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The TOPSIS Evaluation on Carbon Emission Economic Efficiency

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Abstract Based on carbon emission data of 17 cities in Shandong Province in 2005 – 2009, this paper analyzes carbon emission economic efficiency. It conducts weight distribution by the Ordered Weighted Averaging (OWA) method, and takes systematic evaluation on carbon emission economic efficiency using TOPSIS method. In eastern coastal regions, including Dongying, Yantai, Weihai and Qingdao, the carbon emission economic efficiency is generally higher than inland regions of Shandong Province. The conclusion reached after correction of time weight is basically consistent with traditional TOPSIS overall evaluation, further proves validity of the evaluation. Finally, it gives recommendations for improving carbon emission economic efficiency in Shandong Province.

Key words Carbon emission economic efficiency, OWA, TOPSIS evaluation model

1 Theoretical basis of carbon emission research

The degree and development level of carbon emission can be measured by its economic efficiency. Carbon emission economic efficiency refers to economic benefits gained from per unit of carbon dioxide emission. If this index is higher, the degree of mutual progress and balance of sustainable development will be higher. Many scholars have undertaken extensive researches on carbon emission. Those researches mainly focus on following 4 aspects. (1) Influencing and driving factors of carbon emission. Xu Guoquan established the Factor Decomposition Model for per capita carbon emission of China by Logarithmic Mean Weight Divisia (LMD) method, analyzed influence of changes in energy structure, energy efficiency and economic development on per capita carbon emission of China in 1995 – 2004, and concluded that exponential growth of the contribution rate of economic development to China's per capita carbon emission, and the inverted U shape of contribution rate of energy efficiency and energy structure to restraining China's per capita carbon emission. (2) Calculation of carbon emission. Jiang Jinhe estimated carbon emission coefficient of energy consumption allocation from the aspect of different types of energy consumed by GDP. Wang Zheng *et al.* calculated the carbon emission from the perspective of business accounting by different methods. (3) The relationship between economic growth and carbon emission. Song Bangying set up the panel data model of carbon emission and low carbon economic development and obtained degree of factors influencing carbon emission. Ye Xiaojia comprehensively calculated carbon emission of Zhejiang Province in 1995 – 2008 based on 12 types of energy consumption data in 3 major industries and resident living sectors. (4) Carbon emission economic efficiency. Zhou Jian defined carbon emission economic efficiency as economic income received from per unit of CO_2 emission. It is a positive index, the higher the value, the higher carbon emission economic efficiency. It can be expressed by the formula: carbon emission economic efficiency = GDP/CO_2 emission.

From the above review of carbon emission researches, we can know the researches focus on calculation of carbon emission, the relationship between carbon emission and economic growth, and driving factors of carbon emission. Few researches touch upon carbon emission economic efficiency, and even less on the carbon emission economic efficiency of a certain area. In this situation, taking Shandong Province as an example, we assign weight by OWA method for carbon emission data of 2005 – 2009, and make systematic evaluation on carbon emission economic efficiency of 17 cities in Shandong Province with the aid of TOPSIS method.

2 Research methods

TOPSIS refers to Technique for Order Preference by Similarity to Solution and it is an effective multi-index decision-making method. When using TOPSIS model, the key point is to select proper weight assignment method according to selected evaluation index, and then evaluate and analyze research objects as per steps of TOPSIS model.

2.1 Methods for determining time weight OWA operator weight assignment is to determine corresponding weight according to decision data. Since YAGER initiated OWA operator, its fairness of weight assignment has been improved constantly. Here, with reference to the method used by Zhou Jian in evaluating carbon emission economic efficiency of all provinces of the country, we assign weight by OWA operator in combination with decision data. Thus, it solves the problem of neglecting weight assignment of the same index in different period. In addition, TOPSIS uses Euclidean distance theory in fuzzy data and ranks research objects, so it is quite objective. OWA operator weight assignment includes following steps: (1) Use X_{it} to signify the carbon emission economic efficiency of city i in time t, *i. e.* the ratio of GDP to carbon emission. Firstly sum X_{it} of each year and get the average value $\overline{X}_t = \sum_{i=1}^{m} X_{it}/m$, which signifies the annual overall carbon emission economic efficiency of Shandong Province and is taken as

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weight decision-making data, $x=(x_1, x_2, \cdots, x_t)$, $t=(1, 2, \cdots, n)$. Initial weight of each value is $1/n$. Then, it can calculate the average value of this sequence $\bar{x}=\sum_{t=1}^{n} x_{it}/n$ and the standard deviation $\sigma=\sqrt{\frac{\sum_{t=1}^{n}(x_t-\bar{x})^2}{n}}$. (2) Standardized processing. We conduct standardized processing of decision-making data sequence using the average value and variance in step (1), get the new sequence α_t, and $\alpha_t=\frac{x_t-\bar{x}}{n}$, then $\alpha=(\alpha_1, \alpha_2, \cdots, \alpha_t)$. (3) Using generally accepted standard normal distribution density function $\beta_t=\varphi(\alpha_t)=\frac{1}{\sqrt{12\pi}}e^{-\frac{\alpha_t^2}{2}}$ to calculate the density function value corresponding to α_t. (4) For calculated $\beta_1, \beta_2, \cdots, \beta_t$, conduct standardized processing as per formula $\omega_t=\beta_t/\sum_{t1}^{n}\beta_t$, we get $\omega_, \omega_2, \cdots, \omega_t$, *i. e.* the calculated weight vector.

2.2 Steps of TOPSIS model As an overall evaluation method for limited solution multi-objective decision-making analysis in systematic project, TOPSIS can rank evaluation objects (or indexes) by advantage and disadvantage in a comprehensive, reasonable and accurate way, so it can be applied in benefit evaluation, decision-making and management fields. In this study, the evaluation objects are 17 cities, and evaluation indexes are 5 years of panel data (carbon emission economic efficiency) of these cities. The specific steps are as follows:

(1) Building the decision-making matrix. In the 5 years of evaluation indexes, 17 cities correspond to respective carbon emission economic efficiency data, and accordingly form the required decision-making matrix, as shown in Table 1.

(2) Normalized processing of decision-making matrix. The conversion formula $a_{it}=X_{it}/\sqrt{\sum_{i=1}^{n}X_{it}^2}$ (the denominator is the sum of data quadratic sum in the condition of year not changed), get the following normalized matrix:

$$A=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{nm} \end{bmatrix}$$

(3) Finding out the evaluation set of the best and worst solution in the normalized matrix:

The best solution $A^+=(a_{i1}^+ + a_{i2}^+, \cdots, a_{im}^+)$; the worst solution $A^-=(a_{i1}^+ + a_{i2}^-, \cdots, a_{im}^-)$.

(4) Calculating the distance from index value of each region to the best and worst solution. The calculation formula is as follows:

$$D_i^+=\sqrt{\sum_{i=1}^{n}(a_{it}^+ - a_{it})^2},\ D_i^+=\sqrt{\sum_{i=1}^{n}(a_{it}^- - a_{it})^2}$$

where D_i^+ and D_i^- signify the distance from the i-th evaluation object to the best solution and worst solution separately; a_{it} denotes the value of an evaluation object i in the index t.

(5) Calculating proximity or similarity. The calculation formula is $C_i=\frac{D_i^-}{D_i^+ + D_i^-}$, rank the evaluation objects as per calculation results.

(6) When correcting the time weight, the calculation formula for calculating the distance from index to the best and worst solutions should be changed to:

$$D_i^+=\sqrt{\sum_{i=1}^{n}\omega_t(a_{it}^+ - a_{it})^2} \text{ and } D_i^+=\sqrt{\sum_{i=1}^{n}\omega_t(a_{it}^- - a_{it})^2},$$

others are not changed.

3 Empirical evaluation of carbon emission economic efficiency of Shandong Province

3.1 Current situations of economic development level and carbon emission economic efficiency of Shandong Province

According to data in Shandong Statistical Information Website, in 2011, Shandong realizes GDP of 4 542.92 billion yuan, 10.9% over the previous year. The primary industry increased 4.0% (397.38 billion yuan), the secondary industry increased about 11.7% (2 403.74 billion yuan), and the tertiary industry increased 11.3% (1 741.8 billion yuan). Industrial structural adjustment moves forward steadily, and the proportion of three industries changes from 9.2:54.2:36.6 to 8.8:52.9:38.3. At the same time of economic development, Shandong Province actively regulates industrial structure, energetically develops low carbon industries, and attaches great importance to energy saving and emission reduction works, for example, it takes low carbon marine industry as key development object. Studying carbon emission economic efficiency of 17 cities in Shandong Province is of great significance to promoting economic development and energy saving and emission reduction works of Shandong Province, and can provide reference for other provinces to improve their carbon emission economic efficiency. Since the data is accessible, we select carbon emission of 17 cities of Shandong Province in 2005 – 2009 to evaluate the carbon emission economic efficiency of Shandong Province.

Take Dongying and Weihai as an example, they ranked the first in 2009, and their carbon emission economic efficiency in other years also was relatively high. However, not all regions are like this. Weifang, Ji'ning and Tai'an significantly improved their carbon emission economic efficiency in 2005 – 2009, while Laiwu has no obvious change in these years. According to the last row in Table 1, we can get the decision-making data sequence [1.009, 1.242, 1.295, 1.391, 1.452]. Each value has the weight of 1/5, the average value of the sequence is 1.28 and the standard deviation is 0.15. As per the average value and standard deviation, we can get the standardized sequence [–1.18, –0.25, –0.1, 0.74, 1.15]. Substitute it into the normal distribution density function, we can get rough weight [0.078, 0.387, 0.397, 0.303, 0.206], and the weight sequence of different years [0.06, 0.28, 0.29, 0.22, 0.15] can be obtained after normalized processing. It should be noted that the weight assignment of time is not subdivided as per regions, instead we just take all regions as a whole to distribute the weight. This is because there are few samples of "unusual data" in regions of Shandong Province in recent years, in other words, research level of most regions are close to each other.

Table 1 Current situations of carbon emission economic efficiency of Shandong Province

	2005	2006	2007	2008	2009
Ji'nan	1.079	1.303	1.366	1.461	1.544
Qingdao	1.409	1.751	1.842	1.959	2.066
Zibo	0.666	0.795	0.834	0.898	0.955
Zaozhuang	0.640	0.782	0.833	0.901	0.957
Dongying	1.558	1.987	2.083	2.249	2.380
Yantai	1.416	1.775	1.859	1.975	2.084
Weifang	0.996	1.196	1.255	1.356	1.444
Ji'ning	0.863	1.033	1.087	1.165	1.234
Tai'an	0.901	1.106	1.160	1.255	1.336
Weihai	1.463	1.758	1.841	1.979	2.102
Rizhao	0.992	1.204	1.139	1.198	0.903
Laiwu	0.301	0.352	0.371	0.407	0.435
Linyi	1.052	1.262	1.325	1.432	1.515
Dezhou	0.875	1.093	1.147	1.234	1.308
Liaocheng	0.764	0.959	0.994	1.078	1.147
Binzhou	1.007	1.293	1.347	1.460	1.545
Heze	1.179	1.460	1.530	1.645	1.738
Whole province	1.009	1.242	1.295	1.391	1.452

The above data are taken from *Shandong Statistical Yearbook* (2006 –2010).

Note: The last row is listed for assigning weight for year. It is the overall carbon emission economic efficiency of Shandong Province.

3.2 TOPSIS empirical analysis We firstly use traditional TOPSIS method (in other words, not assign weight of time) to obtain evaluation results. Then, we compare the results of traditional TOPSIS with the results after correction of time weight, to further verify credibility of TOPSIS method.

(1) Conducting normalized processing of data in Table 1, and listing results obtained from calculating $a_{it} = X_{it} / \sqrt{\sum_{i=1}^{n} X_{it}^2}$, as shown in Table 2.

(2) Determining the best and worst vectors according to Table 2. In other words, it is to select the maximum and minimum sequence from all cities. MAX sequence = [0.357, 0.369, 0.371, 0.373, 0.376], and MIN sequence = [0.069, 0.065, 0.066, 0.067, 0.069]. Then, we calculate the distance between each index value and the best and worst vectors, calculate the proximity by TOPSIS method, and rank all regions as per the proximity. The results are listed in Table 3.

Table 2 Matrix of normalized processing

	2005	2006	2007	2008	2009
Ji'nan	0.247	0.242	0.243	0.242	0.244
Qingdao	0.323	0.325	0.328	0.325	0.327
Zibo	0.153	0.148	0.148	0.149	0.151
Zaozhuang	0.147	0.145	0.148	0.149	0.151
Dongying	0.357	0.369	0.371	0.373	0.376
Yantai	0.324	0.330	0.331	0.327	0.329
Weifang	0.228	0.222	0.223	0.225	0.228
Ji'ning	0.198	0.192	0.193	0.193	0.195
Tai'an	0.206	0.205	0.206	0.208	0.211
Weihai	0.335	0.326	0.328	0.328	0.332
Rizhao	0.227	0.224	0.203	0.199	0.143
Laiwu	0.069	0.065	0.066	0.067	0.069
Linyi	0.241	0.234	0.236	0.237	0.239
Dezhou	0.200	0.202	0.204	0.205	0.207
Liaocheng	0.175	0.178	0.177	0.177	0.181
Binzhou	0.231	0.240	0.240	0.242	0.244
Heze	0.270	0.271	0.272	0.273	0.275

Table 3 TOPSIS evaluation results of carbon emission economic efficiency

Region	Best distance	Worst distance	Proximity	Order	Region	Best distance	Worst distance	Proximity	Order
Ji'nan	0.281	0.394	0.584	6	Weihai	0.092	0.587	0.865	2
Qingdao	0.098	0.578	0.855	4	Rizhao	0.388	0.303	0.436	12
Zibo	0.491	0.185	0.274	15	Laiwu	0.675	0	0	17
Zaozhuang	0.495	0.181	0.268	16	Linyi	0.295	0.381	0.564	8
Dongying	0	0.675	1	1	Dezhou	0.370	0.305	0.452	11
Yantai	0.093	0.584	0.863	3	Liaocheng	0.429	0.247	0.365	14
Weifang	0.323	0.353	0.522	9	Binzhou	0.290	0.385	0.570	7
Ji'ning	0.392	0.284	0.420	13	Heze	0.217	0.458	0.676	5
Tai'an	0.362	0.313	0.464	10					

Note: the Order column refers to regions ranked as per proximity.

(3) Analysis of carbon emission economic efficiency with correction of OWA time weight. In results of Table 3, there is no weight assignment of year, but suppose the index value of each year has consistent weight. To further verify accuracy and credibility of TOPSIS evaluation results, we assign weight to different years through OWA operator, the weight of 2005 –2009 is 0.06, 0.28, 0.29, 0.22, and 0.15 respectively (calculated as per the last column of Table 3). According to the derived time weight, we can get following rules: (i) the weight in middle section is comparatively higher, which can be proved that the weight of 2007 (0.29) is the highest; (ii) features of standard normal distribution density function determine that assignment of weight should be high in the middle and low in two sides, and the above weight sequence also conforms to such feature. Overall evaluation results of carbon emission economic efficiency by TOPSIS method after correction of OWA time weight are listed in Table 4.

From values of Table 4, we can see that they are basically consistent with results of Table 3. Only the preference proximity of Weihai and Yantai is exchanged, mainly because the carbon emission economic efficiency of Yantai in 2006 and 2007 is 1.775 and

1.859 respectively, higher than that of Weihai (1.758 and 1.841, and 2007 and 2007 are in the middle section and take up higher weight. The order ranking of other regions is totally consistent with results in Table 3, proving accuracy and credibility of overall evaluation results of TOPSIS.

Table 4 Overall evaluation results by TOPSIS method after correction of OWA time weight

Region	Best distance	Worst distance	Proximity	Order	Region	Best distance	Worst distance	Proximity	Order
Ji'nan	0.128	0.176	0.579	6	Weihai	0.043	0.262	0.859	3*
Qingdao	0.0449	0.259	0.852	4	Rizhao	0.173	0.137	0.442	12
Zibo	0.222	0.082	0.270	15	Laiwu	0.304	0	0	17
Zaozhuang	0.223	0.081	0.266	16	Linyi	0.134	0.170	0.559	8
Dongying	0	0.304	1	1	Dezhou	0.167	0.137	0.451	11
Yantai	0.042	0.263	0.862	2*	Liaocheng	0.193	0.111	0.365	14
Weifang	0.147	0.158	0.518	9	Binzhou	0.130	0.174	0.572	7
Ji'ning	0.178	0.127	0.416	13	Heze	0.099	0.206	0.675	5
Tai'an	0.164	0.140	0.461	10					

Note: * signifies change compared with Table 3.

4 Conclusions and recommendations

4.1 Analysis of evaluation results According to TOPSIS evaluation analysis and research results, we can divide carbon emission economic efficiency of 17 cities in Shandong Province into 3 levels. The first level includes Dongying, Weihai, Yantai, Qingdao, Heze, Ji'nan, Binzhou, Linyi and Weifang. These 9 regions have immense economic strength and have made significant achievement in energy saving and emission reduction and improving resource utilization efficiency, and their preference proximity exceeds 0.5. The second level has preference proximity of 0.3 – 0.5 and includes Tai'an, Dezhou, Rizhao, Ji'ning and Liaocheng. These 5 regions are in the middle of economic development in Shandong Province, their usable resources are few, technical level is low, and resource consumed by per unit of GDP is not high. The third level has preference proximity lower than 0.3. This level includes Zibo, Zaozhuang and Laiwu. These 3 regions belong to underdeveloped areas of Shandong Province. Especially Laiwu, the carbon emission economic efficiency keeps at 0.3 – 0.4. Possible reasons: (1) these areas have low GDP and belong to backward areas in Shandong Province; (2) energy saving and emission reduction efficiency of these areas is low, in other words, their economic development largely depends on development of high carbon industries, so their industrial structure is to be further optimized.

4.2 Countermeasures and recommendations Empirical research indicates that Shandong Province should learn experience of developed regions to improve its carbon emission economic efficiency. (1) From the perspective of external factor, coastal developed regions should actively bring into play their radiation function and transfer their superior industries to underdeveloped regions, to drive development of underdeveloped regions and to improve carbon emission economic efficiency of underdeveloped regions. (2) From the perspective of internal factor, underdeveloped regions, such as Zaozhuang and Laiwu, should develop suitable low carbon industries in accordance with their local conditions. In addition, they should introduce advanced production technology of Dongying and Yantai, reduce energy consumption of per unit GDP, improve their economic development, and raise the carbon emission economic efficiency. (3) Government should formulate policies favorable for economic development of underdeveloped regions. On the one hand, it should provide necessary financial support, orient towards domestic demand, drive development of inland regions, and increase GDP. On the other hand, it should encourage backward regions give full play their resource advantages, actively develop and utilize new energy, get rid of high carbon industries, and develop low carbon industries that are suitable for local situations.

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