Evaluation of city energy revolution in China: Taking 40 Surveyed Cities as Examples

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Abstract. Cities are the main battlefields of world's energy consumption and energy reform. A comprehensive evaluation of the current progress of China's city energy reform will help to guide the future direction of China's energy revolution. This paper collects the indicators of city energy reform from the two dimensions which are energy transition achievement and reform motivation. Based on the 2017 sample data of 40 cities in Chinese mainland, empirical research is conducted using entropy method. Shenzhen, Beijing, Xiamen, Chengdu, Shanghai, Tianjin, Suzhou, Hangzhou, Qingdao, and Mianyang ranked in the top 10. The results of this paper can provide reference for studying the effectiveness of city energy revolution in China and formulating reasonable transition strategies.

1. Introduction

As a series of problems such as energy depletion, environmental destruction and climate warming follow one after another, energy transition has become an inevitable choice for sustainable economic and social development. The world is also currently taking strong measures to explore and promote energy revolution and low-carbon transformation. Since November 2015, nearly 200 countries have signed the "Paris Agreement" to jointly tackle global climate change. In 2014, General Secretary of CPC Central Committee Xi Jinping emphasized the promotion of Chinese energy production and consumption revolution. It has been more than 5 years since the energy revolution was proposed. Since then, China has continuously promoted the implementation of the energy revolution. From the development trend, the world is currently carrying out the energy transition from the "oil era" to the "low carbon era". Low-carbon energy sources (solar, wind, hydrogen, etc.) will increasingly be used to replace high-carbon energy sources [1,2]. But the energy transition of various countries presents different characteristic. For example, Germany encourages the large-scale development of renewable energy through financial subsidies, but the United State continues to increase the proportion of clean energy by relying on technological progress [3].

As the most important main battlefield of the energy revolution, cities have a vital influence on the effectiveness and process of Chinese energy revolution. Regarding city energy development, the transformation and upgrading of its mode is of great significance to promoting energy revolution and...
development [4]. Energy revolution has become the main theme of energy development, ecological civilization construction and urban development. Various cities, governments, and energy companies have all implemented the energy revolution, but the goals, approaches and methods are still in the groping stage.

The city energy revolution is aimed at establishing a clean, low-carbon, safe and efficient new city energy system under the concept of coordinated development of cities and energy. Therefore, the evaluation of city energy transition should also be based on the coordinated development of cities and energy, and in accordance with local conditions. After that, through inspection and evaluation of their own development, we should find sample cities to learn advanced experience and promote the development of city energy transformation. The current evaluation studies related to city energy transition mainly focus on certain aspects, such as low-carbon cities [5-8], energy conservation evaluation [9, 10], total energy control [11], etc. Related research has established different evaluation indicators through different evaluation methods and completed the analysis of the case cities. Generally speaking, the evaluation conclusions can only reflect the achievements of the city in a certain aspect, but cannot fully cover all aspects and various effects of the city energy transition due to different focuses. Compared to existing literature, this article conducts a comprehensive evaluation of city energy transition from two aspects which are energy transition achievement and reform motivation. Then based on the actual sample data of 40 cities in China, this paper applies entropy method and indicator systems to evaluate and analyze city energy transition.

2. Data and methods

The basic data of this article mainly covers various energy data in 2017. The data mainly comes from questionnaire survey in 40 cities which are Anyang, Baoding, Beijing, Chengdu, Dongying, Guangzhou, Hangzhou, Huzhou, Jining, Jiaxing, Lanzhou, Luzhou, Luoyang, Mianyang, Nanjing, Ningbo, Pingdingshan, Qingdao, Xiamen, Shanghai, Shangrao, Shenzhen, Shenyang, Suzhou, Suizhou, Taiyuan, Tianjin, Wuxi, Wuhan, Xi’an, Xining, Xinyu, Xuzhou, Xuchang, Yantai, Yichang, Yulin, Zaozhuang, Zhangjiakou, Chongqing. Subsequently, we cleaned and corrected the preliminary basic data, checked the data consistency, processed invalid and missing values, and finally formed the data source for evaluation. Considering that the statistical data contains multiple index data of different dimensions, we standardize the data processing in order to eliminate the limitation of data units.

This article uses an objective method for evaluation, which is the entropy method. The evaluation result of entropy method is mainly based on objective data. It is hardly affected by subjective factors, and can avoid the interference of human factors to a large extent. Entropy is a measure of uncertain information. If the information entropy of an indicator is smaller, the amount of information it provides is greater, and the corresponding weight should be higher. After constructing the sample data matrix for standardization, we calculated the entropy and entropy weight of the indicators, and finally calculated the comprehensive score. The main formulas are as follows:

\[
H_j = -k \sum_{i=1}^{m} f_{ijt} \cdot \ln f_{ijt} \tag{1}
\]

\[
w'_j = \frac{1 - H_j}{\sum_{i=1}^{n}(1 - H_i)} = \frac{1 - H_j}{n - \sum_{i=1}^{n}H_i} \tag{2}
\]

\[
Z_i = \sum_{j=1}^{n}(w'_j \times r_{ij}) \tag{3}
\]

Where ‘t’ represents the year, ‘m’ represents the number of samples, ‘n’ represents the number of indicators, i=1,2,...,m; j=1,2,...,n.

Starting from portraying the different characteristics of city energy revolution, the evaluation index system contains two dimensions (listed in Table 1): energy transition achievement and reform motivation. The indicators of transition achievement, including electricity supply reliability, the
proportion of clean energy in primary energy, the proportion of power generation in coal consumption, energy consumption per unit of GDP, the proportion of electricity in terminal energy, pollutant emissions per unit of GDP, public transit mode share, the number of weather levels above grade 2 per year, reflect the city's current energy revolution results. The indicators of reform motivation include the proportion of R&D in GDP, the proportion of energy conservation and environmental protection budget expenditure in public budget expenditure, the proportion of tertiary industry output, the proportion of strategic emerging industries, the annual investment in energy infrastructure per capita, GDP per capita.

Table 1. Variables and data collected by questionnaire survey

| First Level Indicator | Variable                                                                                                                                 |
|-----------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| Transition achievement| electricity supply reliability                                                                                                          |
|                       | the proportion of clean energy in primary energy                                                                                      |
|                       | the proportion of power generation in coal consumption                                                                               |
|                       | energy consumption per unit of GDP                                                                                                   |
|                       | the proportion of electricity in terminal energy                                                                                      |
|                       | pollutant emissions per unit of GDP                                                                                                  |
|                       | public transit mode share                                                                                                            |
|                       | the number of weather levels above grade 2 per year                                                                                   |
| Reform motivation     | the proportion of R&D in GDP                                                                                                         |
|                       | the proportion of energy conservation and environmental protection budget expenditure in public budget expenditure                      |
|                       | the proportion of tertiary industry output                                                                                        |
|                       | the proportion of strategic emerging industries                                                                                       |
|                       | the annual investment in energy infrastructure per capita                                                                                 |
|                       | GDP per capita                                                                                                                         |

Table 2. City Energy Transition Index of 40 cities in the 2017

| Ranking of Reform Change Index | City          | Score | Ranking of Reform Change Index | City          | Score |
|-------------------------------|---------------|-------|-------------------------------|---------------|-------|
| 1                             | Shenzhen      | 0.577 | 21                            | Suzhou        | 0.301 |
| 2                             | Beijing       | 0.530 | 22                            | Zhangjiaokou  | 0.301 |
| 3                             | Xiamen        | 0.492 | 23                            | Lanzhou       | 0.292 |
| 4                             | Chengdu       | 0.463 | 24                            | Dongying      | 0.287 |
| 5                             | Shanghai      | 0.445 | 25                            | Wuhan         | 0.286 |
| 6                             | Tianjin       | 0.436 | 26                            | Xi‘ning       | 0.280 |
| 7                             | Suizhou       | 0.408 | 27                            | Baoding       | 0.271 |
| 8                             | Hangzhou      | 0.401 | 28                            | Xuchang       | 0.270 |
| 9                             | Qingdao       | 0.400 | 29                            | Yulin         | 0.266 |
| 10                            | Mianyang      | 0.392 | 30                            | Taiyuan       | 0.262 |
| 11                            | Chongqing     | 0.376 | 31                            | Anyang        | 0.255 |
| 12                            | Huzhou        | 0.350 | 32                            | Xinyu         | 0.251 |
| 13                            | Ningbo        | 0.347 | 33                            | Shangrao      | 0.248 |
| 14                            | Xi’an         | 0.338 | 34                            | Luoyang       | 0.242 |
| 15                            | Luzhou        | 0.338 | 35                            | Pingdingshan  | 0.229 |
| 16                            | Guangzhou     | 0.336 | 36                            | Xuzhou        | 0.222 |
| 17                            | Wuxi          | 0.334 | 37                            | Shenyang      | 0.220 |
| 18                            | Nanjing       | 0.331 | 38                            | Yichang       | 0.209 |
| 19                            | Yantai        | 0.327 | 39                            | Zaozhuang     | 0.179 |
| 20                            | Jiaxing       | 0.302 | 40                            | Jining        | 0.178 |

3. Results
As shown in Table 2, using entropy method city energy transition Index of 40 surveyed cities in 2017 are calculated below.
4. Conclusions and recommendations
This paper constructs an evaluation index system to understand China's city energy transition, and evaluates the development of China's city energy transition in 2017 from the two dimensions containing energy transition achievement and reform motivation. The main conclusions and recommendations are as follows:

On the whole, cities in economically developed regions have a better foundation for energy transition, and it is easier to gather talents, funds, and technologies that cities and energy development urgently need. In order to have a better performance in energy evaluation, economically developed regions also pay more attention to the urban environment, spatial layout, formulate relevant policies and management measures.

Although city energy transition has achieved great results, there are large differences in some specific indicators between different cities. Compared with the excellent cities, the lower-ranking cities have more room for structural improvement and energy efficiency improvement.

The evaluation of city energy transition involves many aspects such as energy revolution and urban development. This article only conducts research on the basis of city energy transition of selected indicators in surveyed cities. After that, we should expand the evaluation indicators of energy transition, and also conduct a more comprehensive evaluation.

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References
[1] ZuoxianL,PingX, ChengchengD. World Energy Transition and Development——Global Trends and Chinese Characteristics in the Low-Carbon Era [J]. Petroleum and Petrochemical Green and Low Carbon, 2019, 4(01): 6-16+21.
[2] YoushengZ, MingS, GuangY, LeiT. The development of world energy transition and its enlightenment to my country [J]. Macroeconomic Management, 2015(12): 37-39.
[3] Jipeng S, ZheZ. Enlightenment of energy transition of major countries in the world to my country [J]. China Electric Power Enterprise Management, 2020(07): 92-95.
[4] Weiyang L. Supporting Suzhou's creation of a model city for international energy reform and development, exploring sustainable urban energy system construction [J]. Energy Review, 2017, 57-61.
[5] Yufang W. Research on Low-Carbon City Evaluation System [D]. Hebei: Hebei University, 2010.
[6] Shengnan N. Evaluation index system and research methods of low-carbon cities based on sustainable development [D]. Beijing: North China Electric Power University, 2012.
[7] Yuming L. Low-carbon city index system and empirical research based on city value [D]. Beijing: China University of Geosciences, 2012.
[8] Fei F. Research on Low-Carbon Energy Structure Evaluation Indexes of Low-Carbon Cities [D]. Zhejiang: Zhejiang University of Technology, 2016.
[9] Zhang J. The Research on the Industrial City Energy Conservation Evaluation Model and Application [D]. Hubei: Huazhong University of Science and Technology, 2010.
[10] Fengjia S. China and international green building energy assessment and applied research [D]. Xi'an: Xi'an University of Architecture and Technology, 2016.
[11] Ran T. Shanghai Energy Forecast Model and Energy Utilization Efficiency Evaluation Index System [D]. Shanghai: Shanghai Jiaotong University, 2012.