Analysis of Static and Dynamic Comprehensive Evaluation of Urban Low-Carbon Development Quality

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Abstract. In order to evaluate the quality of low-carbon development of each city in China more comprehensively, this paper innovatively introduces low-carbon innovation into the evaluation model and evaluates the quality of low-carbon development of each city in China using the dynamic evaluation method. Through the static evaluation model, it is obtained that the cities of Beijing, Shanghai Chongqing and Shenzhen are at the stage of high-quality low-carbon development; through the dynamic evaluation model, it is concluded that the cities of Shanghai and Shenzhen have higher potential for sustainable low-carbon development in the future.

Keywords: Low-Carbon Development, TOPSIS, Dynamic Evaluation Method.

1. Introduction

The concept of low-carbon was first introduced in the economic sphere in 2003 and was gradually extended. With the promotion of the concept low-carbon city, LCD has become a hot topic in city development and government planning. LCD generally means the city can maintain low energy consumption and carbon dioxide emissions under the premise of rapid economic development [1]. The construction of low-carbon city includes four aspects: development of low carbon energy, clean production, recycling and sustainable development.

By promoting low-carbon technology innovation [2], stimulating industrial upgrading [3], attracting talent aggregation and other ways, low-carbon city policies promote cities' development [4]. At the same time, compared with non-low carbon pilot cities, the construction of low carbon cities can effectively reduce carbon emissions [5], promote the development of green economy, improve total factor productivity of enterprises [6], and promote technological innovation of enterprises [7]. Low-carbon city construction is crucial to promote high-quality economic development.

Comprehensive and objective evaluation of urban low-carbon development quality is not only an important measure of the effectiveness of national policies, but also provides theoretical support for future policy formulation. At present, the research on low carbon city evaluation system can be divided into two categories. Some scholars established the evaluation system with carbon emission reduction as the ultimate goal. The evaluation system of this kind of research focuses on carbon emissions and environmental protection. For example, Geng [8] established the evaluation system of urban low-carbon development with carbon emissions, industrial pollution emissions and social resource consumption as the criterion layer. Glaeser [9] regard zero greenhouse gas emissions as the main indicator to measure environmental externalities, and evaluate the quality of urban low-carbon development by calculating the elastic coefficient of energy consumption and economic growth. Chen [10] found total carbon throughflow (TCT) and total carbon inflow (TCI) provide unique information in the ranking of low-carbon performance. Other scholars established the comprehensive development quality of multiple subsystems. Fu [11] first proposed the Economic-Energy-Environment (3E) evaluation system in 2010. Drawing on this theoretical framework, scholars have conducted low-carbon development quality evaluation and prediction at the urban level [12-14]. In addition to the 3E evaluation system, there are scholars who use PPSIR. [15-16].

Existing studies have achieved substantial results in the evaluation of urban low-carbon development, which provides an important reference for this paper to build an evaluation system of urban low-carbon development quality. The evaluation methods used in low carbon city evaluation

include objective weighting method represented by TOPSIS entropy weighting method and principal component analysis and subjective weighting method represented by analytical hierarchy process.

2. TOPSIS entropy weight method and dynamic evaluation method with speed feature

To construct a comprehensive evaluation system of low-carbon cities in China, this paper adds the low-carbon innovation subsystem on the foundation of 3E1S evaluation system and evaluates the development of low-carbon cities from 5 first-level indicators: low-carbon innovation, low-carbon economy, low-carbon society, low-carbon environment and low-carbon energy. Reference previous research, we designed innovation technology, innovation system and innovation environment as the 3 secondary indicators in low carbon innovation. The low-carbon economy indicator includes 2 third-level indicators, they are economic increment and economic structure, the low-carbon society indicator includes individual development and public service, the low-carbon environment indicator includes environment governance and environment pressure, and the low-carbon energy indicator includes energy consumption and energy reserve.

According to the original data, we can build an initial matrix of low-carbon development quality evaluation indicators: $X = (\mathrm{x}_{\mathrm{ij}})_{m\times n}$, in which m and n are the number of the evaluated cities and evaluation indicators, respectively.

$$X = (x_{ij})_{m\times n} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{1m} & x_{2m} & \cdots & x_{nm} \end{bmatrix} \tag{1}$$

Here, $i = 1,2,...,m \;\; j = 1,2,...,n$

A normalized matrix Y is obtained.

$$Y = y_{ij} = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ y_{m1} & y_{m2} & \cdots & y_{mn} \end{bmatrix} \tag{2}$$

The ratio of evaluation index j of i city is defined by:

$$p_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}} \tag{3}$$

Calculating the entropy value e_j of evaluation index j:

$$e_j = -\frac{1}{\ln m}\sum_{i=1}^{m} p_{ij}\ln(p_{ij}) \tag{4}$$

Calculating the attribute weight by:

$$w_j = \frac{1-e_j}{\sum_{j=1}^{n}(1-e_j)} \tag{5}$$

Calculating the weighted normalized matrix as the normalized matrix multiplication with weights of indexes:

$$v_{ij} = w_{ij} y_{ij} \tag{6}$$

Defining positive ideal solution V^+ of low-carbon development quality is:

$$V^+ = (V_1^+, V_2^+, ..., V_n^+) \tag{7}$$

And negative ideal solution V^-:

$$V^- = (V_1^-, V_2^-, ..., V_n^-) \tag{8}$$

Here V^+ and V^- are the maximum and minimum value of the j th index among all evaluation object.

Estimating the distance from the positive ideal alternative:

$$D^+ = \sqrt{\sum_{j=1}^{n}(V_{ij} - V_j^+)^2} \tag{9}$$

Estimating the distance from the negative ideal alternative:

$$D^- = \sqrt{\sum_{j=1}^{n}(V_{ij} - V_j^-)^2} \tag{10}$$

The relative degree of approximation can be calculated by:

$$C_i = \frac{D_i^-}{D_i^- + D_i^+} \tag{11}$$

Defining the speed of the relative degree of approximation:

$$V_{ij} = \frac{(C_{i,j+1} - C_{i,j})}{t_{j+1} - t_j} \tag{12}$$

And obtain speed matrix:

$$V = v_{ij} = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{2n} \\ v_{21} & v_{22} & \cdots & v_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix} \tag{13}$$

Applying Newton's second law to the academic evaluation system of low-carbon cities. Defining the academic evaluating value as the definite integral of δ multiplication with R_i^v:

$$Y_i^* = \sum R_i^v(t_j, t_{j+1}) \times \delta(a_{ij}) \tag{14}$$

Where Y_i^* represents the development quality of the low-carbon cities. When $Y_i^* > 0$, it indicates that the cites is in the trend of optimization and wise versa. A zero value indicates the city is in a stable state.

3. Study area and data

There are 283 prefecture cities in China. To ensure a scientific, objective and authoritative evaluation result, the data was collected from the urban statistical yearbook of 2015-2019. Cities lacking of more than 2-year data are deleted and the average value of two consecutive years are used to replace the single blank data. This paper selects 228 cities as the evaluation object. And these cities are divided in to eastern cities, middle cities and western cities. It is note-worthy that this group formation is according to the economic development rather than geographic feature, which is shown in Figure 1.

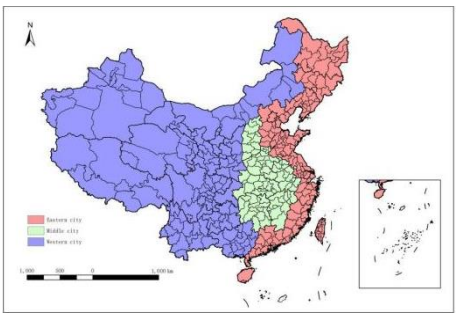


Figure 1. The division of cities in China

4. Results and discussions

According to the natural breakpoint method of ArcGIS, cities with total scores between 0.0400-0.0810 are poor quality cities for low carbon development, between 0.0811-0.1540 are medium to low quality cities, between 0.1541-0.3390 are medium to high quality cities, and between 0.1541-0.3390 are high quality cities.

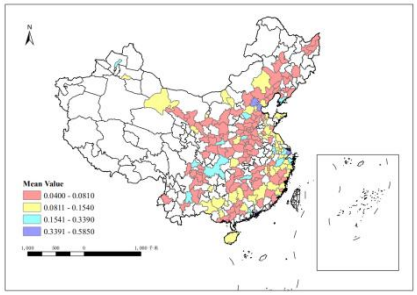


Figure 2. Overall static evaluation results from 2015 to 2019

Overall, it is clear to see from the Figure 2 that most of the high and medium quality cities are concentrated in the municipalities and special administrative regions in the eastern and central regions of China. Cities with high quality scores are represented by Beijing, Shenzhen, Shanghai and Chongqing, all of which scored high in all five first-level indicators. Shanghai, for example, has an overall score of 0.484, an innovation score of 0.51, and a low-carbon society score of 0.509, which are 8 and 6 times higher than the average of these two first-level indicators. The high-quality low-carbon development in Shanghai has also successfully led other cities in the Yangtze river delta region to become medium to high quality low-carbon cities, such as Hangzhou, Suzhou and Nanjing.

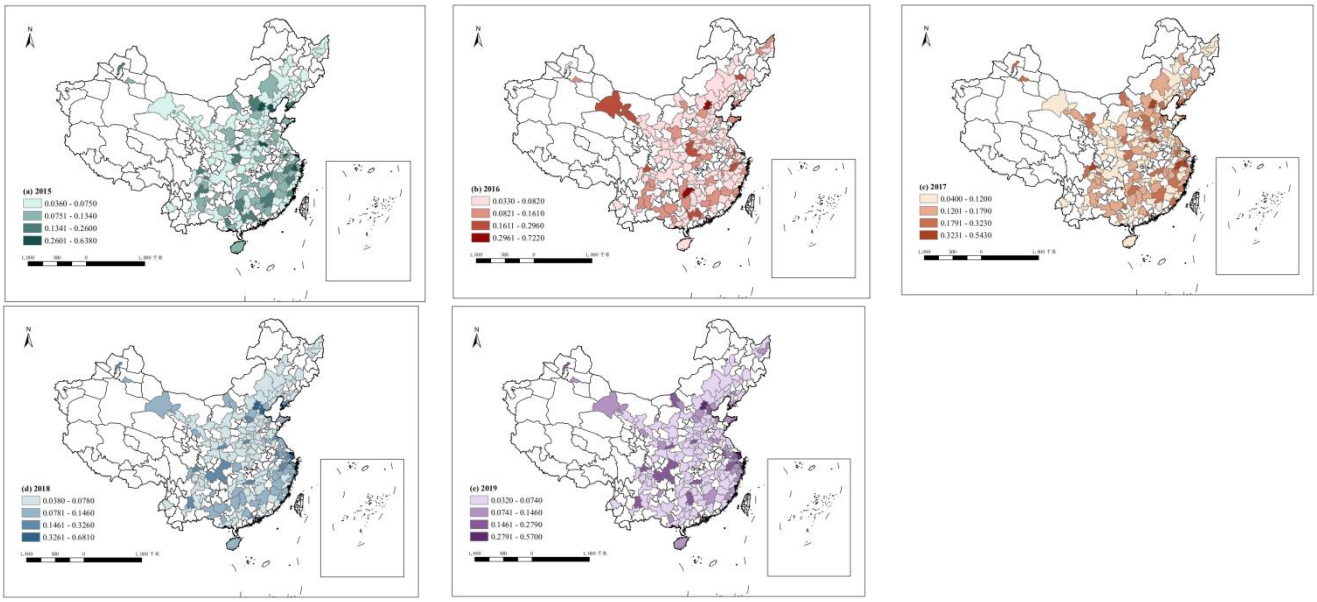


Figure 3. Static evaluation results for each year from 2015 to 2019

The Figure 3 above provided demonstrates the differences in the low-carbon development quality of 222 prefecture-level cities in China from 2015 to 2019. It is worth noting that the cities with higher ratings in China are gradually expanding from eastern cities to central and western cities.

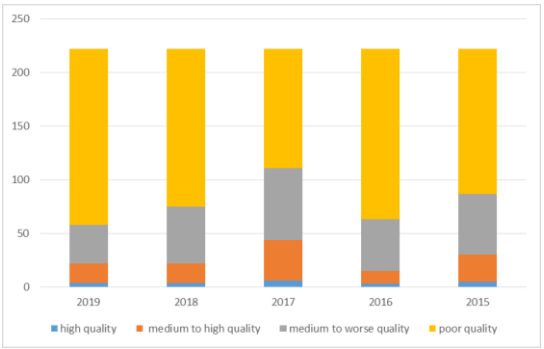


Figure 4. The overall rating results for the 222 participating cities from 2015-2019.

From Figure 4, considering the number of cities with medium-high and high-level ratings as category A and the number of cities with medium-low and low-level ratings as category B, it is clear that the number of cities with A and B ratings is similar overall in 2018 and 2019, while the number of cities with A ratings in 2016 has a slight decrease compared to the numbers in 2018 and 2019. Unexpectedly, there was a significant spike in the number of cities receiving A ratings in 2017 relative to those in 2018 and 2019, reaching 44, almost three times as many as in 2016 and twice as many as in 2018 and 2019.

The dynamic evaluation of the low-carbon development level of 222 cities in China can be accessed, and the results are shown in the Figure 5. When the evaluation result is positive, it is considered that the low carbon development of this city is being optimized, and vice versa.

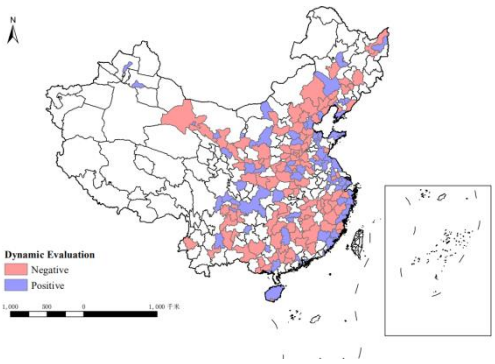


Figure 5. Overall dynamic evaluation results from 2015 to 2019

From the comprehensive dynamic evaluation values of 2015-2019, it can be find that all 222 cities participating in the evaluation of low-carbon development capacity are in dynamic change, and a total of 88 cities have positive scores, and low-carbon development shows an optimization trend. These cities are located in central, western and eastern China, with most of the eastern region being dominated by coastal cities.

It is worth noting that，among the three first-tier cities, Shenzhen and Shanghai ranked first and second, receiving ratings of 0.410 and 0.375 respectively, while Beijing ranked at the bottom of the 222 cities with a rating of -0.054.

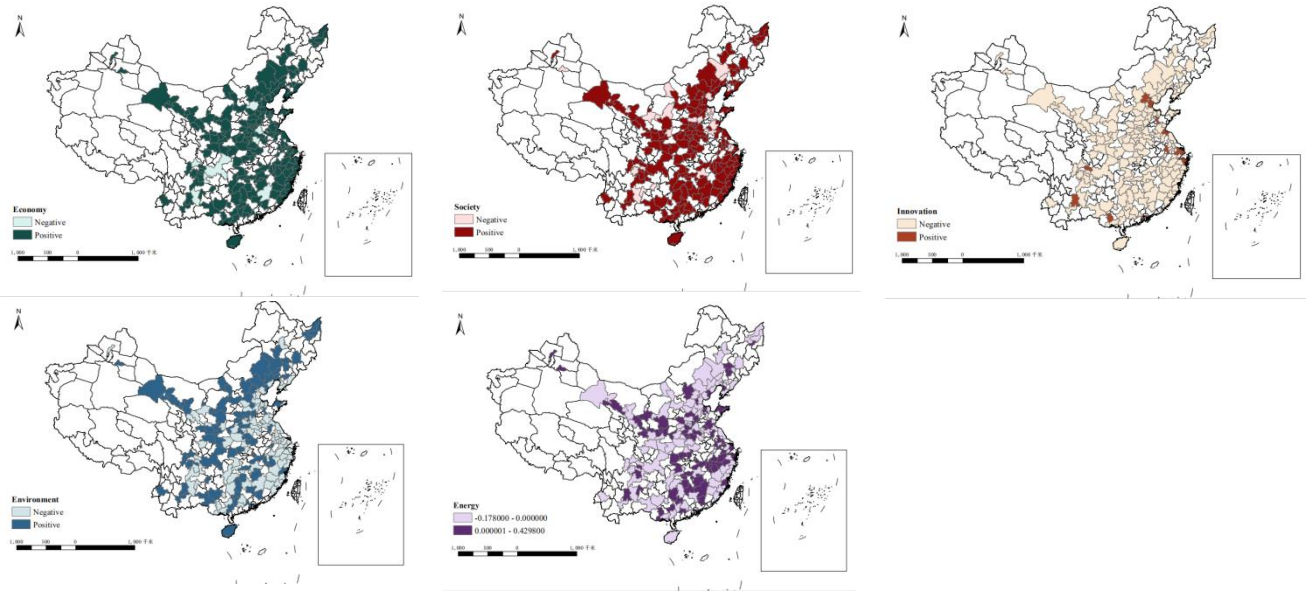


Figure 6. Overall evaluation results for each indicator from 2015 to 2019

Figure 6 shows the dynamic scores of the 222 participating cities in the five major indicators. Overall, most cities show good development in both economic and social aspects, while innovation capacity is seriously lacking.

The two first-level indicators of low carbon society and low carbon economy are in a dominant position at the overall level and have a high quality of development in the country. In addition to the contribution of GDP growth, they depend on the universal development of carbon finance and the construction of the national carbon market. The low-carbon innovation is in a negative state nationally. There are many reasons for the lack of development of low-carbon innovation. Although the government attaches high importance to it and supports it more obviously in terms of government investment, it is undeniable that factors related to the difficulty of conquering low-carbon technologies, the efficiency of R&D of low-carbon innovation and the impact of foreign investment on R&D efforts all affect the quality of development of low-carbon innovation.

5. Conclusion

This paper statically evaluates the low-carbon development of Chinese cities based on five low-carbon dimensions: innovation, economy, society, environment, and energy. The evaluation results are further analyzed from the perspective of speed characteristics, and a dynamic comprehensive evaluation model is established to empirically study the low-carbon development capability of 222 cities in China. Comprehensive analysis shows that the low-carbon development level of each city in China is determined by a combination of five first-level indicators, and dynamic changes in all aspects may cause changes in the overall low-carbon development capacity.

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