An Empirical Case on the Measurement of China's regional Low-carbon Development Level

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Abstract. The ecological problems brought by the rapid development of the economy and society have threatened humanity's sustainable development. As the world's largest carbon emitter, China is still at a critical stage of industrialization, and it is urgent to solve the problem of how to realize the low-carbon circular development of the economy. This paper constructed the evaluation index system of regional low carbon development from the three dimensions of development, low carbon, and ecology. Based on the entropy weight-TOPSIS model, the index was quantitatively analyzed with the data of 30 provinces in China in 2018. According to the measurement results, 30 provinces were clustered into low-carbon development zones, relatively low-carbon development zones, relatively high-carbon development zones, and high-carbon development zones according to the low-carbon ecological development level. The results show that China's overall low-carbon economic development level is not high in 2018, with the south being superior to the north, and the eastern coastal areas of Guangdong, Jiangsu, Shandong, and Zhejiang being significantly prime to other regions. Finally, suggestions are given for different types of low-carbon development areas.

1. Introduction

In the early 21st century, the U.K. government set out the concept of a "low-carbon economy" in its first energy white paper[1]. It has been widely supported and responded to by the United States, Japan, the European Union, and other developed countries. Seen from the process of industrialization, these countries have now completed the historical task of industrialization and urbanization, gone through the stage of development supported by a large consumption of fossil energy, and moved to a new economic era dominated by information services and the financial industry. In December of the same year, the Paris Climate Change Conference held the G20 Hangzhou Summit held in September 2016 shared the same goals in addressing climate change, promoting green, circular, and low-carbon development.

The rapid growth of China's economy comes from the rapid growth of extensive investment in various industries. The "three high" characteristics of high investment, high consumption, and increased pollution have gradually led to many problems such as excessive consumption of resources, deterioration of the ecological environment, and low resource allocation efficiency [2]. As a typical developing country, China will still be critical from the middle to the later stage of industrialization in the next 10 years or even longer. The urbanization will accelerate, the economic scale will continue to expand, and the total demand for resources and energy will rise rapidly[3]. For China, low-carbon development is China's responsibility to mitigate global climate deterioration and a strategic choice for China's economic development and transformation and upgrading[4].

In the context of low carbon development becoming an essential demand of all countries globally, the academic community has begun to pay attention to the theory and practice of low carbon development
and continuously deepen its research. In 1994, John Elkington proposed the "triple bottom line" of sustainable development: environment, economy and society. At the same time, he pointed out that environment, economy and society are the three significant aspects that must be coordinated for sustainable human development[5]. Since then, many scholars have used socioeconomic and environmental indicators to evaluate the low-carbon development or sustainable development level. In 2013, Lynn Price established the China Low Carbon City Evaluation Index system, which focuses on measuring the carbon intensity of economic and energy-related activities[6]. In 2014, Floriana summarized the index system of sustainable urban development in Mainland China, Taiwan China and Malaysia. The index system for mainland China includes 4 major indexes: society, environment, economy and resources, and 21 specific indexes[7]. There are many methods to evaluate economic development. At present, the combination method is used to give weight to indexes before comprehensive evaluation. The index weight is of great significance in the overall evaluation. The greater the weight is, the more important the index is and the greater its impact will be. At present, objective weighting method and subjective weighting method are commonly used. Subjective weighting has strong subjective arbitrariness, which is more representative of analytic hierarchy process, fuzzy clustering method and Delphi method[8-10]. The objective weighting method has a strong mathematical theoretical basis and can effectively avoid the subjectivity of weighting by assigning weights to the relation of the initial data. The more representative methods include coefficient of variation and entropy method[11, 12]. The entropy weight method has high precision and can better interpret the results obtained. In addition, it has adaptability and can be used in any process that needs to determine weights. Comprehensive evaluation methods such as fuzzy comprehensive evaluation method, TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution), grey relational method are widely used[13-16]. They all have their advantages and disadvantages.

At present, there are still some limitations in the research on low-carbon development evaluation in China. First, most places in China have begun to transform the economic development mode and develop the low-carbon economy, but the standards for the successful development of a low-carbon economy and the construction of an evaluation index system are not unified. Second, scholars mainly adopt single evaluation methods such as AHP, factor analysis, coefficient of variation and entropy, which cannot effectively reflect the importance of indicators while avoiding subjective arbitrariness of weights. To accurately grasp the regional low carbon development level and existing problems, improve the regional low carbon competitiveness. Based on the concept of "development-low-carbon-ecology," this paper constructs an evaluation system. It conducts an empirical study on China's regional low-carbon development based on the entropy weight-Topsis evaluation model and the raw data of 30 Provinces and cities in China in 2018.

2. Materials and methods

2.1 Evaluation indicators for regional low-carbon development

There are still some problems in the existing evaluation index system of low-carbon development at home and abroad: First, some studies involve too many indicators, which lead to the offsetting of the indicators reflecting the advantages and disadvantages of low-carbon development in cities, and the guiding effect of low-carbon development is not apparent. Second, the index system with high universality, comparability, and uniformity is less studied. Thirdly, some indexes have poor data acquisition, directly affecting the system's application values application value. Therefore, based on domestic and foreign scholars' existing research, this paper constructs the regional low-carbon development measure and evaluation index system: the target layer is the regional low-carbon development level. The criteria are divided into three aspects: development, low carbon and ecology. Development will be measured from the system of economic development and social progress, Low carbon will be measured from the energy system, carbon emission system. Ecology will be calculated from the ecological environment system. "Low-carbon-ecological-development" is a complex concept, which combines the connotation of "low-carbon development" and "ecological civilization". The ecological city takes a circular economy as the core and emphasizes the symbiosis between city and
natural environment. Low-carbon cities mainly consider urban construction from the perspective of "carbon reduction" and emphasize urban carbon emission reduction. The concept of "low-carbon ecology" combines the advantages of the above two single images, highlighting the fusion of ecology and low-carbon, the fusion of social system and natural system, and the fusion of complexity and symbiosis. This complex concept is also more operable in practice, which is more conducive to guide the planning and construction of China's low-carbon development. The evaluation index system should have the following functions: first, monitoring should reflect the basic situation of low-carbon city construction on a time scale, and form an annual dynamic monitoring database to show the changes of low-carbon city indicators; The second is evaluation, which can not only compare the low-carbon development level of a city with other cities or standards at a certain point but also vertically reflect the changes and efforts of the low-carbon construction of the town itself. The third is the creation and planning, which should guide the city in the low-carbon construction, the specific aspects of the work, the measurement standard is the basis to train the city's low-carbon construction. The specific evaluation index system is shown in Table 1.

Table 1. Evaluation indicators for regional low-carbon development

| Criterion layer | System-level | Index level | Weight |
|-----------------|--------------|-------------|--------|
| Expansibility   | Economic development | GDP gross | 0.112 |
|                 |              | GDP per capita | 0.039 |
|                 |              | Industrial added value | 0.145 |
|                 | Social progress | The proportion of tertiary industry in GDP | 0.006 |
|                 |              | Urbanization rate | 0.008 |
|                 |              | Educational input | 0.025 |
|                 | Low carbon emission | Per capita disposal income | 0.029 |
|                 |              | Unemployment rate | 0.125 |
|                 |              | Total carbon emission | 0.032 |
|                 |              | Carbon emissions per capita | 0.038 |
|                 |              | CO2 emissions per unit of GDP | 0.036 |
|                 | Low carbon 0.10543 | Total energy consumption (ten thousand tons of standard coal) | 0.040 |
| Energy structure and consumption level 0.230 | | Energy consumption per unit of GDP | 0.050 |
|                 |              | Per capita energy consumption | 0.045 |
|                 |              | Industrial energy consumption | 0.035 |
|                 |              | Energy consumption in the construction industry | 0.030 |
|                 |              | Transportation energy consumption | 0.030 |
|                 | Carbon sequestration capacity 0.081 | Forest coverage rate | 0.070 |
|                 |              | Green coverage rate /% in built-up areas | 0.002 |
|                 |              | Per capita public green space area | 0.009 |
|                 | Environmental carrying capacity 0.096 | Expenditure on energy conservation and environmental protection | 0.055 |
|                 |              | Quantity of wastewater effluent | 0.022 |
|                 |              | Sewage treatment rate | 0.001 |
|                 |              | Harmless disposal rate of household garbage | 0.001 |
|                 |              | The comprehensive utilization rate of industrial solid waste | 0.017 |

2.2 Entropy weight method

The entropy weight method is an objective weighting method, which eliminates the influence of subjective factors. It uses each evaluation object's index value to construct the judgment matrix, after the normalization of the matrix, calculates the index entropy according to the definition of entropy, and finally calculates the entropy weight of each principal component. Among them, entropy is a measure of the disorder degree of the system. The smaller the information entropy of the index is, the
greater the index’s information and the more significant its role in the comprehensive evaluation. The specific calculation steps of entropy weight are as follows:
(1) Construct index judgment matrix. n measure objects and p principal component factors are set, and a standardized matrix is constructed according to the scores of each principal component \( R = (f_{ij})_{n \times p} (i = 1, 2, 3, \ldots, m) \).

(2) Calculate the entropy and entropy weight of each principal component. According to the definition, the entropy \( e_j \) and entropy weight \( w_j \) of the jth principal component factor are:
\[
\begin{align*}
\text{Entropy weight} & : w_j = \frac{1 - e_j}{\sum_{j=1}^{m} (1 - e_j)} \\
\text{Entropy} & : e_j = -\frac{1}{\ln n} \sum_{i=1}^{n} [b_{ij} \ln b_{ij}] \\
\text{Entropy formula} & : b_{ij} = \frac{f_{ij} + 1}{\sum_{j=1}^{n} (f_{ij} + 1)}
\end{align*}
\]

The original expression of \( b_{ij} \) is
\[
\begin{align*}
b_{ij} & = \frac{f_{ij}}{\sum_{j=1}^{n} f_{ij}}
\end{align*}
\]

When \( b_{ij} = 0 \), \( \ln b_{ij} = 0 \) is meaningless, so the original formula is modified into the formula(4).

2.3 TOPSIS method
C.L. Wang and K.OON first proposed the TOPSIS method in 1981. It is a standard method to analyze the objective decision of the finite scheme in system engineering. Its core idea is that the optimal scheme should have the smallest distance from the positive ideal scenario and the largest gap from the ideal negative scenario. This method can sort several measured objects with measurable attributes, and the specific steps are as follows:

(1) The weighted standardized matrix \( Z = (r_{ij})_{n \times m} \), was constructed to determine the positive ideal solution \( Z^+ \) and the negative ideal solution \( Z^- \).
\[
Z_{ij} = (r_{ij})_{n \times m} = (w_{ij}y_{ij})_{n \times m} = \begin{bmatrix}
w_{i1}y_{11} & w_{i2}y_{12} & \cdots & w_{im}y_{1m} \\
w_{i1}y_{21} & w_{i2}y_{22} & \cdots & w_{im}y_{2m} \\
\vdots & \vdots & \ddots & \vdots \\
w_{i1}y_{n1} & w_{i2}y_{n2} & \cdots & w_{im}y_{nm}
\end{bmatrix}
\]

Where, \( W_i \) is the entropy weight of the jth principal component factor, and \( y_{ij} \) is the score of the jth principal component corresponding to the ith measure object.
\[
\begin{align*}
Z^+ & = \left\{ \left( \max_{j \in J_1} Z_{ij} \right), \left( \min_{j \in J_1} Z_{ij} \right) \right| \left( i = 1, 2, \cdots, m \right) \} = (z_{11}^+, z_{21}^+, \cdots, z_{n1}^+) \\
Z^- & = \left\{ \left( \max_{j \in J_2} Z_{ij} \right), \left( \min_{j \in J_2} Z_{ij} \right) \right| \left( i = 1, 2, \cdots, m \right) \} = (z_{11}^-, z_{21}^-, \cdots, z_{n1}^-)
\end{align*}
\]

Where, \( J_1 \) means that the jth indicator is a forward indicator, and \( J_2 \) means that the jth indicator is a backward indicator.

(2) The distance \( S_{i1}^+ \) and the distance \( S_{i1}^- \), between the ideal positive point and the ideal negative point of each province to be tested is calculated, and the relative proximity \( C_i \) between each province, and the ideal target is obtained to represent each province’s sustainable development ability and city.
\[
\begin{align*}
S_{i1}^+ & = \sqrt{\sum_{j=1}^{p} \left( Z_{ij} - Z_{i1}^+ \right)^2} \quad i = 1, 2, \cdots, m \\
S_{i1}^- & = \sqrt{\sum_{j=1}^{p} \left( Z_{ij} - Z_{i1}^- \right)^2} \\
C_i & = \frac{S_{i1}^-}{S_{i1}^+ + S_{i1}^-} \quad i = 1, 2, \cdots, m
\end{align*}
\]

The higher the value of \( C_i \) the more significant the low-carbon sustainable development capacity of a region; on the contrary, the smaller the value of \( C_i \), the smaller the low-carbon sustainable development capacity of an area.

According to the weight and score, the relative advantage index and the relative disadvantage index can be obtained to determine the type of economic development in each region.
2.4 Clustering analysis
Cluster analysis is a mathematical method to identify the proximity between objects according to certain criteria and classify the similarity into one class. Clustering aims to minimize the difference within the class and maximize the difference between the classes. In this paper, K-means clustering is adopted to classify the low-carbon economic development levels of 30 provinces, autonomous regions, and municipalities. The k-means clustering algorithm is as follows:
(1) Initial cluster center. There are three main methods: First, according to specific problems, select k samples as the initial clustering center by experience; Second, all the samples were randomly divided into K classes, and the sample mean of each class was taken as the initial clustering center. Third, the first K samples are used as the initial clustering center.
(2) Initial clustering. The sample mean is recalculated, and the cluster center is updated by taking the same base and placing it in the class closest to the initial cluster center. Repeat this operation until all samples are placed in the appropriate class.
(3) Judge whether clustering is reasonable. The error square sum criterion function is used to judge whether the clustering is reasonable or not, and the classification is modified if it is not. The loop is judged and modified until the algorithm terminates.
Using the K-means clustering algorithm, the 30 provinces, autonomous regions, and municipalities can be divided into 4 categories according to the low-carbon economic development level, namely, low-carbon development zone, relatively low-carbon development zone, relatively high-carbon development zone, and high-carbon development zone.

3. Results & discussion

3.1 Study area and data source
Considering data availability, this paper's evaluation unit is 30 provinces, autonomous regions, and municipalities in China. The Xizang region and Hong Kong, Macao, and Taiwan region are not included in the research scope due to the lack of data. The research data mainly come from the China Statistical Yearbook, China Energy Statistical Yearbook, and statistical yearbooks of various provinces and cities obtained directly or through a simple calculation. Carbon emission data refer to IPCC methods and domestic and foreign literature. This paper uses the relationship between energy consumption and carbon emission coefficient for accounting. This article chooses coal, coke, crude oil, gasoline, kerosene, diesel oil, fuel oil, natural gas, electricity as the research object. Based on the IPCC carbon accounting methods, using statistical energy yearbook of statistics are given detailed all fuel consumption value (The unit is ton standard coal) for carbon dioxide emissions estimates. Carbon dioxide emissions from fossil fuel consumption were calculated according to the Department of Energy's benchmark method in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

3.2 The calculation results
According to formula (1) - (4), the entropy weight result can be calculated, as shown in Table 1. According to the entropy weight calculation results, the developmental weight accounts for 0.48848, followed by the low-carbon 0.33466, and the relatively low ecological weight accounts for 0.17686. Among them, indicators such as industrial added value, unemployment rate, energy consumption per unit of GDP, forest coverage rate, and expenditure on energy conservation and environmental protection account for relatively high weight.
According to formula (5) - (8), TOPSIS scores were obtained. In order to make the evaluation more intuitive, the values were expanded by 100 times without affecting the evaluation results, and the score was sorted, as shown in Table 2. The highest score was 74.48 in Guangdong, which was also one of China's first low-carbon urban provinces. The lowest score was 25.07 from Xinjiang.
Table 2. The score of low-carbon development level of cities

| Region   | Score | Region   | Score | Region   | Score | Region   | Score |
|----------|-------|----------|-------|----------|-------|----------|-------|
| Guangdong| 74.48 | Beijing  | 43.56 | Shaanxi  | 37.40 | Liaoning | 31.63 |
| Jiangsu  | 71.83 | Sichuan  | 42.16 | Jilin    | 36.95 | InnerMongolia | 29.01 |
| Shandong | 64.53 | Hebei    | 42.04 | Tianjin  | 36.17 | Qinghai  | 28.95 |
| Zhejiang | 59.96 | Anhui    | 41.03 | Hainan   | 35.65 | Ningxia  | 26.32 |
| Henan    | 51.85 | Jiangxi  | 40.62 | Yunnan   | 35.56 | Shanxi   | 25.43 |
| Hubei    | 46.40 | Guangxi  | 39.80 | Guizhou  | 33.72 | Xinjiang | 25.07 |
| Fujian   | 46.03 | Chongqing| 38.48 | Heilongjiang | 33.28 |
| Hunan    | 44.44 | Shanghai | 38.07 | Gansu    | 31.95 |

Using SPSS22.0, k-means clustering was adopted for TOPSIS results, and the clustering results of low-carbon economic development level of 30 provinces and municipalities were shown in Figure 1. According to the low-carbon ecological development level, the 30 provinces, autonomous regions, and municipalities were clustered into low-carbon development zones (purple), relatively low-carbon development zones (blue), relatively high-carbon development zones (yellow), and high-carbon development zones (red).

Figure 1. Clustering results of low carbon economy development level

It is concluded that China's overall low-carbon development level was not high in 2018. Guangdong and Jiangsu are the only low-carbon development areas, while Shandong and Zhejiang are relatively low-carbon development areas. Henan, Hubei, Fujian, Hunan, Beijing, Sichuan, Hebei, Anhui, Jiangxi, Guangxi, Chongqing, Shanghai, and other places are relatively high carbon regions. Shaanxi, Jilin, Tianjin, Hainan, Yunnan, Guizhou, Heilongjiang, Gansu, Liaoning, Inner Mongolia, Qinghai, Ningxia, Shanxi, Xinjiang, and other places are the high-low carbon development areas. In general, the north of China has a low-carbon development level, while the eastern coastal regions have a high level of low-carbon development.

4. Conclusions
This paper constructs an evaluation index system of regional low-carbon development level from three aspects of development, low carbon, and ecology, and makes an empirical analysis based on 30 Chinese provinces in 2018. The results show that China's overall low-carbon economic development level was not high in 2018. Overall, the low-carbon development level of the south is better than that
of the north, and the local development level of the eastern coastal areas is the best. Low-carbon cities can follow the path of ecological restoration development. Based on ensuring the research and development of low-carbon technologies, the transformation of low-carbon clean energy, and the development of low-carbon space, they should pay attention to the ecosystem's delicate operation, especially the improvement of air and water quality. Relatively low-carbon cities can take the path of climate-friendly low-carbon development and reduce the impact of climate change on cities' low-carbon development by optimizing and adjusting the industrial and spatial structure. Relatively high-carbon cities can take the road of factor-driven low-carbon development and give full play to the low-carbon transformation role of industries, residents, energy, and municipalities to release the vitality of low-carbon development. High-carbon cities can take a low-carbon development path constrained by carbon emission reduction, formulate strict carbon emission reduction targets, and realize low-carbon development through low-carbon technological innovation.

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