Benefit Evaluation of Comprehensive Energy Consumption Method for Urban

Quan Zhang1,*, Yufeng Chai1, Xianzhong Dai1, Hongyuan Ren2 and Jun Dong3

1State Grid Energy Research Institute CO. LTD, Beijing, 102206, China
1Beijing Join Bright Digital Electricity Technology Co Ltd, Beijing, 100038, China
2School of Economics and Management, North China Electric Power University, Beijing, 102206, China

*Corresponding author e-mail: 1551517314@qq.com

Abstract. Energy is the source of power for the construction and development of urban economy. Based on the analysis of industrial, commercial and residential energy users in Suzhou, the paper establishes an evaluation model of urban comprehensive energy efficiency and puts forward the optimization plan of urban comprehensive energy supply. Through the evaluation of the comprehensive energy efficiency in Suzhou City, it can provide forward-looking and guiding ideas and measures for the construction of Suzhou's comprehensive energy, which will help to promote Suzhou's urban energy reform and create a smart city model.

1. Introduction
In today's rapid socio-economic development, energy plays a more and more important role in contemporary social life and gradually permeates every aspect of human life. The development of the city cannot do without energy and all industries will not survive without energy. With the "Internet +" strategy proposed, it means that the Internet will be gradually applied in the field of energy research, a large number of innovative research results have gradually emerged, so that energy has the information and data attributes, breaking the traditional energy attributes. At the same time, it accelerates the pace of integration of the Internet and energy, promotes innovation in the energy industry in the Internet industry, optimizes the original energy structure and achieves the goal of energy conservation and emission reduction so that energy can be utilized more reasonably and efficiently.

Suzhou has established pilot projects of "source-network-load" friendly interaction and vigorously promoted the development of grid security, cleanliness, coordination and intelligence so as to ensure the significant improvement of power quality, convenient and efficient power supply services and the full consumption of clean energy. At present, China has serious environmental pollution and insufficient resources. This poses urgent requirements for energy innovation and energy transformation in our country. Therefore, we should actively explore urban energy reform. Many scholars have done a lot of research on comprehensive energy use. Among them, Lin Wei. Studied the three-phase unbalanced distribution system, gas pipeline network and energy center in the regional integrated energy system, And the goal of minimizing the economic cost of the multi-objective optimal hybrid power flow algorithm [1]. Xu Yanli proposed a real-time optimal control method of distributed energy supply system based on short-term load forecasting to achieve the goal of energy-saving optimal control [2].
Gao Zhiyong proposed economy and reasonable industrial park energy supply program [3]. from the initial investment, operating costs and investment payback period analysis of the economy and other aspects.

In order to comply with the trend of energy saving and emission reduction and sustainable development, based on other existing research results, this paper mainly studies the present situation of energy use in various industries in Suzhou and constructs a model for assessing the benefits of urban energy use and then we take Suzhou Industrial Park as an example, based on the evaluation model to optimize the design of energy solutions.

2. City energy consumption status

The mode of urban energy use embodies the energy utilization of the city and the level of development of the city, and embodies the development ability of the city from the side. This chapter analyzes the present situation of energy consumption of the three types of users of industry, commerce and residents in Suzhou by means of research.

2.1. Analysis of industrial energy-using status

The energy consumption characteristics of industrial sectors and energy efficiency are closely related to production process characteristics and product structure. Differences in process characteristics and product structure determine their energy consumption patterns, production processes and energy consumption are quite different, but also because of different types of industries in a region's industrial structure is also different, which also cause energy intensity an obvious difference. Such as agricultural food processing, textile and printing and duplication industry energy intensity is relatively low, energy efficiency is high, while large-scale manufacturing, mining and production and supply industries has high energy consumption. Relevant data show that the average intensity of energy consumption in the industrial sector in Suzhou is decreasing year by year, which means that the output elasticity of investment in industries is gradually increasing, and the energy efficiency is also improving. This is mainly due to the transformation of the energy structure, the adjustment of the industrial structure, the improvement of the R & D level and the continuous improvement of the energy system and mechanism.

From the changes in the consumption of various types of energy in Suzhou industry (Figure 1), the electricity consumption has the trend of first decreasing and then increasing. The electricity consumption decreased by 17.6% from 2013 to 2014, and kept a slight increase from 2014 to 2016. However, this is a slow trend. Natural gas, heat, water consumption in the four years no significant change, has been stabilized at a fixed level of consumption.

![Figure 1. Suzhou Industrial energy consumption trends](image-url)
2.2. Analysis of commercial energy-using status

The energy consumption characteristics of the commercial sector can be described by their carbon emissions, while the commercial carbon emissions can be estimated by the general method of calculating carbon emissions, such as the method in the IPCC Guidelines for Greenhouse Gas Inventories, that is, the commercial standard of energy consumption multiplied by its corresponding CO2 emission factor and then sum to get the total amount of CO2 emissions from all energy consumption. By analyzing and studying the characteristics of annual commercial CO2 emissions, it is clear that the four factors of industry size, energy efficiency, energy structure and population characteristics are the most crucial factors that affect the change of CO2 emissions. At the same time, the commercial energy consumption characteristics can also be described by the direct energy consumption intensity and the direct energy consumption coefficient.

The statistics of natural gas and electricity consumption by Suzhou Commercial in 2013-2016 are shown in Figure 2 above. It can be seen that the commercial energy consumption in Suzhou is constantly rising, rising from 3.66 billion kWh in 2013 to 4.3 billion kWh in 2016, up by 17.5%. Natural gas consumption also enjoys the same trend as electricity consumption, maintaining rapid growth, representing an increase of 28.6% over 2013 consumption. For Suzhou business, the share of electricity and energy consumption is still the relative highest.

![Figure 2. Suzhou Commercial Power and Natural Gas Energy Consumption Trend](image)

2.3. Analysis of residential energy-using status

Residential energy consumption can be divided into direct energy consumption and indirect energy consumption. Among them, direct energy consumption refers to the direct purchase and consumption of energy products by residents, and is generally used for electricity consumption and fuel consumption in cooking, household appliances, heating and bathing. Indirect energy consumption, on the other hand, refers to the indirect consumption of non-energy products and services consumed by residents in ordinary life. Indirect energy consumption exists during the entire life cycle of the production, processing, sales and disposal of the.

Energy consumption as a whole rose from 1,474,300 tons of standard coal to 1,643,100 tons of standard coal, increased by 11.4%. in the total energy consumption of the three households in Suzhou in the period from 2013 to 2016. Then from the energy consumption trend of urban and rural residents, as shown in Figure 3, the consumption of electricity and energy is decreasing first and then increasing, the consumption of natural gas keeps increasing at a small margin, and the consumption of water...
resources has remained stable at a fixed level with no significant changes. In the residential energy use, we can clearly see that electricity consumption occupies a large proportion of energy consumption.

![Figure 3. Suzhou urban and rural energy consumption trends](image)

**3. Benefit evaluation model of Urban comprehensive energy consumption mode**

**3.1. Benefit evaluation index system**

The key to benefit evaluation of urban energy consumption mode is to establish a systematic, scientific and reasonable energy consumption evaluation index system. In the initial establishment of energy consumption evaluation index system, the index selection should be as complete as possible to reflect the characteristics of residential energy consumption more comprehensively and intuitively. In addition, it is necessary to screen carefully when ensuring the completeness of the indexes. The primary indexes were screened by Delphi method with the principles of scientificity, applicability, completeness, conciseness, operability and independence. The evaluation process is divided into three levels: level one index weight calculation, level two index weight calculation and the comprehensive weight calculation.

Based on the analysis of the current situation of energy utilization in different industries, the paper evaluates the urban user's energy use mode from three aspects of city users, energy quality and environment, according to the basic principles of the index system. The preliminary evaluation index system is illustrated in Figure 4. The overall index system is divided into two layers. 3 level one indicators respectively called urban user's energy use, energy quality and environmental impact are in the first layer. Detailed totally 15 level two indicators separated into 7 indicators about urban user's energy use, 6 indicators about energy quality, 3 indicators about environment impact are in the second layer.
The evaluation index system of urban comprehensive energy efficiency is preliminarily established.

**Urban user energy A**
- Total user energy $A_1$
- Comprehensive energy consumption $A_2$
- Per capita energy consumption $A_3$
- Load factor $A_4$
- Energy saving rate $A_5$
- Energy saving $A_6$

**Energy quality B**
- Voltage unqualified cumulative time $B_1$
- Regional average peak-to-valley power load ratio $B_2$
- Public network grid harmonics $B_3$
- Clean energy share $B_4$
- Carbon dioxide emissions per unit of GDP $B_5$
- Distributed natural gas cumulative installed capacity $B_6$

**Environmental impact C**
- Carbon emission $C_1$
- Electromagnetic pollution $C_2$
- Pollutant discharge level $C_3$

**Figure 4.** Preliminary selection of energy index for urban comprehensive energy utilization mode benefit evaluation

Then, 5 level two indicators are deleted by scoring and screening indicators through experts evaluation, consultation questionnaire and expert consultation three steps. Primary indicators screening results are shown in Figure 5.

**Figure 5.** Energy consumption index after screening and optimizing
3.2. Construction of benefit evaluation model

3.2.1. Level one index assessment. The method of hierarchical comprehensive evaluation is used to evaluate the benefit of urban energy consumption. The evaluation process is divided into three levels: level one index evaluation, level two index evaluation and comprehensive weight. The basic steps of AHP (Analytic Hierarchy Process) include constructing pairwise comparison matrix, calculating weight vector and checking consistency.

(1) Constructing pairwise comparison matrix

Using expert evaluation to compare and analyze the level one index, evaluate the importance of the index, and form the evaluation matrix E:

\[ E = (e_{ij}), e_{ij} > 0, e_{ii} = \frac{1}{n_{ij}}, e_{ii} = 1 \]

Table 1. Importance comparative scale of evaluation index

| Scale value | Scale significance |
|-------------|--------------------|
| 1           | Equally significant|
| 3           | Moderate significant|
| 5           | Obviously significant|
| 7           | Strongly significant|
| 9           | Absolutely significant|
| 2,4,6,8     | The intermediate value |

In the upper form, \( e_{ij} \) represents the importance ratio between different indexes, and the evaluation matrix can be obtained through expert evaluation:

\[
E = \begin{bmatrix} 1 & 3 & 5 \\ 1/3 & 1 & 3 \\ 1/5 & 1/3 & 1 \end{bmatrix}
\]

(2) Calculate the weight vector according to formula (1) and calculate the geometric mean of each row element in pairwise comparison matrix:

\[
M_i = (\prod_{j=1}^{n} e_{ij})^{1/n}; i, j=1, 2, \ldots n
\]

\[
M = [M_1, M_2, \ldots, M_n]^T
\]

Normalization of vector M:

\[
m_i = M_i / \sum_{j}^{n} M_j
\]

Finally, the weight vector is:

\[
m = (0.637, 0.258, 0.105)
\]

(3) Check consistency

In order to evaluate the reliability of the judgment matrix, the consistency test must be carried out. The consistency index FI is calculated first:
\[ FI = \frac{(\lambda_{\text{max}}(E) - n)}{(n - 1)} \] \quad (4)

In the formula, \(n\) is the order of matrix \(E\), \(\lambda_{\text{max}}\) is the largest eigenvalue of the matrix \(E\):

\[ \lambda_{\text{max}} = \sum_{i=1}^{n} \sum_{j=1}^{m} e_{ij} / nm_i \] \quad (5)

Finally, put the consistency index \(FI\) and the average random consistency index \(KI\) in comparison to obtain the consistency ratio \(FK\), which is as follows:

\[ FK = \frac{FI}{KI} \] \quad (6)

| Matrix order | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|--------------|---|---|---|---|---|---|---|---|
| KI           | 0 | 0 | 0.58 | 0.89 | 1.12 | 1.26 | 1.36 | 1.41 |

If \(FK\) is less than 0.1, the consistency of judgment matrix is in the acceptable range; if \(FK\) is not less than 0.1, there is the need for appropriate amendments to the judgment matrix. After calculating the parameters of \(FK=0.033\) can be obtained, so the consistency test meet the requirements.

3.2.2. Level two index assessment. According to entropy weight method, the smaller the index entropy, the greater the difference between the various evaluation objects and the amount of information contained, the greater effect it can be in the comprehensive evaluation, so the weight is greater, and weights assignment can be done forward. By using the improved entropy weight method, the entropy weight of each index is calculated by using the information entropy first, then the entropy weight will be corrected leading to the final determination of the weight for each index.

(1) Consistency and dimensionless treatment to indexes.

The dimensionless treatment for indexes in the same type should adopt the following methods: first of all, “centralization” processing makes \(z' = \frac{z - z}{D}\) in which \(z\), \(D\) as the sample mean and sample mean deviation of observed index \(x\) respectively; secondly, “Maximum difference” processing makes \(z' = \frac{z - p}{p - p}\) in which \(p, P\) as the minimum and maximum values of the observed value \(z\) respectively; third, “maximum” processing makes \(z' = \frac{z}{p}\) \((p > 0)\); fourth, “minimization” processing makes \(z' = \frac{z}{p}\); fifth, “mean value” processing makes \(z' = \frac{z}{z}\). The existing evaluation objects counted \(n\) and evaluation indexes counted \(m\) form the original data matrix as follow:

\[ Z = (z_{ij})_{max} = \begin{bmatrix} z_{11} & \cdots & z_{1n} \\ \vdots & \ddots & \vdots \\ z_{m1} & \cdots & z_{mn} \end{bmatrix} \]

In the formula, \(z_{ij}\) is the evaluation value of the evaluation index numbered \(I\) for the evaluation object numbered \(j\).

(2) The entropy value of the first \(I\) evaluation index is calculated as follows:

\[ a_i = -b \sum_{j=1}^{n} z_{ij} \ln z_{ij}, \] in the formula \(b= (\ln p) - 1\).

(3) The difference coefficient of the evaluation index numbered \(I\) is calculated as follows:

\[ t_i = 1 - a_i \]
(4) The entropy weight of the index numbered I is calculated as follows:

\[ v_i = \frac{t_i}{\sum_{i=1}^{n} t_i} \]

(5) The weight determination by entropy weight correction.

If the maximum value of \( v_i^* \) > 0.3, then the maximum value is forced to be corrected to \( v_i^* = 0.3 \), and other entropy rights need to be corrected as:

\[ v_i^* = v_i + \frac{v_i}{\sum_{i=1}^{m} v_i} \times (v_i^* - 0.3) \]

in the formula \( i \neq i^* \), \( i = 1, 2, ..., m \). The weight is determined as:

\[ v^* = (v_1^*, E_1^*, ..., E_m^*) \]

3.2.3. Comprehensive weight evaluation model. The weight vector for level one index is \( m = (m_1, m_2, ..., m_n) \) based on AHP (Analytic Hierarchy Process) method by subjective assessment and the weight vector for level two index \( k = (k_1, k_2, ..., k_m) \) improved entropy weight method by objective evaluation. Though comprehensive weighting method, The comprehensive energy evaluation model is constructed as:

\[ y = \sum_{i=1}^{n} m_i \left[ \sum_{j=1}^{m} v_{ij} z_{ij} \right] \]

In order to judge the comprehensive weight of each index.

4. Application analysis (taking Suzhou Industrial Park as an example)

4.1. Energy utilization assessment.

Based on the comprehensive energy consumption data of Suzhou Industrial Park, the comprehensive energy efficiency evaluation of Suzhou Industrial Park during the "three year" construction period in 12th Five-Year is comprehensively evaluated by using the comprehensive energy utilization evaluation model. Establishing the level one indexes of energy consumption evaluation for Suzhou urban users with energy usage, energy quality and environmental impact factors, and through AHP (analytic hierarchy process), the weights of 0.581, 0.309 and 0.11 are obtained respectively. According to the total energy consumption data of the park and entropy weight method, the weights of level two indexes of Suzhou Industrial Park are determined, and the energy utilization data of Suzhou Industrial Park are processed to form the energy index which can be dealt with.

| Indexes | Weight |
|---------|--------|
| A_1     | 0.179  |
| A_2     | 0.148  |
| A_3     | 0.181  |
| A_4     | 0.168  |
| A_5     | 0.143  |
| A_6     | 0.187  |
| B_1     | 0.268  |
| B_2     | 0.21   |
| B_3     | 0.267  |
| B_4     | 0.255  |
| C_1     | 1      |
Using the urban comprehensive energy efficiency evaluation model to calculate the weight of the level two indexes under the user's energy consumption and environmental impact indicators.

The comprehensive evaluation model of energy consumption is: \( y = \sum_{i=1}^{n} m_i \sum_{j=1}^{m} v_{ij}z_{ij} \). According to the established comprehensive benefit evaluation model of urban energy consumption, the comprehensive energy utilization benefit of Suzhou Industrial Park in 2013-2015 can be evaluated. The evaluation results are shown in table below.

**Table 4 Evaluation result**

| Indexes  | A    | B    | C    | Overall assessment |
|----------|------|------|------|--------------------|
| Year 2015| 0.477| 0.231| 0.085| 0.793              |
| Year 2014| 0.502| 0.109| 0.08  | 0.691              |
| Year 2013| 0.414| 0.177| 0.072| 0.663              |

As shown in table 4, the comprehensive energy utilization level of Suzhou Industrial Park in 2015 is the highest, which is better than that in 2014 and 2013.

4.2. Comprehensive energy supply optimization scheme

Based on the future "13th Five-Year" planning on the Suzhou industrial park and comprehensive energy usage efficient assessment results, regional characteristics, energy usage habits of various industries in the park and comprehensive energy supply situation, optimization scheme can be designed for comprehensive energy supply, the steps are as follows:

1) According to the results of the above model operation, the current annual indicators are combed to find out the key indicators change, in which are regional monthly peak valley power load ratio, unit GDP carbon dioxide emissions, proportion of clean energy to total energy consumption.

2) According to the above analysis of park industry development status and "13th Five-Year Planning" scheme of the park, prediction and analysis of key factor data of model and combined with the urban energy efficiency evaluation model. The data were adjusted reasonably in 2015, and the rationality evaluation of energy consumption evaluation model was carried out according to the energy supply adjustment planning data.

3) The evaluation results are analyzed to adjust the existing comprehensive energy supply scheme.

Comprehensive energy supply scheme:

Through the above model calculation. Adjusting the proportion of clean energy, regional monthly peak valley power load ratio, energy saving rate and other related indicators have a significant impact on the comprehensive energy efficiency of the park. It is necessary to optimize the existing integrated energy supply plan and adjust the corresponding energy supply structure in order to achieve the improvement of relevant indicators in the future.

First, increasing the proportion of clean energy in the park, such as electricity and natural gas. From 2013, 2014 to 2015, comparative analysis of energy consumption can be obtained that crude oil, heat, gasoline and other trends have little change, these situation is flat in three years basically. But in 2014 and 2015, natural gas and electricity consumption is significantly promoted, coal consumption has decreased. So in the protection of other energy supply remaining unchanged, combined with the park production planning and future development trend of electric power, natural gas consumption, electricity consumption in 2015 based fee of 301.9 tons of standard coal units had increased to 318.09 per million tons of standard coal (coal conversion), while increasing the amount of natural gas supply to 140.27 per million tons of standard coal (coal conversion). With the improving of the electricity and natural gas in the energy supply proportion in clean energy, the consistent 1.6% promotion about clean energy proportion of the park will be accomplished in the future.

Secondly, the total control of power consumption and coal use in the park and the improvement of its use efficiency will be the main breakthrough in reducing carbon emissions in the future energy consumption areas. For the control of electricity, it is reasonable to change the proportion of the electric...
power transferred outside the park and solar power generation inside the park. From 2013 to 2015, the power supply of the park increased from 7 billion 610 million kwh to 8 billion 100 million kwh. The carbon emission from electricity consumption outside the park was 6 million 107 thousand tons, accounting for the highest proportion of carbon dioxide emissions related to the park and energy consumption, reaching 54.72%. From 2013 to 2015, it can be seen from the proportion of distributed power and transferred power to the total power consumption of the park that improving the structure of the distributed power supply is conducive to improving the proportion of clean energy in the park, improving the energy saving rate of the users and reducing the carbon dioxide emissions of the unit GDP in the park. Through the data analysis, it can be obtained that each reduction of 100 million kwh of power supply outside the park can reduce the carbon dioxide emissions of 5.323 tons co2/ kWh. Finally, improving the development environment of solar energy industry and reducing transmission pressure of power grid. Though the previous years data calculation using prediction model, under the premise of ensuring the power load balance of the park, increasing photovoltaic power generation to 2347.026579 kwh in the future can effectively reduce the carbon dioxide emissions cause by park energy consumption and improving energy efficiency indicators, balancing the peak and valley load difference, shaving and filling peak which can effectively alleviate the contradiction between peak and valley grid; solar energy is conducive to reducing heating coal consumption of the city, reducing fog and haze, promoting clean energy heating supply for the city and optimizing future energy supply structure in the park.

5. Conclusion

In this paper, by analyzing the status quo of energy use in all industries in cities, this paper establishes a model to evaluate the efficiency of urban energy use and draws the following conclusions.

(1) Based on the survey of energy, electricity, natural gas, water, heat and other energy sources of industrial, commercial and residential users in Suzhou City, this paper conducts a survey and research on the structures, modes and habits of urban industrial, commercial and residential users. The survey results show that: Suzhou, industrial, commercial, residential electricity, gas, water, heat and other energy consumption with the economic development of Suzhou is increasing year by year. Among them, business users with a steady increase in energy consumption, residential users to increase the trend of energy consumption year by year, but with price changes.

(2) Through the construction of a comprehensive model of urban energy efficiency evaluation model to help build a city integrated energy system. From the energy supply point of view, the price, environmental impact, power quality and other factors for distribution and adjustment integration of various forms of energy. From the perspective of energy services, the model can analyze the impact of different users demand indicators. Clear the specific characteristics of different users need and consider the user's multiple needs, through the reasonable scheduling to achieve rational use of energy.

References

[1] Lin Wei, Jin Xiaolong, Mu Yunfei, Jia Hongjie, Xu Xiaodong, Yu Xiaodan. Multi objective optimal hybrid power flow algorithm for regional integrated energy system [J/OL]. proceedings of the Chinese Journal of electrical engineering:1-13 (2017-03-27)

[2] Xu Yanli, Zhu Qiuyu. Research on real-time optimization control of distributed energy supply system based on short-term load forecasting [J]. industrial control computer, 2014, 27 (04): 27-28

[3] Economic analysis of the application of gas-fired CCHP system in Industrial Park [J]. energy saving, 2014, 33(03): 25-27+4.

[4] Feng Hongli. Domestic and foreign comprehensive energy service development status and business model research [J]. Electric Appliance Industry 2017, (06): 34-42.

[5] Assessment of off-design performance of a small-scale combined cooling and power system using an alternative operating strategy for gas turbine [J]. Wei Han, Qiang Chen, Ru-mou Lin, Hong-guang Jin. Applied Energy. 2015
[6] Optimal option of natural-gas district distributed energy systems for various buildings [J]. Miao Li, Hailin Mu, Nan Li, Huanan Li, Shusen Gui, Xin Chen. Energy & Buildings. 2014

[7] Li Jinghua, Sang Chuanchuan. Optimization planning and operation framework of energy integrated system [J]. Electric Power Construction, 2015, 36(08): 41-48.

[8] Optimal design and operation of an integrated multi-energy system for smart cities. BEUZEKOM I V, MAZAIRAC L A J, GIBESCU M, et al. IEEE International Energy Conference. 2016

[9] Peng Ke, Zhang Cong, Xu Bingyin, Chen Yu, Zhao Xueshen. Current situation and Prospect of multi energy Cooperative integrated energy system demonstration project [J]. Electric power automation equipment, 2017, 37 (06): 3-10.