |                  | triple supply unit    |
|                                  |                      |                  | output value          |
|                                  |                      |                  | CO₂ emission          |
|                                  |                      |                  | Gas boiler unit output |
|                                  |                      |                  | value                 |
|                                  |                      |                  | CO₂ emission          |
|                                  |                      |                  | Renewable energy ratio|
| Energy system security           | Unit output pollutant |                  | Power supply adequacy |
| security                          | discharge            |                  | Thermal supply margin |
|                                  |                      |                  | Thermal interruption hours |

1.2. Indicator interpretation

- **Energy system input-output ratio**

  The energy system input-output ratio is defined as the ratio of the total value of various energy products supplied to users in the region to the total cost of the integrated energy system during the reporting period.

- **Energy system thermal efficiency**

  Thermal efficiency = Energy for user terminals in integrated energy systems/Integrated energy system input energy

  \[
  \phi_{\text{th}} = \frac{\sum Q_\text{elec}^u + \sum \epsilon_{\text{h}}^u Q_\text{h}^u + \sum \epsilon_{\text{c}}^u Q_\text{c}^u}{\sum m_{\text{input}}^n \epsilon_{\text{input}}^n}
  \]

  - **Unit production value CO₂ emissions**

    The output per unit of CO₂ emissions is the ratio of the total amount of CO₂ emitted by the integrated energy system to the total price of all energy products (including steam, cold water, electricity, etc.) consumed by the end user.

    CO₂ emission per unit output value = Total CO₂ emission/Total price of terminal energy products

- **Emissions per unit of output value**

  The emission per unit of output value of pollutants is defined as the ratio of the total amount of NOₓ and SOₓ emitted by the integrated energy system to the total price of all energy products (including steam, cold water, electricity, etc.) consumed by the end user.

- **Equipment input-output ratio**

  Equipment revenue output ratio = Total value of energy products produced by the equipment/Total equipment costs Equipment utilization (%)

- **Renewable energy share (%)**

  Renewable energy accounts for primary energy = The amount of renewable energy consumed by the integrated energy system/Total primary energy consumption consumed by integrated energy systems

- **Power supply adequacy**

  Power supply adequacy = Maximum theoretical power supply for integrated energy systems/Actual power consumption of users
2. Model evaluation

2.1. Entropy Weight Method Model Construction

Entropy method is a method that uses the information to determine the weight of the index and make a comprehensive evaluation. In comprehensive evaluation, the value of entropy can reflect the degree of variation of an index and the size of its information quantity, the larger the amount of information, the smaller the value of entropy and vice versa. The implementation steps of the entropy method are as follows:

- The same trend treatment of one index.
- The two indicators are dimensionless and normalized.

\[ P_{ij} = \frac{x_{ij}}{\sum x_{ij}} \]  

(1)

It is assumed that \( x_{ij} > 0 \) if this assumption is not satisfied, appropriate methods (such as efficacy coefficient method) can be used for data transformation.

- Third, calculate the entropy of each index:

\[ e_j = -k \sum_{i=1}^{n} p_{ij} \ln(p_{ij}) \]  

(2)

In the model, \( k = 1/\ln n \), \( 0 \leq e_j \leq 1 \).

- Fourthly, the coefficient of difference of each index is calculated.

\[ g_j = 1 - e_j \]  

(3)

- Fifth, calculate the weight of each index:

\[ w_j = \frac{g_j}{\sum_{j=1}^{m} g_j} \]  

(4)

- Sixth, calculate the comprehensive evaluation value:

\[ v_i = \sum_{j=1}^{m} w_j P_{ij} \]  

(5)

2.2. Evaluation Model

The comprehensive evaluation value is obtained from the evaluation value and weight coefficient of each evaluation index, and the evaluation model is established.

\[ Y = WX \]  

(6)

In the formula, \( Y \) is the comprehensive evaluation value, \( W \) is the weight vector of the evaluation index, and \( X \) is the evaluation value vector of the evaluation index.

Assessment indicators are divided into three categories: positive indicators, inverse indicators, moderate indicators, the higher the level of energy efficiency. The above different types of indicators need to be
dimensionless when evaluating.

3. Case study
Select comprehensive energy efficiency evaluation indicators. The relevant indicator values are shown in Table 2.

| Index                                      | Area A | Area B | Area C |
|--------------------------------------------|--------|--------|--------|
| User load rate                             | 0.3    | 0.45   | 0.3542 |
| Power line loss rate                       | 0.07   | 0.05   | 0.08   |
| Renewable energy ratio                     | 0.15   | 0.3    | 0.0078 |
| Power supply adequacy                      | 1.15   | 1.3    | 1.5    |
| Thermal supply margin                      | 1.15   | 1.3    | 2.25   |
| Thermal interruption hours                 | 5      | 3      | 1      |
| Heating pipe network conveying efficiency  | 0.85   | 0.95   | 0.92   |
| Gas boiler unit output value CO₂ emission  | 11.92  | 12.7   | 12.3   |
| Unit output value CO₂ emission of cogeneration unit | 13.5  | 12.4   | 19.4   |
| Cold, heat and power triple supply unit output value CO₂ emission | 10.52 | 11.5   | 11.2   |

The following table uses the entropy method to calculate the entropy of each indicator. As shown in Table 3.

| Index                                      | Entropy value |
|--------------------------------------------|---------------|
| User load rate                             | 0.0027        |
| Power line loss rate                       | 0.1219        |
| Heating pipe network conveying efficiency  | 0.0174        |
| Power supply adequacy                      | 0.1802        |
| Thermal supply margin                      | 0.1774        |
| Thermal interruption hours                 | 0.1622        |
| Gas boiler unit output value CO₂ emission  | 0.0748        |
| Renewable energy ratio                     | 0.2030        |
| Unit output value CO₂ emission of cogeneration unit | 0.0056  |
| Cold, heat and power triple supply unit output value CO₂ emission | 0.0549 |

Use an index transformation method to convert an index value to a dimensionless value. Multiply the number of converted values by 100 as the result of the evaluation. The evaluation results are shown in Table 4.

| Region                                      | Score |
|---------------------------------------------|-------|
| A regional assessment results               | 33.94 |
| B regional assessment results               | 32.31 |
| C regional assessment results               | 33.75 |

It is concluded that the comprehensive energy effect of the a region is the best, and the comprehensive energy performance of the c region is the second. Energy efficiency is the worst.

4. Conclusion
The basic function of the integrated energy system is to achieve the complementarity of multiple energy sources through the multi-energy collaborative optimization and the coupling mechanism between the various sub-equipments in the case of meeting the needs of the park users for multiple energy sources, and to achieve the Scale access, reduce the use of fossil energy, and improve the overall energy efficiency level. The energy efficiency evaluation of the park's integrated energy system is based on the
entropy method to evaluate the effectiveness of the integrated park, and has certain reference value for
the design of integrated energy systems.

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