Benefit Evaluation of Integrated Energy System in China

Bo Xu*, Shengyu Wu, Qiuli Zhao, Xue Tan
State Grid Energy Research Institute Co., Ltd., Beijing, China
*Corresponding author’s e-mail: xubosdu@163.com

Abstract. This paper proposes a benefit evaluation method for the integrated energy system in China. Firstly, the energy, economic, social, and environmental benefit evaluation indices are presented and quantified. And then, the Analytic Hierarchy Process (AHP) is used to get the weight of different indices. Finally, based on the benefit evaluation index system established by this paper, the comprehensive evaluation index score of the integrated energy system is computed. The proposed method is verified by the results of case studies, which is of great guiding significance to the planning and formulation of relevant government policies required by integrated energy system.

1. Introduction
Traditional energy supply systems are often lack of coordination with each other, which makes it difficult to improve energy efficiency. Through the unified planning and comprehensive utilization of different energy supply systems, such as electricity, heat, cold and gas, the integrated energy system (IES) can improve energy efficiency and increase the proportion of renewable energy consumption [1-2].

A lot of research has been done regarding the benefit evaluation of IES. For example, reference [3] proposes a hybrid multi-attribute decision-making model for efficiency evaluation of IES. Decision maker’s risk preference is considered and the interval-valued multiple-attribute decision-making method as well as fuzzy linguistic multiple-attribute decision-making model are constructed. Reference [4] evaluates the primary energy consumption and CO2-emission for CHP and separate production of heat and power. And then, the boundary conditions are discussed which have to be met by CHP systems for being less energy consuming and less CO2-producing. For any type of poly-generation system with natural gas as the energy input, reference [5] proposes a unified general model for assessing the energy and CO2 emission performance. Reference [6] further analyzes district heating cogeneration systems and gives attention to the NOx pollutant. Reference [7] compares the uses and limitations of many different project evaluation techniques. The applicability of these methods to cogeneration plants is shown. To reduce risk from natural gas price volatility, reference [8] focuses on microgrids that can proceed in a sequential manner with DG capacity and heat exchangers investment. IES can be divided into three levels: national level, regional level and local level [9]. The regional level refers to cities or provinces. However, there have been little research conducted on the benefit evaluation of regional IES. This paper is focused on this issue.

The remainder of this paper is organized as follows. In Section 2, the energy, economic, social, and environmental benefit evaluation indices of IES is presented. Section 3 gives the benefit evaluation method of the IES. Case study is given in Section 4. Section 5 gives the conclusion.
2. Benefit evaluation indices of IES

The benefit evaluation indices of IES include the following four parts: energy benefit, economic benefit, social benefit and environmental benefit. The composition of the benefit evaluation index system can be seen in Figure 1.

![Figure 1. Benefit evaluation indices of IES](image)

The benefit evaluation indices of IES can be calculated as follows.

(1) **Energy benefit**

① Level of power supply facilities

\[ P_{EA} = \frac{C_{ps}}{L_{total}} \]  

Where \( C_{ps} \) is the total generation capacity. \( L_{total} \) is the total regional electric load.

② Electricity consumption per capita

\[ P_{ECP} = \frac{E_{year}}{N_{people}} \]  

Where \( E_{year} \) is the total electricity consumption. \( N_{people} \) is the regional population.

③ Penetration rate of natural gas

\[ P_{gas} = \frac{N_{gas}}{N_{people}} \]  

Where \( N_{gas} \) is the population that have access to natural gas.

④ Ratio of integrated energy supply station

\[ P_{IES} = \frac{N_{IES}}{N_{substation}} \]
Where $N_{ES}$ is number of integrated energy supply stations. $N_{substation}$ is the number of electricity stations and integrated energy supply stations.

5. Ratio of clean energy

$$P_{CE} = \frac{E_{CE}}{E_{energy}}$$ (5)

Where $E_{CE}$ is the clean energy consumption. $E_{energy}$ is the total energy consumption.

6. Energy self-sufficiency

$$\eta_{ss} = \frac{E_{ss}}{E_{energy}}$$ (6)

Where $E_{ss}$ is the total production of energy.

7. Dependence on foreign energy

$$\eta_{df} = \frac{E_{df}}{E_{energy}}$$ (7)

Where $E_{df}$ is the total energy imports.

8. Primary energy efficiency

$$\eta_{pe} = \frac{E_{energy}}{E_{pe}}$$ (8)

Where $E_{pe}$ is the primary energy input.

9. Ratio of power to gas

$$r_{P2G} = \frac{Q_{P2G}}{Q_{gas}}$$ (9)

Where $Q_{P2G}$ is the natural gas produced by the conversion of power to gas. $Q_{gas}$ is the natural gas consumption.

10. Ratio of coal to gas

$$r_{C2G} = \frac{Q_{C2G}}{Q_{gas}}$$ (10)

Where $Q_{C2G}$ is the natural gas produced by the conversion of coal to gas.

(2) Economic benefit

1. Enterprise affordability

$$P_{EA} = \frac{C_{enterprise, energy}}{C_{enterprise}}$$ (11)

Where $C_{enterprise, energy}$ is the energy cost of enterprises. $C_{enterprise}$ is the total production cost of the enterprise.

2. Household affordability

$$P_{HA} = \frac{C_{household, energy}}{C_{household}}$$ (12)

Where $C_{household, energy}$ is the energy cost of households. $C_{household}$ is the total household cost.

3. Energy productivity
\[ P_{EP} = \frac{GDP}{E_{energy}} \]  

(13)

Where GDP represents the gross national income.

(3) Social benefit

1. Employment benefit

\[ P_{EE} = \frac{N_{energy}}{N_{employment}} \]  

(14)

Where \( N_{energy} \) is the employment in energy industry. \( N_{employment} \) is the total employment.

2. Regional equity

\[ P_{RE} = \frac{N_{noncommercial}}{N_{family}} \]  

(15)

Where \( N_{noncommercial} \) is number of non-commercial families. \( N_{family} \) is the total number of families.

3. Social welfare

\[ P_{SW} = \frac{N_{satisfactory}}{N_{consumer}} \]  

(16)

Where \( N_{satisfactory} \) is number of satisfied customers. \( N_{consumer} \) is the total number of customers.

(4) Environmental benefit

1. NOx intensity

\[ P_{NOx} = \frac{Q_{NOx}}{E_{energy}} \]  

(17)

Where \( Q_{NOx} \) is the total NOx emission.

2. SO2 intensity

\[ P_{SO2} = \frac{Q_{SO2}}{E_{energy}} \]  

(18)

Where \( Q_{SO2} \) is the total SO2 emission.

3. CO2

\[ P_{CO2} = \frac{Q_{CO2}}{E_{energy}} \]  

(19)

Where \( Q_{CO2} \) is the total CO2 emission.

3. Benefit evaluation method of IES

The Analytic Hierarchy Process (AHP) is used in this paper to determine the weights of the benefit evaluation indices proposed above. More details about AHP can be seen in reference [10]. Based on that, the comprehensive evaluation index score of IES can be computed as

\[ \beta = P_{benefit} I_{benefit} \]  

(20)

Where \( P_{benefit} \) is the weight vector. \( I_{benefit} \) is the index vector.
4. Case study
To show the validity of the proposed benefit evaluation index system, the basic data in 2017 of some provinces in China is collected and the corresponding IES is evaluated. The evaluation results are shown in Figure 2 and Table 1.

![Figure 2. Benefit evaluation results by provinces](image)

| Classification   | Evaluation score | Provinces                                                                 |
|------------------|------------------|---------------------------------------------------------------------------|
| The first category | [0.8,1)          | Beijing, Tianjin, Shandong, Jiangxi, Shanxi, Jilin, Shaanxi, Zhejiang, Fujian, Jiangsu, Shandong, Jiangxi, Shanxi, Jilin, Shaanxi, Zhejiang, Fujian, Jiangsu, Hubei, Hunan, Guangdong, Hainan, Chongqing, Sichuan |
| The second category | [0.5, 0.8)      | Anhui, Henan, Guizhou, Xinjiang, Gansu, Ningxia, Inner Mongolia, Liaoning, Heilongjiang, Qinghai, Yunnan, Hebei, Guangxi |
| The third category  | [0,0.5)          | Energy efficiency and environment problems are particularly severe in Hebei, Yunnan and Inner Mongolia. In Liaoning and Heilongjiang, environment problem is prominent. The problems of energy infrastructure, energy efficiency and environment in Guangxi, Guizhou and Gansu are especially |

1) The first category
The benefit level of Beijing is relatively high. That’s because the restructuring of energy industry and eco-environment improvement in recent years promote the coordinated development of economy and society.

2) The second category
The benefit level of this category is relatively low. The environment and energy efficiency in Tianjin, Shandong, Jiangxi, Shanxi, Jilin, Fujian and Shaanxi decrease the whole benefit level. The energy efficiency, social benefit and environment in Shanghai, Jiangsu and Zhejiang decrease the whole benefit level. The low level of environment in Guangdong, Hainan, Hunan and Hubei is the main reason for the decreased whole benefit level. The benefit level of energy safety, energy efficiency and environment in Chongqing and Sichuan is low, resulting in decreased whole benefit level.

3) The third category
Energy efficiency and environment problems are particularly severe in Hebei, Yunnan and Inner Mongolia. In Liaoning and Heilongjiang, environment problem is prominent. The problems of energy infrastructure, energy efficiency and environment in Guangxi, Guizhou and Gansu are especially
outstanding and common. The problems of energy efficiency and environment in Xinjiang, Anhui, Henan, Ningxia and Qinghai are serious.

5. Conclusion
IES is composed of multiple-energy supply systems such as electricity, heat, cold and gas. To evaluate the benefit development level of IES, a framework is proposed to conduct benefit evaluation of IES in China. The comprehensive evaluation score of different provinces are computed and used to rank their benefit development level.

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