Evaluation of Low Carbon Economy Development in China's Provinces: Based on Entropy-OWA Algorithm and Grey Correlation Improvement TOPSIS

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Abstract. This study constructs the evaluation indicator system for low-carbon economic development level from the perspective of economic, energy consumption, low carbon, environmental, facilities and input status. Based on entropy-OWA operator weighting and grey correlation improvement TOPSIS comprehensive evaluation model, a comprehensive evaluation is made on the development level of low-carbon economy in 30 provinces and cities in China. The results show that the development level of China's low-carbon economy is gradually decreasing from east to west in the regional distribution. The results show that the low carbon economy development level in China presents a gradual decline from east to west. The low-carbon economy in the eastern coastal areas is developing better, and lower in the western and northern regions. In order to promote the level of low-carbon economic development among different regions, the western and northern regions should focus on energy conservation and emission reduction while promoting economic development, and promote the development of low-carbon economy.

1. Introduction
As one of the most populous countries in the world, China produces a huge amount of carbon dioxide emissions every year. The research on low-carbon economy is carried out from many aspects, such as laws and regulations, low-carbon technology development and so on, especially in the evaluation of low-carbon economic development level. Many scholars use different methods, such as analytic hierarchy process and Delphi method[1-3], to establish an evaluation system for the development level of low-carbon economy from the factors affecting low-carbon[4]. Hu Dali believed that the development of low-carbon economy includes many factors such as technology, society and environment, which should be evaluated from the entire industrial chain from resource production to final treatment[5]. Sun Jiujwen took Xinjiang as an example to assess the low carbon economy in Xinjiang from low carbon output, emissions, consumption and resources[6]. The evaluation index of low-carbon economic development evaluation is complex, and the main impact factors can be determined by factor analysis, which is conducive to suggesting key improvements[7-8]. In recent years, more and more scholars have constructed different quantitative and qualitative evaluation models for the evaluation of low-carbon economy level, and conducted comprehensive evaluation and put forward important countermeasures for a certain province, such as Shanxi, Tianjin and Jiangsu[9-10]. Foreign researches on low carbon economy mainly focus on the relationship between carbon emission and economic development and the
factors affecting low carbon, and the evaluation of low carbon economy level is based on environmental evaluation.

The evaluation of the development level of low-carbon economy is a multi-faceted and complex system with many influencing factors. Most of the evaluation systems currently being constructed are carried out in two aspects, on the one hand, from the main factors affecting the level of development, including economic, technological, environmental and industrial factors; on the other hand, from the connotation of low-carbon economy, the evaluation system consists of low-carbon energy, low-carbon production, low-carbon consumption, low-carbon environment, etc.

2. Low carbon economy development level evaluation index system

Low-carbon economy refers to the social and economic development should consider the emission of carbon dioxide and the consumption of energy, rather than pursuing economic benefits and ignoring the carbon emission and energy consumption. Therefore, the evaluation system selects evaluation indexes from the five aspects of regional economic level, energy consumption level, low carbon level, environmental level, facilities and investment, and establishes the evaluation index system of regional low carbon economic level, as shown in Table 1.

| Target layer          | Criteria layer | Indicator layer | Unit     |
|-----------------------|----------------|-----------------|----------|
| Low-carbon economic development level(A) | Per capita GDP(A1) | Yuan           |
|                       | Regional GDP(A2) | Billion yuan    |
|                       | Urban per capita disposable income(A3) | Yuan       |
|                       | GDP growth rate(A4) | %             |
|                       | Proportion of primary industry(A5) | %           |
|                       | International tourism revenue(A6) | million dollars |
| Energy consumption level(B) | Per capita energy consumption(B1) | t/person |
|                       | Comprehensive energy consumption(B2) | 10^4 t of standard coal |
|                       | Energy consumptions per GDP(B3) | t/thousand yuan |
| Low carbon level(C) | Carbon emission per capita(C1) | t/person |
|                       | Total carbon emission(C2) | t |
|                       | Carbon productivity(C3) | Thousand yuan/kg |
|                       | Carbon intensity(C4) | kg/thousand yuan |
| Environmental level(D) | Emissions per capita(D1) | t/person |
|                       | Total wastewater discharge(D2) | kiloton   |
|                       | Industrial solid waste production volume(D3) | kiloton   |
|                       | Per capita forest area(D4) | Ha/person |
|                       | Forest coverage rate(D5) | %          |
| Facilities and inputs(E) | Urban gas penetration rate(E1) | %          |
|                       | The ratio between fiscal expenditure and GDP(E2) | %          |

3. Models and methods

3.1. Entropy - OWA operator determines index weight

This paper combines the entropy weight method with OWA operator to calculate the combination weight, which makes the calculation of index weight more scientific. The steps for calculating the combined weights are as follows:

(1) Determination of position weight

According to the evaluation object of this study, arithmetic progression (AP) operator method is used to determine the position weight. Assuming that m experts evaluate n indicators, the calculation formula of position weight vector \( w = (w_1, w_2, ..., w_m) \) is shown in formula (1) and formula (2).

When \( m \) is odd,
When \( m \) is even, 

\[
 w_i = \begin{cases} 
 \frac{i}{(m+2)^2}, & i \leq \frac{m+1}{2} \\
 \frac{m+1}{2}, & i > \frac{m+1}{2} 
\end{cases}
\] 

(1)

(2) OWA operator determines subjective weight

Assuming that there are \( n \) evaluation indicators and \( m \) experts, \( a, b \) and \( c \) represent the optimistic, most likely and pessimistic estimates given by experts respectively, which form a fuzzy matrix. The weighted arithmetic mean operator of index \( J \) and the triangular fuzzy weight of each index are shown in formula (3) and formula (4).

\[
 q_i = \frac{a + 4b + c}{6} 
\] 

(3)

\[
 Q_j = \frac{q_j}{\sum_{j=1}^{n} q_j} 
\] 

(4)

The triangular fuzzy weight \( B \) of indicator \( j \) by \( m \) experts is sorted in order from large to small, denoted as \( Q \). Combining the position weight vector with its corresponding triangular fuzzy weight, the subjective weight of indicator \( j \) can be obtained as shown in formula (5).

\[
 f_i = \sum_{j=1}^{n} w_i Q_i 
\] 

(5)

(3) Entropy weight method to determine the objective weight

1) Data standardization

Normalize the formula of forward index:

\[
 r_{ij} = \frac{r_{ij} - \min(r_{ij})}{\max(r_{ij}) - \min(r_{ij})} \quad (1 \leq i \leq m, 1 \leq j \leq n)
\] 

(6)

Normalization formula for negative index:

\[
 r_{ij} = \frac{\max(r_{ij}) - r_{ij}}{\max(r_{ij}) - \min(r_{ij})} \quad (1 \leq i \leq m, 1 \leq j \leq n)
\] 

(7)

2) Calculate the entropy of each index.

\[
 h_j = -\frac{1}{\ln n} \sum_{i=1}^{n} \left[ \ln \left( \frac{r_{ij} + 1}{\sum_{j=1}^{n} (r_{ij} + 1)} \right) \right] 
\] 

(8)

3) Calculate objective weight

\[
 g_i = \frac{1 - h_j}{\sum_{j=1}^{n} (1 - h_j)} 
\] 

(9)

(4) Calculate combined weight

\[
 Q_j = v_1 f_j + v_2 g_j 
\] 

(10)
3.2. Grey Correlation Improvement TOPSIS Evaluation Model

By combining the grey relational model with the TOPSIS model, the positive and negative ideal distance and the grey relational degree can be standardized, and finally the relative closeness can be corrected. The specific steps are as follows:

(1) Constructing decision matrix

We assume that the set of evaluation plans is \( M = (M_1, M_2, ..., M_t) \), and the set of evaluation indicators of the evaluation plan is \( D = (D_1, D_2, ..., D_n) \). The specific evaluation value of the evaluation index \( D_j \) of the scheme \( M_i \) is denoted by \( x_{ij} = (i = 1,2,...,t; j = 1,2,...,n) \), and the initial evaluation matrix \( X \) is established as follows:

\[
X = \begin{bmatrix}
  x_{11} & x_{12} & \cdots & x_{1n} \\
x_{21} & x_{22} & \cdots & x_{2n} \\
  \vdots & \vdots & \ddots & \vdots \\
x_{t1} & x_{t2} & \cdots & x_{tn}
\end{bmatrix}
\]  

(11)

The initial evaluation matrix \( X \) is normalized by the formulas (6) and (7) to form a standardized evaluation matrix, which is denoted as \( Z \).

(2) Determine the matrix weighting and positive and negative ideal scheme

The weight of each evaluation index determined by the entropy-OWA operator calculation is multiplied by the normalized evaluation matrix \( Z \) to obtain a weighted judgment matrix \( R \). According to the maximum possible and minimum possible criteria, the weighted judgment matrix was observed to obtain the positive ideal scheme and the negative ideal scheme, which were denoted as \( S^+ \) and \( S^- \) respectively.

\[
R = \begin{bmatrix}
  z_{11} & z_{12} & \cdots & z_{1n} \\
z_{21} & z_{22} & \cdots & z_{2n} \\
  \vdots & \vdots & \ddots & \vdots \\
z_{t1} & z_{t2} & \cdots & z_{tn}
\end{bmatrix}
\]  

\[
Q = \begin{bmatrix}
  Q_1 & 0 & \cdots & 0 \\
  0 & Q_2 & \cdots & 0 \\
  \vdots & \vdots & \ddots & \vdots \\
  0 & 0 & \cdots & Q_n
\end{bmatrix}
\]  

(12)

\[
S^+ = \left( S^+_1, S^+_2, \ldots, S^+_n \right) \quad S^+_j = \max_{1 \leq i \leq t} \{ r_{ij} \} 
\]  

(13)

\[
S^- = \left( S^-_1, S^-_2, \ldots, S^-_n \right) \quad S^-_j = \min_{1 \leq i \leq t} \{ r_{ij} \} 
\]  

(14)

(3) Calculate the distance between each scheme and positive and negative ideal scheme

\[
d^+_i = \sqrt{\sum_{j=1}^{n}(r_{ij} - S^+_j)^2}, i = 1,2,\ldots,t
\]  

(15)

\[
d^-_i = \sqrt{\sum_{j=1}^{n}(r_{ij} - S^-_j)^2}, i = 1,2,\ldots,t
\]  

(16)

(4) Calculate the grey correlation degree

The grey correlation coefficient between each evaluation scheme and positive and negative ideal schemes is calculated by formula (17) and formula (18) respectively, and the grey correlation coefficient matrix is obtained.

\[
\xi^+_i = \frac{\min_{j} \min \left| S^+_j - r_{ij} \right| + \rho \max_{j} \max \left| S^+_j - r_{ij} \right|}{\left| S^+_j - r_{ij} \right| + \rho \max_{j} \max \left| S^+_j - r_{ij} \right|}
\]  

(17)

\[
\xi^-_i = \frac{\min_{j} \min \left| S^-_j - r_{ij} \right| + \rho \max_{j} \max \left| S^-_j - r_{ij} \right|}{\left| S^-_j - r_{ij} \right| + \rho \max_{j} \max \left| S^-_j - r_{ij} \right|}
\]  

(18)

\( P \) is the resolution coefficient, and the main purpose is to reduce the distortion caused by the error value being too large. Usually, the value of \( P \) is between 0-1. In this study, 0.5 is calculated. The calculated matrix of grey correlation coefficient is:
\[ \xi^+ = \begin{bmatrix} \xi_{11}^+ & \xi_{12}^+ & \cdots & \xi_{1n}^+ \\ \xi_{21}^+ & \xi_{22}^+ & \cdots & \xi_{2n}^+ \\ \vdots & \vdots & \ddots & \vdots \\ \xi_{m1}^+ & \xi_{m2}^+ & \cdots & \xi_{mn}^+ \end{bmatrix} \]  
\[ \xi^- = \begin{bmatrix} \xi_{11}^- & \xi_{12}^- & \cdots & \xi_{1n}^- \\ \xi_{21}^- & \xi_{22}^- & \cdots & \xi_{2n}^- \\ \vdots & \vdots & \ddots & \vdots \\ \xi_{m1}^- & \xi_{m2}^- & \cdots & \xi_{mn}^- \end{bmatrix} \]  

(19)

(20)

Put the calculated grey correlation coefficient matrix into equations (21) and (22) to calculate the grey correlation degree of the evaluation scheme.

\[ \lambda_i^+ = \frac{\sum_{j=1}^{n} \xi_{ij}^+}{n} \]  
\[ \lambda_i^- = \frac{\sum_{j=1}^{n} \xi_{ij}^-}{n} \]  

(21)

(22)

(5) Calculate the relative progress of each evaluation scheme and ideal scheme.

Standardize the distance and correlation between each solution and the positive and negative ideal solutions.

\[ S d_i^+ = \frac{d_i^+}{\max d_i^+} \]  
\[ S d_i^- = \frac{d_i^-}{\max d_i^-} \]  

(23)

(24)

\[ S \lambda_i^+ = \frac{\lambda_i^+}{\max \lambda_i^+} \]  
\[ S \lambda_i^- = \frac{\lambda_i^-}{\max \lambda_i^-} \]  

(25)

(26)

Combine the standardized distance and the grey correlation degree by 1:1 weight, and calculate the relative progress of each evaluation plan and the positive and negative ideal scheme. The larger Z is, the better the evaluated scheme is.

\[ Z_i = \frac{0.5S \lambda_i^- + 0.5S d_i^-}{0.5S \lambda_i^+ + 0.5S d_i^+ + 0.5S \lambda_i^- + 0.5S d_i^-} \]  

(27)

4. Empirical analysis

4.1. Data source and model processing

According to the regional low carbon economy development level evaluation model, take the data of 30 provinces and cities in China in 2016 as an example to calculate the carbon emission of each province and city. The data come from China statistical yearbook 2017 and China energy statistical yearbook.

Entropy -OWA operator is used to calculate the weights of 20 evaluation indexes. Two experts were selected and OWA operator weighting was performed on the evaluation index to obtain the position weight. The position weight of two experts is obtained by combining formula (2) with triangular fuzzy number according to AP weighting method, that is, \( W = (0.5, 0.5) \), so as to obtain the subjective weight of each evaluation index. Formula (6) and (7) are used to standardize each indicator, and entropy weight
method is adopted to determine the objective weight. Finally, the subjective weight obtained by OWA operator and the objective weight determined by entropy weight method are linearly weighted to obtain the combined weight value of each evaluation index.

After calculating the combined weight of 20 indicators, grey correlation improvement TOPSIS model is used to comprehensively evaluate the development level of low-carbon economy of 30 provinces and cities in China. The evaluation results are shown in table 2.

Table 2. Evaluation results of low carbon economy development level of 30 provinces & cities in China

| Provinces & cities | Relative proximity | A Relative proximity | B Relative proximity | C Relative proximity | D Relative proximity | E Relative proximity |
|--------------------|-------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| Beijing            | 0.525             | 0.518               | 0.560               | 0.582               | 0.509               | 0.495               |
| Tianjin            | 0.512             | 0.511               | 0.530               | 0.544               | 0.503               | 0.492               |
| Hebei              | 0.492             | 0.491               | 0.496               | 0.502               | 0.489               | 0.495               |
| Shanxi             | 0.484             | 0.480               | 0.485               | 0.475               | 0.484               | 0.502               |
| Inner Mongolia     | 0.481             | 0.490               | 0.476               | 0.466               | 0.497               | 0.498               |
| Liaoning           | 0.491             | 0.452               | 0.504               | 0.519               | 0.499               | 0.497               |
| Jilin              | 0.513             | 0.486               | 0.568               | 0.535               | 0.524               | 0.491               |
| Heilongjiang       | 0.502             | 0.476               | 0.549               | 0.530               | 0.539               | 0.464               |
| Shanghai           | 0.516             | 0.520               | 0.533               | 0.550               | 0.503               | 0.494               |
| Jiangsu            | 0.501             | 0.541               | 0.502               | 0.516               | 0.493               | 0.499               |
| Zhejiang           | 0.514             | 0.531               | 0.530               | 0.542               | 0.518               | 0.494               |
| Anhui              | 0.513             | 0.488               | 0.555               | 0.530               | 0.506               | 0.498               |
| Fujian             | 0.516             | 0.506               | 0.557               | 0.549               | 0.524               | 0.499               |
| Jiangxi            | 0.517             | 0.489               | 0.564               | 0.536               | 0.525               | 0.499               |
| Shandong           | 0.493             | 0.521               | 0.501               | 0.503               | 0.483               | 0.499               |
| Henan              | 0.495             | 0.497               | 0.526               | 0.521               | 0.499               | 0.468               |
| Hubei              | 0.512             | 0.497               | 0.546               | 0.537               | 0.516               | 0.497               |
| Hunan              | 0.511             | 0.493               | 0.548               | 0.537               | 0.521               | 0.489               |
| Guangdong          | 0.506             | 0.524               | 0.506               | 0.540               | 0.509               | 0.498               |
| Guangxi            | 0.517             | 0.484               | 0.562               | 0.536               | 0.532               | 0.499               |
| Hainan             | 0.524             | 0.491               | 0.568               | 0.535               | 0.519               | 0.518               |
| Chongqing          | 0.516             | 0.494               | 0.565               | 0.541               | 0.516               | 0.498               |
| Sichuan            | 0.507             | 0.492               | 0.534               | 0.535               | 0.512               | 0.486               |
| Guizhou            | 0.505             | 0.489               | 0.551               | 0.527               | 0.516               | 0.480               |
| Yunnan             | 0.500             | 0.482               | 0.556               | 0.533               | 0.533               | 0.476               |
| Shaanxi            | 0.509             | 0.487               | 0.556               | 0.520               | 0.522               | 0.495               |
| Gansu              | 0.511             | 0.485               | 0.544               | 0.530               | 0.503               | 0.509               |
| Qinghai            | 0.505             | 0.487               | 0.493               | 0.527               | 0.502               | 0.508               |
| Ningxia            | 0.490             | 0.490               | 0.501               | 0.503               | 0.496               | 0.513               |
| Xinjiang           | 0.498             | 0.476               | 0.480               | 0.497               | 0.497               | 0.540               |

From the calculation results of relative paste progress of 30 provinces and cities, Beijing has the largest relative paste progress, indicating that it is closest to the positive ideal plan and the development level of low-carbon economy is the highest. On the contrary, Inner Mongolia has the smallest relative paste progress, the closest to the negative ideal plan, and the lowest level of low-carbon economic development. On the whole, China's economic development presents a geographical distribution feature of relatively developed first-tier cities such as Beijing and Shanghai, Guangdong, Jiangsu and Zhejiang, and relatively backward northeast and southwest regions. However, the energy consumption level and low carbon level differ greatly between north and south, while the energy consumption in the north is large, and the low carbon level is relatively low. The southern region consumes less energy and has a relatively high low-carbon level.
5. Conclusion
This paper makes a comprehensive evaluation of the development level of low-carbon economy in 30 provinces and cities in China. From the results of longitudinal evaluation, the development level of low-carbon economy in China is gradually decreasing from east to west in regional distribution. The low-carbon economy in the eastern coastal areas and first-tier cities such as Beijing and Shanghai develops better, while the low-carbon economy in the western and northern regions such as Xinjiang and Hebei develops lower. According to the results of the horizontal evaluation, the economic level, energy consumption level and low carbon level of the western region are not high. It is necessary to strengthen the efficiency of resource utilization and carbon dioxide emission control while increasing economic construction, so as to realize the simultaneous development of GDP and green and low carbon. Beijing, Shanghai, Zhejiang, Jiangsu and other provinces have achieved good results in terms of economic development, low carbon and energy consumption. That provinces need to maintain their advantages, form a sound development cycle, and exchange experience with other provinces and cities to promote balanced development among regions. The energy consumption in Hebei, Shanxi and Inner Mongolia is high, the low carbon level is not good, and the environmental quality needs to be improved. We should pay attention to economic development while also taking into account energy efficiency, making the concept of low carbon deeply rooted, setting emission reduction targets, and promoting the improvement of regional low carbon economy development level.

The low-carbon economic development model is a construction model proposed under the concept of sustainable development to reduce energy consumption, promote emission reduction, and achieve harmonious integration of economic construction and ecological environment. Through comprehensive evaluation of the low carbon economy development level of 30 provinces and cities, it is possible to fully understand the current situation of low carbon economy construction in various provinces and cities, and propose reasonable improvement opinions.

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