Application of Comprehensive Energy System in Value Evaluation of Iron and Steel Enterprises

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Abstract. Industrial and commercial enterprises are the main group of energy consumers, and objectively and accurately evaluating the value of their comprehensive energy system is the basis for optimizing operation and energy auditing. Traditional evaluation methods have shortcomings in promoting multi energy complementarity and renewable energy consumption. Propose a comprehensive energy system value evaluation method based on green economy, objectively and quantitatively calculate based on enterprise energy balance management standards, considering three evaluation indicators: product unit consumption, comprehensive energy efficiency, and renewable energy utilization rate. Using the fuzzy comprehensive evaluation method, the membership functions and dynamic weight coefficients of three indicators are designed to obtain a comprehensive value score, and the optimal operation plan is selected based on the score. The simulation results indicate that the evaluation method can select a reasonable operating mode based on the energy consumption pattern of the enterprise, promote the cascade utilization of energy and the on-site consumption of renewable energy, and verify the effectiveness and rationality of the method.

Keywords: Multi energy complementarity; Green economy; Enterprise energy balance; Fuzzy comprehensive evaluation; Dynamic Weight.

1 Introduction

The quality of energy supply in steel enterprises is directly related to the quality of steel products, and energy consumption directly affects the cost of steel products, thereby affecting a company's competitiveness. In addition, as a major polluter, the rational use and balanced allocation of energy by steel enterprises play a crucial role in environmental protection. The Energy Management System (EMS), as the core of the energy system in steel enterprises, achieves significant improvement in labor productivity through centralized monitoring and effective management of the energy system[1]. In the event of energy system abnormalities and accidents, EMS can provide timely, rapid, and accurate response to minimize the impact of energy system failures, ensure the safe operation and stable energy supply of energy equipment, and fully utilize secondary energy from steel mills, ensuring the economic and reasonable operation of production, and achieving energy-saving and environmental benefits.

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2 Enterprise Energy Balance Management and System Value Analysis

2.1 Energy balance management methods for enterprises

The classification and statistics of energy consumption are the prerequisite for quantitative analysis. At present, industrial and commercial enterprises generally prepare energy balance tables according to national standards and use them for energy audits or analysis. The statistical method for enterprise energy balance simplifies the energy consumption system of enterprises into four stages: purchase, storage, processing and conversion, transportation and distribution, and final use[2]. It also specifies the boundaries of enterprise energy consumption statistics and the measurement and conversion standards between different energy sources, and evaluates the energy utilization rate of enterprises η_{cur} and energy utilization rate η_{eu} has been defined as:

$$\eta_{cur} = \frac{E_{eff}}{E_{ev}} \tag{1}$$

$$\eta_{eu} = \frac{E_{eff}}{E_{eql}} = \frac{\sum \beta_k E_{eff}}{\sum E_{eql}(k)} \tag{2}$$

In the formula, E_{eff} is the effective energy of the final use stage; E_{ev} and E_{eql} are the algebraic sum of various energy equivalent values and equivalent values input into the comprehensive energy system, respectively, in kg (standard coal); β_k is the conversion coefficient of the k-th energy source; E_{eff} (k) and E_{eql} (k) are the equivalent values of the effective energy of the k-th energy source in the output energy and the total input energy, respectively[3].

In addition, the national energy statistics department has established a performance evaluation index system for enterprise energy utilization based on the characteristics of various industries, such as energy consumption per unit product ε_{eup}, comparable energy consumption ε_{cec} et al.

$$\varepsilon_{eup} = \frac{E_{eql}}{P_{op}} \tag{3}$$

$$\varepsilon_{cec} = \frac{E_{eql}}{P_{spo}} \tag{4}$$

In the formula, P_{op} and P_{spo} represent the actual product output of the enterprise and the product output under standard processes, in units of kg/t, kg/m, kg/box, etc. When comparable energy consumption is used to calculate the energy consumption of commercial buildings (such as enterprises, institutions, or universities), the unit is kg/person, kg/m2.

Comparable energy consumption is currently widely used for comparing energy consumption in the same industry, similar products, and under the same basic production conditions. Due to differences in production conditions and raw materials in different regions, the quality of unit consumption varies, and the upper limit of energy consumption usually meets local standards. In addition to the upper limit (admission value), advanced value indicators are also set, such as the energy consumption limit per unit product of aluminum alloy building profiles implemented by a certain province in 2008, and the admission value of product unit consumption $\varepsilon_{eup} \leq 540$ kg/t, advanced value $\varepsilon_{eup} \leq 500$ kg/t[4].

2.2 Value Analysis of Enterprise Comprehensive Energy System

Value measurement mainly includes two categories: asset value and market value, both of which are based on economic value theory to quantitatively evaluate the value of assets or products. A comprehensive energy system is a complex and multi energy flow artificial system that includes multiple links. For enterprises, its value first comes from the products or services created by consuming a certain amount of energy, that is, economic value; Secondly, the level of system energy efficiency is a reflection of its operational efficiency and an important measure of system value; Finally, the comprehensive energy system is a key entity that promotes energy structure adjustment, equipment level improvement, and policy system implementation and improvement. Its low-carbon characteristics reflect environmental benefits. Therefore, the value of an enterprise's comprehensive energy system can be comprehensively evaluated and quantitatively calculated from three aspects: economy, efficiency, and low-carbon[5].

3 Fuzzy Comprehensive Evaluation Method and Process

3.1 Evaluation indicators

(1)Economic indicators

The unit consumption theory is an energy system analysis theory and method designed on the basis of economics, which can be directly linked to cost and technical level. It has been widely promoted and applied in various industries. The reciprocal of equation (3) is selected as the evaluation indicator for economic factors, which means the product created per unit of energy consumption.

(2)Efficiency indicators

Comprehensive energy efficiency is a key indicator that describes the operational efficiency of a system. In the energy balance table, by analyzing the energy consumption status of various energy links, electricity balance, gas balance, and water balance can be analyzed, and the comprehensive energy utilization rate can be calculated through corresponding conversion standards. Equation (2) is selected as the efficiency evaluation indicator[6].

3.2 Membership Function

For the above three evaluation indicators, design membership functions to convert the indicator values to the numerical values in the [0,1] interval, where 0 represents the lowest membership degree and the lowest value contribution degree; 1 represents the highest degree of membership and value contribution.

(1) Unit consumption membership function

The range of product unit consumption values for industrial and commercial enterprises in different fields such as manufacturing and service varies greatly. It is necessary to define the upper and lower bounds of products or services in this field based on the current industry process, and convert them into dimensionless expressions through linear normalization.

$$\varepsilon_{\text{eup}}{}' = \begin{cases} 0 & P_{op} = P_{\min} \\ \dfrac{P_{op} - P_{\min}}{P_{\max} - P_{\min}}, & P_{\min} < P_{op} < P_{\max} \\ 1 & P_{op} = P_{\max} \end{cases} \tag{5}$$

In the formula, Pmax and Pmin represent the theoretical upper and lower bounds of energy consumption Eeql for producing products or services, respectively. When the unit consumption reaches the national standard admission value, the evaluation value $\varepsilon'_{\text{eup}}$ is 0.6, and when the unit consumption reaches the national standard advanced value, the evaluation value $\varepsilon'_{\text{eup}}$ is 0.8.

(2)Efficiency membership function

Comprehensive energy efficiency is a representation of the macro level efficiency of a system, considering various factors such as energy conversion, transmission distribution, and application losses. However, it cannot reflect the quality of energy utilization. Therefore, the energy quality coefficient is introduced to evaluate the advantages and disadvantages of energy utilization modes. The energy quality coefficient is developed by combining the "quality" and "quantity" of energy based on energy analysis, and has been applied in primary energy, secondary energy, and load application efficiency. The membership function is as follows:

$$\varepsilon'_{eqc} = \begin{cases} 0 & Q_k = 0 \\ \dfrac{\sum \beta_k \mathrm{E}_{eff}(k)\gamma_{k,s}(t)}{\sum \Sigma_{eql}(k)} & 0 < Q_k < \Sigma_{eql} \\ 1 & Q_k = \Sigma_{eql}, \gamma_{k,s}(t) = 1 \end{cases} \tag{6}$$

In the formula: $\gamma_{k,s}(t)$ is the energy quality coefficient of the k-th energy source at time t and the s-th utilization method; Qk is the cumulative energy consumption value of the k-th energy source.

3.3 Dynamic weighting strategy

Set the weight vector A containing three factors as:

$$A = [a_1 \quad a_2 \quad a_3] \tag{7}$$

a1, a2, a3 are the weight value of u1, u2, and u3 in the influence factor U, and satisfy A 1 + a2 + A 3 = 1. The weight vector comparison matrix M of the three factors determined by hierarchical analysis is as follows:

$$M = \begin{matrix} & \begin{matrix} a_1 & a_2 & a_3 \end{matrix} \\ \begin{matrix} a_1 \\ a_2 \\ a_3 \end{matrix} & \begin{bmatrix} 1 & 2 & 4 \\ \frac{1}{2} & 1 & 2 \\ \frac{1}{4} & \frac{1}{2} & 1 \end{bmatrix} \end{matrix} \tag{8}$$

Through consistency testing, the final weight vector A is determined to be [0.57, 0.29, 0.14].

In the production process of enterprise products, the distribution patterns of electricity/heat demand and renewable energy show certain randomness and dynamic changes. Therefore, the method of fixed weights cannot meet the time-varying needs of complex operating conditions. It is necessary to dynamically adjust the weight values based on specific scenarios to reflect the intrinsic value of economic, efficiency, and low-carbon factors in different scenarios and achieve online optimization. Design dynamic weight coefficients w1, w2, and w3 as follows:

$$w_1 = a_1 \frac{\sum P_{L,K}(t)}{P_{L,\max}} \tag{9}$$

$$w_2 = a_2 \left(e^{\sum \frac{P_{L,k}(t) - P_{LS,k}}{P_{L,k,\max}(t)}} - 1 \right) \tag{10}$$

$$w_3 = a_3 \sin\left(\frac{P_{re}(t)}{P_{rate}} \times \frac{\pi}{2} \right) \tag{11}$$

In the formula: $P_{L,k}(t)$ is the actual load of the k-th energy source at time t; $P_{L,\max}$ is the maximum value of the total load, taken as the sum of k energy load demands $P_{L,k,\max}$; $P_{LS,k}$ is the minimum starting load for the k-th energy source of the coupled unit; Prate and Pre (t) represent the installed capacity of renewable energy and the output value at time t.

The meaning of w2 is that when the demand for various loads exceeds the minimum starting load set by the coupling node, the weight value is higher. For the convenience of calculating the value contribution of each indicator, the final weight vector obtained after normalizing w1, w2, and w3 is:

$$V = [w_1' \quad w_2' \quad w_3'] \tag{12}$$

3.4Comprehensive Value Scoring and Evaluation Process

This paper can directly obtain the membership degree of indicators through the membership function, without the need to obtain it through the column vector Rm of the fuzzy relationship matrix R. Therefore, the comprehensive value scoring value is the result of the operation of the weight vector and the membership column vector:

$$\mathrm{F} = \mathrm{VS} \tag{13}$$

According to the above equation, the essence of the comprehensive energy system value evaluation method based on green economy is to integrate the economic, efficiency, and low-carbon characteristics that affect the comprehensive energy system value through the fuzzy comprehensive evaluation method, and conduct a comprehensive quantitative evaluation. Compared to traditional statistical methods, the advantages of this approach mainly include the following aspects.

1) Universality. The evaluation method is applicable to comprehensive energy systems with different unit combinations. Scoring the value of the system from an energy perspective can be effectively applied to peer enterprise comparisons and energy efficiency analysis across different industries[7].

2) Feasibility. The indicators are improved on the basis of current unit consumption, energy utilization rate, etc., which can be compatible with the future, while taking into account the

development goals of national energy conservation and emission reduction and the expectations of enterprise energy cost reduction.

3) Ease of use. The calculation data of indicators are all sourced from the enterprise energy balance table, which can be statistically analyzed based on existing measuring equipment. The calculation process is concise and can be effectively applied in engineering practice. Propose a dynamic evaluation process based on the operational strategy of the comprehensive energy system in conjunction with the actual production activities of the enterprise, as shown in Figure 1.

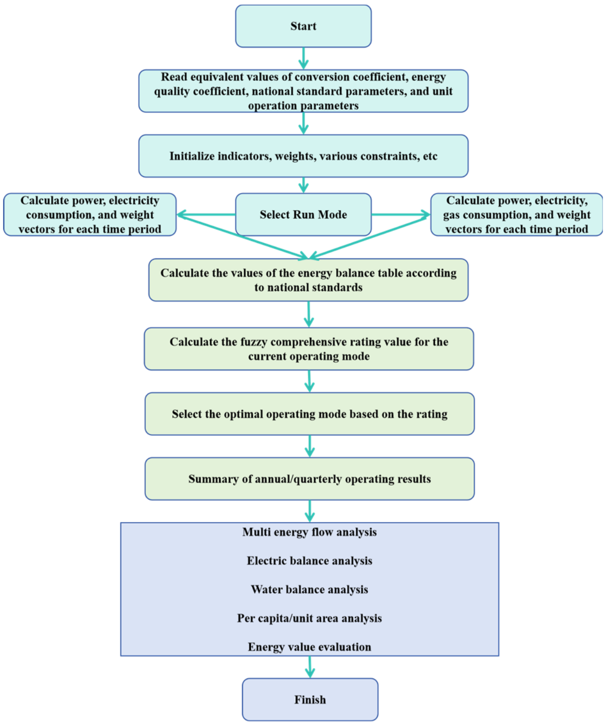

Figure 1. Value evaluation process of enterprise integrated energy system

4 Simulation examples

4.1 Simulation mode

This paper selects three typical modes of pure electricity, distributed power supply, and combined power supply to validate the effectiveness of the proposed method for energy consumption scenarios of enterprises at different time periods. Select the following three scenarios to verify the rationality and superiority of the evaluation method.

Scenario 1: During the intensive production period of user products, the assembly line starts 24 hours a day, and the load demand is mainly for a large amount of electricity and varying degrees of heat, with electricity/heat synchronization[8].

Scenario 2: During the transition period of user product production, the assembly line starts during working hours (08:00-17:00), and the load demand mainly includes less electricity and specific temperature heat, and the electricity/heat demand is not fully synchronized.

Scenario 3: In the off-season of user product production, the opening period of the assembly line is irregular, and the load demand is less electricity and less heat, with irregular electricity/heat demand.

4.2 Analysis of operation results

The following conclusions can be drawn through the analysis of the three scenarios.

1) Although the comprehensive energy efficiency of the triple supply system is high, planning and operation should consider the energy consumption characteristics of the enterprise to determine the start-up time, solve some or most of the energy needs in the product production process, and then supplement it with municipal electricity and natural gas direct combustion[9].

2) When the electric heating demand of enterprises is not synchronized, it can be considered to operate independently through separate supply, or to meet a larger range of supply and demand matching through methods such as surplus power grid connection and wall trading.

3) During periods of low energy demand in enterprises, pure electricity mode can be used to improve energy efficiency to meet diverse and time-varying energy demands. Using the value evaluation method proposed in this paper, the optimal operation plan was obtained and compared with the traditional optimization plan with the lowest unit consumption and cost. The results are shown in Table 1.

In the lowest unit consumption scheme, the consumption level of renewable energy is relatively low; In the lowest cost solution, due to the low electricity price during the valley period, the system will excessively operate in pure electricity mode, resulting in an increase in product unit consumption; Optimizing operation with the goal of achieving the highest green economic evaluation value can improve the overall energy efficiency of the system and the consumption of renewable energy without significant increase in unit consumption[10].

Table 1. Comparison of running results for the 3 optimization targets

Optimization objective	Single consumption of products/ (kg ·t - 1)	Comprehensive energy efficiency/%	Renewable energy utilization rate/%
Single consumption minimum	487 .15	48 .9	5 .6
The lowest cost	578 .42	37 .7	16 .7
Green commission economy	488 .63	52 .7	15 .9

5 Conclusion

This paper proposes a comprehensive energy system value evaluation method based on green energy economy to address the shortcomings of current evaluation methods in promoting multi energy complementarity and renewable energy consumption. Taking into account three factors: economic efficiency, operational efficiency, and low-carbon characteristics, the energy utilization value of the enterprise's comprehensive energy system was objectively and quantitatively calculated. Strategies such as Analytic Hierarchy Process and dynamic weighting were adopted to solve the dynamic optimization problem of enterprises in different energy consumption scenarios. The calculation example shows that this evaluation method can select a reasonable operating mode based on the energy consumption pattern of the enterprise, promote the cascade utilization of energy and the consumption of renewable energy.

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