Design of Comprehensive Evaluation System and Empirical Research of City Energy Transition

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Abstract. City is the main body of world energy consumption and the main battlefield of energy transition. A comprehensive evaluation of the progress of city energy transition in China is of great reference significance to guide the future direction of China’s energy revolution. Based on the concept of collaborative development between city and energy, from the point of view of energy transition driving city development, this paper puts forward the evaluation index of city energy transition which reflects the different dimensions of city energy transition, such as the basis, present situation, trend and motive force. Through the combination of subjective assignment and objective evaluation, the paper completes the construction of evaluation system structure for different indices, and performs an empirical study based on the actual sample data of 40 cities in China. The research shows that the overall effect of city energy transition in China is obvious, but some specific indices in some cities still have greater room for improvement compared to the excellent city level, and the city’s development level is strongly correlated with the effect of its energy transition.

1. Introduction
The extensive development and utilization of fossil energy has supported the development of the world economy and human society, but at the same time it has also brought problems of environmental pollution and climate change, which pose a great threat to the sustainable development of mankind. The energy revolution seeks the replacement of the main energy and the improvement of energy efficiency, which is an urgent need and an important means to solve the problems caused by the current energy system. Since General Secretary Xi Jinping put forward the strategic thinking of the national energy revolution, China has continuously promoted the implementation of the energy revolution. China introduced the Energy Production and Consumption Revolution Strategy (2016-2030) in 2016 and expects the share of non-fossil energy generation to reach 50% in 2030 [1]. The strategy is China’s positive response to the challenge of climate change and China’s ambitious planning and powerful push for energy transition.

From the historical point of view of energy consumption, the use of world energy has gone through the era of fuelwood, the era of coal and the era of oil and gas, and is now gradually entering the era dominated by new energy [2]. The essence of energy transition is the transition of energy system, which replaces the high-carbon energy system dominated by fossil energy with a low-carbon energy system dominated by new and renewable sources of energy, culminating in 0 carbon emissions [3]. As
the most important main battlefield of this energy revolution, the city has a vital influence on the effectiveness and process of China’s energy revolution. It has been more than 4 years since the energy revolution was put forward, and various cities, government at all levels, all kinds of energy enterprises and energy consumption enterprises have carried out the practice of energy revolution, but they are still in the exploratory stage in their goals, paths and methods.

The current evaluation studies related city energy transition focus on some aspects of city energy transition, such as low-carbon cities [4][5][6][7], energy conservation assessment [8][9], total control [10] etc. Wang Y [4], Niu S [5] and Fan F [7] established an evaluation system for the development of low-carbon cities in China with sustainable development as the core. Wang Y selected a total of 14 indices in economic development, low-carbon development and social development, and performed an empirical study on Beijing. Niu S used the fuzzy coordination model for low carbon city evaluation and carried on the empirical research on Shanghai. Lian Y [6] introduced the theory of city value chain and the construction of ecological civilization in the evaluation index system of low-carbon city development in China. Zhang J [8] studied the energy conservation evaluation of the city, determined the construction principle of the energy saving index system and selected 27 city energy saving evaluation indices, which divided the system of city energy consumption into four kinds: industry, construction, city transportation and residents’ life. Song F [9] performed a comparative study of the contents of energy assessment in US LEED, UK BREDDAM and China’s Green Building Evaluation Standards, and further established the AHP-FCE composite evaluation model for energy evaluation of green buildings in China. Tao R [10] researched on energy prediction model and energy efficiency evaluation index system, established the medium and long term energy cointegration model and the energy utilization efficiency ANP evaluation model, and carried out the application and evaluation in Shanghai.

The paper focuses on the development and impact of city energy transition in China from 2013 to 2017, makes a comprehensive evaluation of city energy transition and selects actual cities for evaluation case analysis, mainly from three aspects including the transition effect, the transition trend, and the transition motive force. The content structure of the article is as follows: in the second part, the relevant evaluation methods and data processing methods in this paper are introduced. The third part introduces the construction of the comprehensive evaluation index system of city energy transition. The fourth part, based on the actual sample data of 40 cities in China, applies the evaluation methods and index system proposed in this paper to evaluate and analyze city energy transition. The fifth part give the main conclusion of this paper.

2. Methods and Data

2.1. Chosen Methods

The paper uses the method of subjective and objective combination to evaluate. The subjective evaluation method used in this paper is the expert scoring method [11]. This method has been widely used in the establishment of various evaluation index systems and the determinations of indices, and in this paper, it is also applied to the assignment process of the weights of each index in the construction of the subsequent index system. The advantage of expert scoring method is that the method is simple and easy to operate, there are fewer constraint conditions, and it is easier to realize in engineering application. The scoring results have certain authority and high reliability.

The objective evaluation method adopts the fuzzy entropy weight method [12], which is a method to apply the entropy weight theory to fuzzy evaluation. The comprehensive evaluation method of fuzzy entropy weight is an objective evaluation method to test the degree and usefulness of data information based on the original data, and thus obtain an objective evaluation method of weight.
2.2. Processing Data

2.2.1. Data origins. The basic data cover mainly energy data for the period 2013-2017 five years. There are three main ways of source: official bulletin statistics, questionnaire research feedback, Internet official website extract.

2.2.2. Data cleaning and supplement. In this paper, the preliminary basic data are cleaned, the data consistency is checked, and the invalid value and missing value are processed. The blank index data is supplemented and perfected by trend extrapolation and grey prediction.

The basic idea of trend extrapolation [13] is that when the predicted object changes over time and does not fluctuate significantly with the seasonal variation, and the change can be reflected by the appropriate functional relationship, the trend extrapolation method is used to predict. For example, the “industrial solid waste utilization rate” in the index, a few years of blank indices can be predicted according to the trend extrapolation method.

Grey prediction method [14] is a method to predict some grey system where some information is known and some information is unknown. The commonly used models are GM (1, 1) and so on. For example, using the “energy decline rate of unit output value in key energy-consuming industries” in the index data, the blank index of a few years can be predicted according to the grey prediction method.

2.2.3. Data standardization. Because the statistics contain a variety of different dimensional index data, in order to remove the unit limit of the data, to facilitate comparing and weighting the different units or magnitude, data need to be standardized. In this paper, the “z-score” method based on raw data mean and standard deviation [15] is used to standardize the data, which is the most commonly used standardized method in SPSS, and the steps are as follows: for the original data series ,

(1) Calculate the mathematical expectations of each variable μ and standard deviation σ;

(2) The original data series is standardized processed as in equation (1):

\[ x' = \frac{x - \mu}{\sigma} \]  

(1)

(3) The positive and negative signs before the inverse index are reversed.

Based on the probability of this computable index in the corresponding standard normal distribution, it is used as the “score” situation of the index.

3. Evaluation Index System Construction

3.1. Research Idea

This paper includes the consideration of different angles, involving the influence of energy transition on city development and the influence of city development on energy transition, and establishes the evaluation index system of city energy transition which reflects the different dimensions such as foundation, current situation, trend and motive force. The paper collates and analyzes the actual sample data of the city, perfects the optimization index, and provides the objective and comprehensive analysis results and opinions for the city energy development and energy transition. The research method framework is shown in the figure 1.

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3.2. Index System Design

The basic principles of the construction of the comprehensive evaluation system of city energy transition adopted in this paper include: comparability, accessibility, systematization and consistency, with the aim of improving the accuracy, science and comprehensiveness of the evaluation system.

From the three different characteristics of city energy transition, the evaluation index system contains three dimensions: transitions’ current situation, trend and motive force, whereas each dimension is divided into three levels, forming a comprehensive evaluation system of “3-3-N”. Among them, transition’s current situation, trend and motive force belong to the first level indices, as shown in the figure 2. The indices of transition’s current situation are portrayed from the perspective of fundamental infrastructure, energy supply, energy consumption and environment quality, reflecting the effectiveness of the energy transition that the city has achieved. According to the energy structure and energy efficiency, the indices of transition’s trend reflect the future trend of city energy consumption. From four aspects of technology, policy, administration and subject, the indices of transition’s motive force reflect the internal driving force of city energy transition.

3.3. Weight Assessment

This paper adopts the method of combining subjective and objective evaluation to assign the weight of each index of index system, in which the method of subjective evaluation is expert scoring method and the method of objective evaluation is the comprehensive evaluation method of fuzzy entropy weight. Subjective weight can reflect the expert’s preference for evaluation index, and entropy weight embodies the evaluation function of objective information index, which is objective weight.

In the allocation of index weights of different dimensions, in order to highlight the importance of the current results, taking into account the large number of indices in transition’s current situation, the
paper focuses on improving the index weight of transition’s current situation in the subjective weight design. In its corresponding tertiary level indices, considering the focus on city energy consumption, the indices of energy consumption are given more weight. For a small number of indices with poor data quality, special adjustments are made when the weight is assigned to reduce the effect of the difference. The weight distribution of indices at all levels is shown in the table 1.

### Table 1. Weight Assessment of Indices.

| Primary Index          | Weight Assessment (100 pt) | Secondary Index                     | Weight Assessment (100 pt) | Tertiary Index                                                                 |
|-----------------------|---------------------------|-------------------------------------|---------------------------|--------------------------------------------------------------------------------|
| Transition’s Current  | 55                        | Fundamental Infrastructure           | 25                        | Gas penetration rate 25                                                        |
|                      |                            |                                     |                           | Power grid reliability rate 20                                                 |
|                      |                            |                                     |                           | Number of charging piles per unit area 20                                     |
|                      |                            |                                     |                           | Variable Power capacity per capita 15                                           |
|                      |                            |                                     |                           | Energy access index 20                                                          |
|                      |                            | Energy Consumption                  | 30                        | Energy consumption level per unit of GDP 30                                     |
|                      |                            |                                     |                           | Electric energy accounts for the proportion of terminal energy 20               |
|                      |                            |                                     |                           | Proportion of scattered coal 8                                                 |
|                      |                            |                                     |                           | Elasticity coefficient of energy consumption 12                                |
|                      |                            |                                     |                           | Energy consumption of unit output value in key energy-consuming industries 10   |
|                      |                            |                                     |                           | Energy consumption level per unit building area 12                             |
|                      |                            |                                     |                           | Public transport sharing rate 8                                                |
|                      |                            | Energy Supply                        | 25                        | Renewable energy installed capacity per city unit area 33                       |
|                      |                            |                                     |                           | Share of clean energy in primary energy 37                                     |
|                      |                            |                                     |                           | Coal consumption level for electricity supply 30                               |
|                      |                            | Environment Quality                 | 20                        | Industrial solid waste utilization rate 25                                     |
|                      |                            |                                     |                           | Carbon dioxide emissions per unit of GDP 25                                     |
|                      |                            |                                     |                           | Emissions of pollutants per unit of GDP 25                                     |
|                      |                            |                                     |                           | Number of days with weather of level 2 or above per year 25                   |
| Transition’s Trend   | 15                        | Energy Structure                    | 45                        | Rising rate of clean energy in disposable energy 55                            |
|                      |                            |                                     |                           | Growth rate of local renewable energy’s installed capacity 45                  |
|                      |                            | Energy Efficiency                   | 55                        | Decline rate of energy consumption per unit of GDP 55                          |
|                      |                            |                                     |                           | Energy consumption decline rate of unit output value in key energy-consuming industries 45 |
| Transition’s Motive   | 30                        | Technology                          | 23                        | Ratio of investment in scientific research to GDP 64                           |
|                      |                            |                                     |                           | Amount of patent authorization per capita 36                                    |
|                      |                            | Policy                              | 28                        | Proportion of energy saving and environmental protection budget expenditure to public budget expenditure 34 |
|                      |                            |                                     |                           | The integrity of city energy planning 40                                       |
|                      |                            |                                     |                           | Number of demonstration projects on energy transition 26                      |
|                      |                            | Administration                      | 24                        | Energy service platform penetration rate 51                                     |
|                      |                            |                                     |                           | Energy saving management assessment mechanism 49                               |
|                      |                            | Subject                             | 25                        | Share of GDP in tertiary industry 25                                            |
4. 40 Cities Case Analysis

4.1. Sample Cities’ Introduction

This paper investigates 74 cities and selects 40 cities in China with good data integrity to carry out evaluation and analysis. In 2016, 40 sample city energy consumption amounted to 1.439 billion tons of standard coal, accounting for 37.4% of the country’s total city energy consumption, accounting for 33% of the country’s total energy consumption.

As shown in the figure 3, from the administrative aspect, 40 sample cities include 4 municipalities, 11 sub-provincial cities and 25 prefectural cities. From the point of view of resource endowment, 9 cities belong to resource-based cities and 31 belong to ordinary cities. In terms of the stage of development, 15 cities are in the middle of industrialization, 14 cities are in the late stages of industrialization and 11 cities are in the post-industrialization stage. Overall, the 40 sample cities selected in this paper can sufficiently reflect the progress of city energy transition in China.

4.2. Comprehensive Assessment

4.2.1. City energy transition index in 2017. According to the results of the evaluation of city energy transition in China (as shown in the figure 4), the top ten cities of the city energy transition index in 2017 are: Beijing, Shanghai, Shenzhen, Hangzhou, Suzhou, Jiaxing, Nanjing, Chengdu, Tianjin, Xiamen. The top ten cities in 2017 are located in 8 different provinces (cities), including 3 municipalities, 3 provincial capitals, 2 planned cities, and 2 prefecture-level cities in economically developed areas. The governments of the above-mentioned cities have leading investment in policy, capital and technology in energy-related fields, including the work of air pollution prevention and control in Beijing, Tianjin, Hebei and surrounding areas, the construction of clean energy demonstration provinces, a model of energy transition and development of city construction and other special actions, which provides a powerful boost to energy transition efforts in the concerned cities.
4.2.2. Ranking changes of city energy transition index in 2013-2017. The table 2 shows the ranking changes among the top ten cities in 2013-2017. Among them, the ranking of Beijing and Suzhou have risen considerably, and cities such as Chengdu, Tianjin and Nanjing have made greater progress in entering the top ten cities. Of the top 10 cities in 2017, 7 were in the top 10 in the 2013 energy base assessment. Overall, with a better foundation for energy development, the above-mentioned cities are also in the leading position in energy-related fields.

Table 2. Ranking changes in 2013-2017

| Rank | 2013  | 2014  | 2015  | 2016  | 2017  |
|------|-------|-------|-------|-------|-------|
| 1    | Shenzhen | Shenzhen | Shanghai | Beijing | Beijing |
| 2    | Shanghai | Shanghai | Beijing | Shanghai | Shanghai |
| 3    | Xiamen | Beijing | Shenzhen | Hangzhou | Shenzhen |
| 4    | Jiaxing | Jiaxing | Jiaxing | Shenzhen | Hangzhou |
| 5    | Beijing | Hangzhou | Chengdu | Jiaxing | Suzhou |
| 6    | Hangzhou | Chengdu | Suzhou | Suzhou | Jiaxing |
| 7    | Wuxi | Suzhou | Xiamen | Nanjing | Nanjing |
| 8    | Qingdao | Nanjing | Nanjing | Tianjin | Chengdu |
| 9    | Ningbo | Wuxi | Tianjin | Chengdu | Tianjin |
| 10   | Suzhou | Mianyang | Hangzhou | Wuxi | Xiamen |

a Arrows represent changes in rankings compared to the previous year.

4.2.3. The extent of city energy transition progress in 2013-2017. The extent of progress in city energy transition is measured by the average annual rate of change, which is calculated as:

1. Calculate the average annual rate of change of a single index from 2014-2017;
2. Combine the corresponding weight coefficient of the index, weight and sum the average annual change rate of each index and calculate the annual change rate of the city compound.

The results of the calculation are shown in the figure 5, and it can be seen that all the city energy transition evaluated are progressing steadily, with an average annual rate of change of 6.77%. The main contributing factors to energy transition are the massive utilization of renewable energy and the extensive construction of electric vehicle charging facilities.
Figure 5. 40 cities’ average annual growth rate of energy transition in 2014-2017.

4.3. Assorted Assessment

According to the table 3, judging from transition’s current situation in 2017, Shanghai ranks first, followed by Beijing and Shenzhen. From transition’s trend from 2013 to 2017 (i.e., key indices of transition such as energy structure and energy efficiency), as a result of the vigorous development of renewable energy that significantly reduce the level of energy consumption in key energy-consuming industries, Shangrao, Suizhou and other small and medium-sized cities have made great process. From transition’s motive force (science and technology investment and transition, policy support, administration improvement, the quality of the city’s own development, etc.), Beijing, Xuchang, Suzhou, etc. are ahead of other cities.

Table 3. Top 10 evaluation results of classified evaluation in 2017.

| Rank | Transition’s Effect | Transition’s Trend | Transition’s Motive Force |
|------|---------------------|--------------------|--------------------------|
| 1    | Shanghai 40.1       | Shangrao 9.4       | Beijing 26.3             |
| 2    | Beijing 39.9        | Suizhou 8.7        | Xuchang 25.2             |
| 3    | Shenzhen 38.8       | Yichang 7.9        | Suzhou 23.3              |
| 4    | Nanjing 37.9        | Chengdu 7.7        | Xining 23.1              |
| 5    | Jiaxing 37.7        | Shenzhen 7.7       | Shanghai 22.9            |
| 6    | Hangzhou 37.6       | Luzhou 7.4         | Shenzhen 22.7            |
| 7    | Suzhou 37.5         | Ningbo 7.3         | Nanjing 22.7             |
| 8    | Chengdu 37.1        | Chongqing 7.2      | Tianjin 22.2             |
| 9    | Tianjin 36.2        | Qingdao 7.0        | Ningbo 22.1              |
| 10   | Xiamen 35.8         | Xining 7.0         | Hangzhou 22.1            |

5. Conclusion

The main conclusions of this paper are given as follows.

(1) Overall, the effectiveness of city energy transition is obvious. Over the past 5 years, all city energy transition that have been evaluated have progressed. City energy system as a whole embodies a cleaner, low-carbon, safe and efficient feature. The awareness of energy services has increased, the
ease of energy intelligence has increased. Changes of renewable energy installed capacity per city unit area is the most obvious.

(2) The highest ranked cities in the comprehensive evaluation of city energy transition are Beijing, Shanghai, Shenzhen, Hangzhou, Suzhou, Jiaxing, Nanjing, Chengdu, Tianjin, Xiamen. Compared to the base year of transition 2013, Beijing, Shanghai, Shenzhen, Hangzhou, Jiaxing, Suzhou, Xiamen etc. are still among the top 10. Judging from the effectiveness of the transitions in 2017, Shanghai, Beijing, Shenzhen, Nanjing, Jiaxing etc. have achieved the top score, whose foundations for future change are also better. Judging from the motive force of transition, Beijing, Xuchang, Suzhou, Xining, Shanghai etc. have increased their investment in technology, policy, administration and city development investment, which are expected to lead the future of city energy transition.

(3) Although the overall results have been achieved, some specific indices in some cities still have a greater room for improvement than the excellent cities. There are significant differences in energy structure and energy efficiency between different cities, which means it needs to work together to achieve a more energy-efficient and better energy structure through city development and energy system upgrading. City energy administration is linear segmented, which lacks the endogenous power and the sufficient information sharing, so it has a negative impact on city energy transition.

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