Analysis on Potential of Electric Energy Market based on Large Industrial Consumer

Jingyi Lin\textsuperscript{1, a}, Xinzhi Zhu\textsuperscript{2, b}, Shuo Yang\textsuperscript{2, c}, Huaijian Xia\textsuperscript{4, d}, Di Yang\textsuperscript{2, e}, Hao Li\textsuperscript{1, f}, Haiying Lin\textsuperscript{4, g}

\begin{itemize}
  \item \textsuperscript{1} China Electric Power Research Institute, Beijing, China
  \item \textsuperscript{2} State Grid Hebei Electric Power Company, Hebei, China
  \item \textsuperscript{3} North China Electric Power University, Beijing, China
  \item \textsuperscript{4} China-Power Information Technology Co., Ltd, Beijing, China
\end{itemize}

\textsuperscript{a} linjingyi@epri.sgcc.com.cn
\textsuperscript{b} zhuxz@he.sgcc.com.cn
\textsuperscript{c} yangs@he.sgcc.com.cn
\textsuperscript{d} xiahaijian@sgitg.sgcc.com.cn
\textsuperscript{e} dyy-yangd@he.sgcc.com.cn
\textsuperscript{f} lihao@epri.sgcc.com.cn
\textsuperscript{g} linhaiying@sgitg.sgcc.com.cn

Abstract. The implementation of electric energy substitution by enterprises plays an important role in promoting the development of energy conservation and emission reduction in China. In order to explore alternative energy potential of industrial enterprises, to simulate and analyze the process of industrial enterprises, identify high energy consumption process and equipment, give priority to alternative energy technologies, and determine the enterprise electric energy substitution potential predictive value, this paper constructs the evaluation model of the influence factors of the electric energy substitution potential of industrial enterprises, and uses the combined weight method to determine the weight value of the evaluation factors to calculate the target value of the electric energy substitution potential. Taking the iron and steel industry as an example, this method is used to excavate the potential. The results show that the method can effectively tap the potential of the electric power industry.

1. Introduction

In recent years, the energy crisis and environmental pollution have been highly valued by the whole society. To further promote the rapid development of energy conservation and emission reduction of China, State Grid has put forward the development strategy of electric energy substitution at the right time. Electric energy substitution is not only an important measure to promote the proportion of renewable and clean energy consumption, but also an important means to reduce environmental pollution. Many researchers have carried out relevant theoretical research on the status of electric energy substitution in China. For example, the reference [1] establishes the rural electric energy substitution potential model according to the characteristics of energy consumption in rural areas and...
makes case study of electric energy substitution in rural areas in 26 provinces of China; the reference [2] establishes the benefit analysis model of environmental pollution reduction for electric energy alternative energy in Beijing according to the relationship between energy consumption and environmental emission in Beijing City and discusses the energy conservation and emission reduction and economic benefits of alternative energy-coal; through establishing grey energy demand forecast model, the reference [3] analyzes and forecasts the future demand for energy of the main terminals of Beijing; based on the forecast results, it analyzes the potential of various industries using electricity to substituting coal and oil. As the main energy consumer of China, industrial enterprises’ energy consumption accounts for about 70% of the total national energy consumption, so the promotion of alternative energy in the field of industrial enterprises is of great significance to China's energy conservation and emission reduction. According to the industrial enterprise energy consumption characteristics, propose a industrial enterprise energy substitution potential evaluation method; through process simulation of industrial enterprises, carry out the electric energy substitution transformation of high energy consuming equipment in different work procedures of enterprises; determine the predictive value of electric energy substitution potential; establish the evaluation model of factors influencing industrial enterprises’ electric energy substitution; use maximum deviation method and entropy method to determine the weights of evaluation factors in the evaluation system; evaluate the predictive value of industrial enterprises’ electric energy substitution potential. Finally, taking the steel industry as an example, this method is used for mining potential and verifying the effectiveness of the method.

2. Assessment of energy substitution potential of industrial enterprises
For enterprises, the process will have an important impact on energy consumption and pollutant emission. In the analysis of electric energy substitution potential of enterprises, firstly we must simulate enterprise processes, determine the high energy consuming processes, carry out electric energy substitution transformation of high energy consuming equipment in different work procedures and determine the predictive value of electric energy substitution potential [4].

2.1. Simulating the technological process of enterprise
Different industries, different scales and different processes are different in terms of energy consumption and pollutant emission, so in electric energy substitution transformation, the selected electric energy substitution technology will differ greatly. In the process of process analysis of an enterprise, it is needed to understand the specific industry sector, raw materials required in the enterprise production process, process route, process type, process equipment, product and stimulate the enterprise production process.

2.2. Analysis on energy consumption level and pollution emission of industrial enterprises
The formula for calculating the total energy consumption of industrial enterprises can be used to analyse the algebraic sum of the coefficient product of the work procedure energy consumption and the work procedure yield ratio [5], namely the specific formula for calculating the energy consumption of the enterprise is:

\[ E_0 = \sum_{i=1}^{n} e_i p_i \]  \hspace{1cm} (1)

Where: \( E_0 \) indicates the total energy consumption of industrial enterprises;
\( e_i \) indicates the energy consumption of each work procedures
\( p_i \) indicates the ratio between the yield of work procedure and the yield of enterprise

In general, in the production process of a product, pollutant emission of the industrial enterprises refers to the production of pollutants during the production under the existing technology and
management level; it is expressed as the product of the product yield and the pollutants producing coefficient [6]. That is:

$$T_p = \sum_{i=1}^{m} \sum_{k=1}^{n} G_{i,k} \cdot C_i, \ i, k = 1, 2, 3 \ldots$$

(2)

Where: $C_i$ indicates the i kind of yield

$G_{i,k}$ indicates the pollution emission coefficient of the i kind

2.3. **Analysis of electric energy substitution technology**

In terms of enterprise process, analyze the energy consumption of centralized link and key link of enterprise during production process, determine the high energy consuming work procedure during enterprise process, analyze the high energy consuming equipment and optimize the electric energy technology. At present, the electric energy substitution technology includes 3 kinds: coal, oil and gas; 14 main energy substitution methods and about 50 segmental technologies. According to the characteristics of industrial enterprise production technology, table 1 lists the electric energy substitution technology of some industrial enterprises [7].

| Electric energy substitution technology | Substituted object | Technology application field |
|----------------------------------------|--------------------|----------------------------|
| Electric boiler technology | Coal fired boiler and gas boiler | Heat for industrial production, etc. |
| Casting medium frequency electric furnace technology | Coal-fired cupola | Casting, forging and heat treatment, etc. |
| Electrothermal tunnel kiln technology | Coal and gas tunnel kiln | Smelting, roasting process, etc. |
| Arc furnace technology | Coal fired furnace, gas furnace and fuel oil furnace | Metal smelting, smelting, etc |
| Resistance furnace technology | Chamber type flame furnace and rotary furnace | Forging, heating and heat treatment etc. |
| Medium and high frequency induction furnace technology | Coal converter | Forging, heating, smelting, etc |

2.4. **Determine the predictive value of electric energy substitution potential**

In the process of potential analysis, carry out electric energy substitution transformation for high energy consuming equipment, after which, the annual substitute electric energy quantity is taken as the predicted potential value of enterprises implementing energy substitution.

$$M = \sum_{j=1}^{n} f_i (i = 1, 2, \ldots, n)$$

(3)

Where: $f_i$ indicates the annual substitute electric energy quantity of the i kind of electric energy substitution technology;

In practical process, the electric energy substitution of enterprises is influenced by many factors, so it is necessary to construct the evaluation index system of influence factors and further analyze the potential of electric energy substitution.
3. Construct the evaluation model of the influence factors of electric energy substitution in industrial enterprises

3.1. Construct the evaluation index system of influence factors

The evaluation index system of enterprises’ electric energy substitution potential carries out potential evaluation from the following respects respectively: enterprise basic condition, energy factor and economic factor. The specific evaluation system is shown in Table 2.

Table 2. Influence factor index system of electric energy substitution in industrial enterprises

| Overall goal A | Index layer B | Potential evaluation factor C |
|----------------|--------------|-------------------------------|
| Influence factor index system A | Basic condition B1 | Proportion of electric energy substitution investment C1 |
| | | Yield growth rate of enterprise product C2 |
| | Energy consumption status B2 | Annual growth rate of enterprise energy demand C3 |
| | | Proportion of enterprise energy consumption expenditure cost C4 |
| | | Proportion of electric energy to the total energy consumption C5 |
| | Energy conservation and emission reduction capability B3 | Carbon dioxide emission reduction effort C6 |
| | | Energy conservation and emission reduction technology investment C7 |

(1) basic conditions

1) Proportion of electric energy substitution investment

Electrical energy substitution involves distribution network upgrade, equipment investment, energy conservation transformation and other projects; the initial investment is relatively large. Therefore, when evaluating the potential of enterprises to implement electric energy substitution, the proportion of electric energy substitution investment is regarded as the evaluation factor in the influence factor indexes; the formula is as follows:

\[ \tau = \frac{C_{B1}}{B} = 1/2/3 \ldots \tag{4} \]

\[ \tau = \frac{\sum_{i=1}^{n} b_i}{B}, \quad i = 1, 2, 3 \ldots \tag{5} \]

Where:

\( \tau \) indicates the proportion of electric energy substitution investment;

\( b_i \) indicates the investment cost of the i electric energy substitution equipment;

\( B \) indicates the total operating expenses of enterprise.

2) Energy consumption growth rate of unit product of enterprise

In general, the amount of energy investment increment increases gradually once an enterprise produces one more produce, which shows that the enterprise’s energy utilization rate is low and the energy consumption is large [8]; the calculation formula is as follows:

\[ \alpha = \frac{D_i - D_{i-1}}{D_{i-1}}, \quad i = 1, 2, \ldots \tag{5} \]

Where:
\( \alpha \) - indicates the energy consumption growth rate of unit product of enterprise;

\( D_i \) - indicates the unit product energy consumption of the i year;

\( D_{i-1} \) - indicates the i-1-unit product energy consumption.

(2) Energy consumption situation;

1) Average annual growth rate of enterprise energy demand

\[
\delta = \frac{Y_i - Y_{i-1}}{Y_{i-1}} \quad i = 1, 2, \ldots n
\]

Where:

\( \delta \) indicates the average annual growth rate of enterprise energy demand;

\( Y_i \) indicates the energy demand for the year \( i \);

\( Y_{i-1} \) indicates the energy demand for the year \( i-1 \).

2) Proportion of enterprise energy consumption expenditure cost

\[
\varepsilon = \frac{m}{M}
\]

Where:

\( \varepsilon \) indicates the proportion of enterprise energy consumption expenditure cost;

\( m \) indicates the cost of energy consumption expenditure cost;

\( M \) indicates the total operating expenses of the enterprise.

3) Proportion of electric energy to the total energy consumption

\[
\zeta = \frac{s}{S}
\]

Where:

\( \zeta \) — indicates the Proportion of electric energy to the total energy consumption;

\( s \) — indicates the energy consumption of enterprise;

\( S \) — indicates the total energy consumption of enterprise.

(3) Energy conservation and emission reduction capacity;

The smaller the carbon dioxide emission reduction effort, the greater the potential for electric energy substitution; similarly, the greater the energy conservation and emission reduction technology investment, the greater the potential for electricity substitution. Therefore, the carbon dioxide emission reduction effort and the energy conservation and emission reduction technology investment are taken as evaluation factors in the influence factor evaluation index system; the calculation formula is as follows.

1) Carbon dioxide emission reduction effort

\[
\beta = \frac{E_i - E_{i-1}}{E_{i-1}} \quad i = 1, 2, \ldots n
\]

Where:

\( \beta \) — indicates the carbon dioxide emission reduction effort;

\( E_i \) — indicates the carbon dioxide emission in the year \( i \);

\( E_{i-1} \) — indicates the carbon dioxide emission in the year \( i-1 \).

2) Energy conservation and emission reduction technology investment
\[ \eta = \sum_{i=1}^{n} \frac{c_i}{C} \quad i = 1, 2, \ldots, n \]  

(10)

Where:
- \( \eta \) indicates the energy conservation and emission reduction technology investment;
- \( c_i \) indicates the capital investment of energy conservation and emission reduction technology;
- \( C \) indicates the total operating expenses of the enterprise.

3.2. Combination weighting method for determining index weight

(1) Maximum deviation method for determining weight

The maximum deviation method can determine the weight of the index by calculating the proportion of deviation of the \( i \) index to the total deviation of all indexes [9].

1) Calculate the index deviation

Suppose \( x_{ij} \) is the \( i \) standard value in the \( j \) index layer and \( w_j \) is the corresponding weight. Assume \( E_{ij}(w) \) is the deviation between the \( i \) index and other indexes.

\[ E_{ij}(w) = \sum_{k=1}^{m} \left| x_{ij}w_j - x_{kj}w_j \right| \]  

(11)

Suppose

\[ E_j(w) = \sum_{i=1}^{n} \sum_{k=1}^{m} \left| x_{ij}w_j - x_{kj}w_j \right| \]  

(12)

2) Construct the objective function

\[ \max E(w) = \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{m} \left| x_{ij}w_j - x_{kj}w_j \right| \]  

(13)

The above formula is equivalent to the following model:

\[ \left\{ \begin{array}{l}
\max E(w) = \sum_{j=1}^{n} \sum_{i=1}^{m} \sum_{k=1}^{m} \left| x_{ij}w_j - x_{kj}w_j \right| \\
w_j \gg 0, j \in N, \sum_{j=1}^{n} w_j^2 = 1
\end{array} \right. \]  

(14)

3) Determine the weight

Obtain the index weight by putting the index attribute vector in the formula.

\[ w_j = \frac{\sum_{i=1}^{n} \sum_{k=1}^{m} \left| w_j - x_{kj} \right|}{\sum_{j=1}^{n} \sum_{i=1}^{m} \sum_{k=1}^{m} \left| x_{ij} - x_{kj} \right|} \]  

(15)

(2) Entropy method for determining weight

The entropy method can determine the index weight according to the size of the information provided by each index, and the specific steps are as follows: [10]

Calculate the proportion of the \( i \) index of the \( j \) index:
\[ p_j = \frac{X_{ij}}{\sum_{i=1}^{n} X_{ij}}, \quad (i=1,2,...,n, j=1,2,...,m) \]  
\[ (16) \]

Calculate the entropy of the \( j \) index.

\[ e_j = -k \sum_{i=1}^{n} p_j \ln(p_j) \]  
\[ (17) \]

Where, \( k > 0, \quad k = 1/\ln(n), \quad e_j \geq 0 \)

When calculating the deviation coefficient of the \( j \) index, the deviation coefficient can be defined as \( g_j \):

\[ g_j = \frac{1 - e_j}{m - E_s} \]  
\[ (18) \]

Where:

\[ E_s = \sum_{j=1}^{n} e_j, \quad 0 \leq g_j \leq 1, \sum_{j=1}^{n} g_j = 1 \]  
\[ (19) \]

Determine the index weight:

\[ w_j = \frac{g_j}{\sum_{j=1}^{n} g_j} \quad (1 \leq j \leq m) \]  
\[ (20) \]

3.3. Determine the combination weight
In the process of analysis, to determine the subjective and the objective combination weight, the maximum deviation method \( k_1 \) and the entropy weight weighting \( k_2 \) are determined by applying the Lagrange conditional extremum principle [11].

\[ k_1 = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m} p_{ij} x_{ij}}{\sqrt{\left(\sum_{i=1}^{n} \sum_{j=1}^{m} p_{ij} x_{ij}\right)^2 + \left(\sum_{i=1}^{n} \sum_{j=1}^{m} q_{ij} x_{ij}\right)^2}} \]  
\[ (21) \]

\[ k_2 = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m} q_{ij} x_{ij}}{\sqrt{\left(\sum_{i=1}^{n} \sum_{j=1}^{m} p_{ij} x_{ij}\right)^2 + \left(\sum_{i=1}^{n} \sum_{j=1}^{m} q_{ij} x_{ij}\right)^2}} \]  
\[ (22) \]

Where: \( k_1 > 0, k_2 > 0, k_1^2 + k_2^2 = 1 \)

Thus, the final weight is:

\[ w = k_1 w_1 + k_2 w_2 \]  
\[ (23) \]
3.4. Potential prediction equation
Suppose that the potential value of the enterprise energy substitution is $M$, the predicted potential value of the electric energy substitution $E_{si}$ can be calculated by the following formula:

$$E = \left( M \times \sum_{i=1}^{n} \omega_i E_i \right) / 100 \ (i = 1, 2, ..., n) \quad (24)$$

Where:
- $M$ indicates the target potential value;
- $\omega_i$ indicates the weight of the $i$th evaluation factor;
- $E_i$ indicates the score of the $i$th evaluation factor.

4. Example analysis
Take the iron and steel enterprises as an example, their production including coking, sintering, ironmaking, steelmaking processes; their production equipment include coking furnace equipment, sintering machine equipment, coal fired cupola and other high energy consuming equipment; the production process is simulated as shown in Fig. 1

![Fig. 1 Enterprise production process](image)

Through the analysis of the energy consumption of each process, we find that the energy consumption of iron smelting process is the highest, followed by coking process, sintering process and steelmaking process.

![Fig. 2 Energy consumption analysis of different enterprise processes](image)

In the ironmaking process, the main energy consuming equipment is coal fired cupola; therefore, the casting medium frequency electric furnace technology is selected to carry out electric energy
substitution transformation for coal-fired cupola; through the analysis of the equipment, we can determine that the predictive value of the enterprise electric energy substitution potential is 8 million kW·h.

Put the weight of the evaluation factors in the influence factor evaluation system obtained by maximum deviation method and entropy method in formula (18) and (19), the combined weight coefficient can be obtained; put the coefficient $k_1$ and $k_2$ in (20), the combined weight as shown in table 3 can be obtained.

**Table 3.** Subjective and objective weighting method index system weight

| Potential index                                      | Maximum deviation weight assignment | Entropy method weight assignment | Combination weight assignment |
|-----------------------------------------------------|-------------------------------------|---------------------------------|------------------------------|
| Proportion of electric energy substitution investment C1 | 0.1341                              | 0.143                           | 0.139173                     |
| Yield growth rate of enterprise product C2           | 0.1001                              | 0.159                           | 0.133673                     |
| Annual growth rate of enterprise energy demand C3    | 0.1721                              | 0.174                           | 0.173183                     |
| Proportion of enterprise energy consumption expenditure cost C4 | 0.142                              | 0.151                           | 0.14713                      |
| Proportion of electric energy to the total energy consumption C5 | 0.165                              | 0.134                           | 0.14733                      |
| Carbon dioxide emission reduction effort C6          | 0.1201                              | 0.128                           | 0.124603                     |
| Energy conservation and emission reduction technology investment C7 | 0.166                              | 0.106                           | 0.1318                       |

Based on the above data, the target potential value is

$$E = M \times \sum_{j=1}^{n} \omega_j \theta_j = 3.77 \text{ million kW·h}$$

5. Conclusion

In view of the energy consumption characteristics of industrial enterprises, the process flow of industrial enterprises is simulated and analyzed, to analyze the high energy consuming equipment in different processes and select appropriate electric energy substitution technology. Take the substitution energy quantity after equipment transformation as predicted potential value, construct the evaluation model of the factors influencing enterprise electric energy substitution, determine the target potential value of industrial enterprise through the weight of evaluation factors; carry out case analysis by taking steel industry as an example, the results show that this method can effectively evaluate the industrial enterprises’ electric energy substitution potential; this provides research methods and basic ideas for the analysis of industrial enterprises’ electric energy substitution potential; meanwhile, this provides theoretic and technical reference for the promotion of electric energy substitution technology.

Acknowledgments

This research was supported by the Science and Technology Project of State Grid Corporation Headquarters (Grant No. YD71-16-014).
References

[1] Zheng Jincheng. Analysis of Rural Electric Energy Substitution Potential and Environmental Benefit [D]. Beijing: Master Thesis of North China Electric Power University, 2015.3.

[2] Zhao Yinhui. Energy Substitution Analysis and Optimization Model Research under the Environmental Reduction Targets in Beijing [D]. Beijing: Doctoral Thesis of North China Electric Power University, 2014.6.

[3] Yin Hang. Research on the Evaluation Methods of Electric Energy Substituting Other Energy Resources in Energy Conservation and Emission Reduction Environment [D]. Beijing: Master Thesis of North China Electric Power University, 2013.3.

[4] Zhang Chenkai. Analysis of Industrial Energy Conservation and Emission Reduction Potential and Collaborative Control: a Case Study Of Steel Industry [D]. Beijing: Master Thesis of North China Electric Power University, 2016.6.

[5] Liu Wenchao, Cai Jiuju, Zhang Qi, et al. Energy consumption analysis and Energy Conservation Countermeasures Research of Iron and Steel Enterprises [J]. Industrial Furnace, 2011 (03):8-11.

[6] Hao Yongli, Ouyang Zhaobin, Qiao Qi, et al. Evaluation Method for Pollutant Emission Control and Reduction Potential - a Case Study of Small and Medium Sized Iron and Steel Enterprises [J]. Environmental Pollution and Control, 2010, 32 (5):82-84.

[7] Song Shenghe, Liu Chunhua, Li Zhibin, et al. Implement Electric Energy Substitution to Promote Energy Conservation and Emission Reduction [J]. Technology Entrepreneur, 2013.

[8] Wang Xiaojie, Zhou Yingnan, Liu Huanhuan. Study on prediction model of the Energy Conservation Potential of Industrial Enterprises [J]. Population, Resources and Environment of China, 2010, 20 (5):27-31.

[9] Li Chunhua, Ran Jingxue, Gao Huisheng. Comprehensive Evaluation of Power Communication Network Transmission Part Based on the Maximum Deviation Method [J]. Power System Protection and Control, 2008, 36 (15):33-36.

[10] Lu Tianchao, Kang Kai. Application of Entropy Method and Analytic Hierarchy Process in the Determination of Weight [J]. Computer Programming Skills and Maintenance, 2009 (22):19-20.

[11] Meng Fansheng, Li Meiying. Study on the Influence Factors of CO2 Emission in China Based on Combination Weighting Method [J]. Operation and Management, 2014 (1):157-165.

[12] Hao Changsheng, Sheng Junkun, Fan Xueqin. Mine Safety Comprehensive Evaluation Model Based on Fuzzy Analytical Hierarchy Process [J]. Coal Technology, 2016 (02):234-237.