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ARTICLE

Research on the Comprehensive Evaluation of Low Carbon Economic Development in Shandong Province Based on the Weighted Gra-topsis Method

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ABSTRACT

This paper starts from the analysis of the connotation of low-carbon economy, and establishes the evaluation index system of regional low-carbon economic development level. The main research content is to determine the index weight, judge the correlation degree and sort the decision-making units by entropy method, grey correlation analysis and TOPSIS method, and finally make a comprehensive evaluation of the low-carbon economic development level of Shandong Province. The conclusion shows that the development level of low-carbon economy in Shandong Province shows a good trend year by year, but the consumption dependence on high energy consumption resources and backward ecological benefits are increasingly becoming the bottleneck of the development of low-carbon economy in Shandong Province.

1. Introduction

In recent years, the global climate is deteriorating, and energy supply such as oil is constantly in crisis under the influence of political, military and other factors. Under such a large international background, all countries are looking for new development opportunities. Among them, the development of low-carbon economy is one of the consensuses of governments. China has a large population, rich resources but limited per capita, so the government has always attached great importance to the choice of economic development path. In 2015, the Fifth Plenary Session of the 18th CPC Central Committee clearly proposed the low-carbon development of economy. However, from the perspective of data statistics, China's carbon emissions have been high in recent years. Therefore, it is very urgent for China's economic development to realize the low-carbon transformation and form an efficient low-carbon production mode as soon as possible.

Shandong Province is a strong coastal economic province, with a GDP of 7.27 trillion yuan in 2017, an increase of 7.4% over the previous year, accounting for 8.79% of the total GDP of the country, ranking the third among all provinces, whose economic level has an important impact on the national economic development. The rapid economic growth has increased the demand for energy. In 2016, primary energy consumption in Shandong province accounted for 8.94% of the total national consumption. This proportion is higher than the GDP of Shandong Province. The total energy production of the province in that year was 140.208 million tons of standard coal, which was close to 2.76 times of the total production. In

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the energy consumption structure of Shandong Province, coal energy has a high proportion. According to the data in 2016, the proportion of coal in the total energy consumption reached 77%, 14 percentage points higher than the national average. The high imbalance between energy supply and energy consumption makes it a strategic choice for economic development of Shandong Province to take the road of low-carbon economy under the severe background. In 2016, the 13th five-year plan of Shandong Province clearly proposed to carry out energy transformation and upgrading, taking low-carbon economic work as the strategic focus of future regional economic work.

Based on this, this paper analyzes the development of low-carbon economy in Shandong Province from the aspects of economic output, energy consumption, low-carbon technology, and then extensively investigates the key index data in its development. Through the index system, the comprehensive evaluation of its low-carbon economy level is carried out. The evaluation conclusion can provide reference for the development of low-carbon economy in Shandong Province and other coastal areas. So, what is the development status of Shandong Province's high-yield GDP and low-carbon economy? How to improve the ability of low-carbon economic development in Shandong Province? Based on the above background, this paper hopes to carry out relevant research on this issue on the basis of extensive data research.

Scholars have carried out relevant research on the development of China's low-carbon economy. Although the time is short, the research results are very rich. Through literature review, we found that the evaluation methods are generally divided into two categories: one is based on the total factor productivity theory, using DEA model-based efficiency evaluation. Wu Qi (2009) established a DEA energy efficiency evaluation model that can deal with unexpected output. The main contribution is to put environmental efficiency into the energy efficiency research framework [1]. Based on the meta frontier theory, Wu Qiaosheng (2016) incorporated the unexpected output of SO_2 emission into the DEA model, compared and analyzed the regional differences of total factor energy efficiency of urban agglomerations in the middle reaches of the Yangtze River from 2005 to 2014, and then studied the decomposition of energy inefficiency and the real and potential energy intensity[2]; Chen Xiaohong (2017) integrated the dual objectives of GDP growth and CO_2 emission control. Standard, using sbm-dea method to build a dynamic planning model, and calculate the low-carbon economic development efficiency and carbon emission reduction potential of 30 provinces in China[3]. The advantage of this method is that it is not affected by subjective factors. The disadvantage of this method is that the random interference term is regarded as an efficiency factor, which makes the reliability of the results questioned. The other is the comprehensive evaluation of low-carbon development. The steps are as follows: first, set up a low-carbon economic development target system guided by sustainable development, which should be a multi-level evaluation index system covering economy, energy, environment and other aspects. Secondly, the mathematical decision-making evaluation model is introduced to integrate different indicators, and then the evaluation results are obtained. Fu Jiafeng (2010) proposed an evaluation index system based on five dimensions of low-carbon output, low-carbon consumption, low-carbon resources, low-carbon policies and low-carbon environment, and studied the development potential[4]; Qu Xiaoe (2013) first introduced the people's living indicators in the study of the development level of low-carbon economy in Shaanxi Province, and made a horizontal comparison between the situation of Shanxi Province and the national average[5]; Li With economic development as the core, Yunyan (2016) used the fuzzy comprehensive evaluation method to process the low-carbon development indicators of domestic municipalities directly under the central government, and obtained the evaluation results and predicted the low-carbon development trend[6]. There is a deficiency in this method. The index integration in the comprehensive evaluation research needs expert opinion and has certain subjectivity.

By summarizing the previous research results and synthesizing the advantages and disadvantages of various methods, this paper adopts the comprehensive evaluation model based on Entropy Weight Grey Relation TOPSIS. The steps are as follows: first, use entropy weight method to determine the weight; second, calculate the ideal value of relevant indicators; third, use grey correlation analysis to judge the closeness; fourth, use TOPSIS analysis method to calculate the closeness of each evaluation unit to the ideal scheme; fifth, rank the evaluation units according to the front calculation. This comprehensive evaluation method avoids subjectivity and enhances the credibility of results. Make the evaluation result more scientific and reasonable.

2. Current Situation of Energy Consumption and Carbon Emission in Shandong Province

2.1 Description of the Current Situation of Energy Consumption in Shandong Province

The remarkable feature of low-carbon economy is that the energy consumption per unit output and carbon emission

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are declining[7]. As a major economic province in China, Shandong is also one of the regions with the largest energy consumption in China. In 2016, the total primary energy consumption of Shandong Province reached 387.228 million tons of standard coal, and the total terminal energy consumption reached 371.603 million tons of standard coal. Since 2011, the annual energy consumption of Shandong Province has been relatively stable, with an average annual growth rate of about 3%, which is in the forefront of the country. From the perspective of energy consumption structure, the disposable energy consumption in Shandong Province mainly includes raw coal, crude oil, natural gas, electricity, etc. Among them, raw coal accounts for the highest share of energy consumption in Shandong Province. In 2013, the share of raw coal consumption accounted for 79.74% of the total consumption, and the proportion has been maintained at about 80% since 2013. Until 2016, the proportion dropped significantly, becoming 76.87%, indicating that the relevant low-carbon measures in Shandong Province have been slightly effective, but the proportion is still much higher than the national average level. The consumption proportion of crude oil energy in Shandong Province has been relatively stable, maintained at about 16%, which was 16.27% in 2016, but the total consumption of crude oil energy is also increasing year by year. Natural gas, electric power and other renewable energy are the future energy advocated by Shandong Province. The total consumption and consumption proportion have increased year by year. The consumption proportion of natural gas has increased from 2.8% in 2011 to 3.39% in 2016, while the consumption proportion of electric power and other energy has increased from 0.1% in 2011 3to 1.87% in 2016. The change of the data reflects the policy orientation of energy consumption in Shandong Province. In the long run, with the development of solar energy technology and bio power generation technology, electric power and other renewable low-carbon energy will gradually replace the share of raw coal and crude oil in the energy consumption of Shandong Province. At the same time, Shandong Province has a high proportion of heavy industry and chemical industry in the development of industrial structure, and these industries have a very high energy consumption system; moreover, Shandong Province's economic growth and life rhythm are extremely rapid; these aspects make Shandong Province's problems of high energy consumption, high pollution and high emission more serious than other provinces[12].

2.2 The Current Situation of Carbon Emission in Shandong Province

As an authoritative organization of low-carbon economic research, the Intergovernmental Panel on climate change pointed out in its research report that the large use of fossil fuels is the main reason for the increase of carbon emissions[8]. Therefore, the calculation of carbon emissions in academic circles generally focuses on the calculation of energy consumption. In this study, the carbon emission of Shandong Province is calculated by multiplying the consumption of coal, oil and natural gas by their respective coefficients. The formula is as follows:

$$E = \sum_i E_i = \sum_i \frac{C_i}{C} * \frac{E_i}{C_i} * C = \sum_i R_i * Coe_i * C$$

In the above formula, E is represents the total carbon emission (ton); E_I represents the carbon emission (ton) of class I energy; C represents the total energy consumption (ton of standard coal); C_I represents the consumption of class I energy (ton of standard coal); R_I represents the proportion of class I energy (%); Coe_i represents the emission coefficient (ton / ton of standard coal) of class I energy, and the carbon emission coefficient given by IPCC is shown in Table 1 below.

Table 1. Emission coefficients of different energy sources (IPCC)[7]

Energy types	Raw coal	Crude oil	Natural gas	Electricity
Discharge coefficient	0.7559	0.5857	0.4483	0

Shandong Province's economic development is in the forefront of the country, industrialization, urbanization level is constantly improving. In this process, the consumption of resources is huge, environmental degradation and other issues become more and more important. Shandong Province is a province with large energy consumption and carbon emission. According to the calculation, the total carbon emission of Shandong Province increased from 25591 million tons to 310.7 million tons in 2011-2016, with an average annual growth rate of 4.28%; the per capita carbon emission increased from 1012 tons to 1.215 tons (according to the Shandong Statistical Yearbook published in 2017). In terms of energy types, coal still accounts for the majority of total carbon emissions in Shandong Province; in 2016, the total consumption of raw coal and crude oil in Shandong Province reached 93.04%, while raw coal and crude oil are recognized as high carbon emission energy[1]. Therefore, Shandong Province faces great challenges in emission reduction. Of course, although the current carbon emission of Shandong Province is quite considerable, we should also see that with the development of new energy and the wide use of new technologies, the carbon emission is greatly reduced, and

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we still have the ability to achieve the target mentioned in the 12th Five Year Plan, the carbon emission per unit GDP by 2020 is 20% lower than that in 2015[9].

3. Establish a Comprehensive Evaluation Index System and Model for Low-Carbon Economy

3.1 Comprehensive Evaluation Index System

Comprehensive and balanced consideration of low-carbon development in economy, resources, environment, technology and other aspects is the core to judge the level of low-carbon economic development in a country or region [10]. The index system should not only consider the widely accepted and used indexes in the current theory and practice, but also consider the economic development status of countries or regions, reflecting their work for the transition to a low-carbon economy. Based on the above considerations, this study establishes a comprehensive evaluation index system of low-carbon economy from three levels: target level, criterion level and index level. The target layer should reflect the idea of sustainable development and the degree of low-carbon economic development to be achieved under the guidance of the idea; the criteria layer includes four levels: low-carbon economic indicators, low-carbon energy indicators, low-carbon ecological indicators and low-carbon technical indicators; in different criteria layers, indicators are selected around their objectives, and then the specific indicators are selected by the expert group, a total of 20. The index system fully refers to the previous research conclusions, which can comprehensively reflect the intensity and trend of regional low-carbon economic development, and can also be used for the horizontal comparison of regional low-carbon development with other regions, so it has strong theoretical and practical value. (see Table 2 for relevant indicators)

3.1.1 Indicators Reflecting Low Carbon Economy

Sustainable development is the strategic goal of low-carbon economic development. This index covers six indexes: GDP per capita describes the absolute level of economic development; GDP growth describes the relative level of economic development, which measures the current situation of economic development from different perspectives; industrial structure is measured by the proportion of tertiary industry in this study to reflect the mode of economic growth; carbon productivity is measured by the output value of carbon emission per unit to reflect the efficiency of energy consumption. Urbanization index reflects people's life style; Engel coefficient is used to measure people's living affluence and represents the consumption structure of non-industrial groups.

3.1.2 Indicators Reflecting Low Carbon Energy

Energy utilization will directly affect the level of carbon emissions, so this study uses low-carbon energy indicators to measure the energy utilization of a region, and then determines the implementation effect of low-carbon economy. Specifically, it includes six indicators: the total energy consumption describes the total amount of various energy consumed by the material and non-material sectors in Shandong Province, measured in 10000 tons of standard coal; the proportion of coal consumption is listed separately because the utilization rate of coal is not high, the pollution is serious, and it is the main energy in Shandong Province; the proportion of renewable energy consumption is the relative level of zero carbon energy consumption, among which the renewable energy consumption accounts for the relative level of zero carbon energy consumption. Energy mainly refers to electric power and other energy sources; energy carbon emission coefficient reflects the difference of energy consumption structure in different regions as a whole; energy conversion rate refers to the economic output per unit energy consumption, which measures energy consumption efficiency; per capita carbon emission reflects per capita consumption of carbon emission quantity, which can more directly measure regional emission level.

3.1.3 Indicators Reflecting Low Carbon Ecology

This study used low-carbon ecological indicators to measure regional ecological quality outcomes. The indicator is measured by four small indicators: smoke (powder) dust emissions are used to measure the environmental damage of industrial pollutants. The direct result of dust pollution is that the number of haze days will increase; forest and green land are carbon absorbers and converters, with high forest coverage, indicating that the stronger the area's ability to absorb and store carbon dioxide, that is, the higher the area's carbon sink capacity; per capita afforestation area reflects the human initiative to promote the transition to a low-carbon economy initiative The higher the indicator, the more efforts are made; in the current situation of resource shortage, the recycling of industrial solid waste can take into account the dual objectives of economy and ecology. The higher the utilization rate, the greater the potential for sustainable economic development. The probability of a successful implementation of a low carbon economy is greater.

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Table 2. Evaluation index system of regional low carbon economic development

Arget layer	Criterion layer	Index layer	Code	Index Interpretation	Direction of action
Evaluation index system of regional low carbon economic development	Low carbon economic indicators	GDP per capita	A1	Yuan / person	P
		GDP growth	A2	%	P
		Industrial structure	A3	%, proportion of tertiary industry	P
		Carbon productivity	A4	10000 yuan / ton, output value per unit of carbon emission	P
		Urbanization level	A5	%, proportion of urban population	P
		Engel coefficient	A6	%Food expenditure as a proportion of total consumption expenditure	N
	Low carbon energy indicators	Total energy consumption	B1	Ten thousand tons standard coal	N
		Proportion of coal consumption	B2	%	N
		Proportion of renewable energy consumption	B3	%, Electricity and other energy accounts for the proportion of total energy consumption	P
		Energy carbon emission coefficient	B4	Tons / ton of standard coal, carbon emissions as a proportion of total energy consumption	N
		Energy conversion rate	B5	10000 yuan / ton of standard coal, output value generated by unit energy consumption	P
		Per capita carbon emissions	B6	Tons / person	N
	Low carbon ecological indicators	Smoke (powder) dust emission	C1	Ten thousand tons	N
		forest coverage	C2	%	P
		Afforestation area per capita	C3	Hectare / 10000 people, average annual afforestation area per person	P
		Effective utilization rate of industrial solid waste	C4	%	P
	Low carbon technical indicators	R&D investment rate	D1	%R&D expenditure of Enterprises above Designated Size accounts for the proportion of GDP	P
		Patent authorization	D2	Ten thousand, and the number of valid patents approved in that year	P
		Proportion of low carbon technology input	D3	%The proportion of the total investment in fixed assets of the information industry, financial industry and scientific research service industry in the current year	P
		Number of employees in scientific research and technology industry	D4	10000 people, annual equivalent of R&D personnel in Enterprises above Designated Size	P

Notes: P indicates a positive relationship between this index and the evaluation effect; N indicates a negative relationship between this index and the evaluation effect.

3.1.4 Indicators Reflecting Low Carbon Technology

This study uses low-carbon technology indicators to measure the technical conditions for the implementation of low-carbon economy, which determine the development potential and speed of low-carbon economy in the region. There are four detailed indicators: the first indicator is the investment rate of R&D funds, which reflects the potential of regional technological innovation; the second indicator is the amount of patent authorization, which reflects the reserve of low-carbon technology, and patents are more competitive, which shows the achievements in the process of transition to a low-carbon economy; the third indicator is the proportion of fixed assets investment in low-carbon industry in the year, China's total investment. There are many types of industries in the Yearbook, among which the technology industry with zero carbon emission and its development promoting the implementation of low-carbon economy is selected. In this paper, it is classified as low-carbon industry, mainly including information technology industry, financial industry and science and technology service industry. The annual fixed asset investment proportion of low-carbon industry reflects the government's attention to the transformation of low-carbon economy. The larger the proportion is, the stronger the regional low-carbon innovation ability is; the fourth indicator is the number of practitioners in the scientific research and technology industry, which is the driving force of low-carbon technology research and development. The more the number is, the higher the success rate of low-carbon technology adoption is.

3.2 Model Establishment

It is assumed that there are m evaluation units $A_i, i \in M = \{1,2,...m\}$ in the low-carbon econom-

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ic evaluation system, including n evaluation indexes $F_j, j \in N = \{1,2,...n\}$. Set the evaluation matrix as $X = (x_{ij})_{m*n}$, where x_{ij} is the attribute value of the i-th evaluation unit under the j-th index. Then the evaluation steps based on Entropy Weight Grey Relation TOPSIS are as follows:

3.2.1 Determine the Normalization Matrix

Because of the difference in dimension, order of magnitude and positive and negative orientation of each index, the range method is used to normalize the obtained original data, and the standard matrix is set as $Y = (y_{ij})_{m*n}$.

For positive indicators:

$$y_{ij} = [x_{ij} - \min_i(x_{ij})] / [\max_i(x_{ij}) - \min_i(x_{ij})]$$

For negative indicators:

$$y_{ij} = [\max_i(x_{ij}) - x_{ij}] / [\max_i(x_{ij}) - \min_i(x_{ij})]$$

3.2.2 Measuring Positive and Negative Ideal Values

According to the entropy weight method, the index weight $w = (w_1, w_2, ..., w_n)$; furthermore, the normalized decision matrix of the weight can be defined as $Z = (z_{ij})_{m*n}$, in which $z_{ij} = w * y_{ij}, i \in M, j \in N$, the positive and negative ideal solutions of the weighted normalized matrix can be determined after further data analysis.

$$Z^+ = (z_1^+, z_2^+, ..., z_n^+), Z^- = (z_1^-, z_2^-, ... z_n^-)$$

in which

$$z_j^+ = \max_i(z_{ij}) = w_j, Z^- = (z_1^-, z_2^-, ... z_n^-).$$

3.2.3 Calculate the Grey Correlation Degree

In each evaluation index, the grey correlation coefficient matrix between the actual value and the ideal value can be obtained after calculation. The correlation matrix of positive ideal solution and negative ideal solution can be defined as $R^+ = (r_{ij}^+)_{m*n}$, $R^- = (r_{ij}^-)_{m*n}$ where:

$$r_{ij}^+ = [\min|z_j^+ - z_{ij}| + \rho\max|z_j^+ - z_{ij}|] / [|z_j^+ - z_{ij}| + \rho\max|z_j^+ - z_{ij}|] = \rho w_j / (w_j - z_{ij} + \rho w_j)$$

$$r_{ij}^- = [\min|z_j^- - z_{ij}| + \rho\max|z_j^- - z_{ij}|] / [|z_j^- - z_{ij}| + \rho\max|z_j^- - z_{ij}|] = \rho w_j / (z_{ij} + \rho w_j)$$

In the above formula, $\rho \in (0,\infty)$ is the resolution coefficient between the actual value and the ideal solution; the value of ρ is inversely proportional to the resolution, and the normal value range is (0, 1). In actual operation, the value can be taken according to the specific situation, generally $\rho = 0.5$.

Then calculate the grey correlation degree between each evaluation index and positive and negative ideal solution: $r_i^+ = \sum_{j=1}^{n} r_{ij}^+ / n$, $r_i^- = \sum_{j=1}^{n} r_{ij}^- / n$.

3.2.4 Analyze the Distance Between Evaluation Scheme and Ideal Scheme

The Euclidean distance between the real correlation degree of each evaluation index and the positive and negative ideal solutions was calculated d_i^+, d_i^-:

$$d_i^+ = \sqrt{\sum_{j=1}^{n} (z_{ij} - z_j^+)^2}, d_i^- = \sqrt{\sum_{j=1}^{n} (z_{ij} - z_j^-)^2}$$

Dimensionless treatment is made for the correlation degree r_{ij}^+, r_{ij}^- and the Euclidean distance d_i^+, d_i^- respectively:

$$R_i^+ = r_i^+ / \max r_i^+, R_i^- = r_i^- / \max r_i^-$$

$$; D_i^+ = d_i^+ / \max d_i^+, D_i^- = d_i^- / \max d_i^-;$$

Then, combining the Euclidean distance and the correlation degree, we get the following results:

$$S_i^+ = \alpha R_i^+ + \beta D_i^-, S_i^- = \alpha R_i^- + \beta D_i^+ \quad i \in M,$$

Where α and β reflect the evaluator's preference for position and shape, and $\alpha, \beta \in [0,1]$, $\alpha + \beta = 1$. Decision makers can determine α and α values according to their preferences. S_i^+ synthetically reflects the approach degree of evaluation index and ideal scheme, and the higher the value is, the better the scheme degree is; S_i^- synthetically reflects the distance degree between evaluation index and ideal scheme, and the higher the value is, the worse the scheme degree is.

3.2.5 Calculate the Relative Closeness of Each Scheme and Get the Evaluation Value

The relative closeness of each scheme can be calculat-

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ed as $C_i^+ = S_i^+ / (S_i^+ + S_i^-)$, $i \in M$. The calculated value of relative closeness is directly proportional to the evaluation effect, that is, the greater the value, the better the effect, and the better the evaluation effect of the scheme; otherwise, the less ideal the effect[11] .

4. An Empirical Analysis of the Development of Low Carbon Economy in Shandong Province

The above-mentioned comprehensive evaluation index system and evaluation model are used to analyze the situation of Shandong Province in 2012-2016. (see Table 3 for calculation results)

Table 3. Shandong Province' evaluation index data of low carbon economy (2012-2016)

Unit	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4
2012	53943.51	8.20	47.30	4.46	67.40	36.90	24080.97	46.4	20.1	53.15
2013	58694.84	8.50	48.83	4.65	67.76	35.00	24930.93	46.4	20.0	53.86
2014	63231.86	7.80	48.99	5.12	68.00	34.30	25636.29	43.7	22.9	51.67
2015	67114.53	8.00	50.61	5.58	68.71	34.50	25662.31	42.7	24.1	50.83
2016	72290.25	7.50	52.59	5.95	69.20	34.18	27157.91	39.7	25.6	49.23
Unit	B5	B6	C1	C2	C3	C4	D1	D2	D3	D4
2012	2.37	1.28	32.8	57.7	10.15	84.62	2.08	153598	2.84	62.91
2013	2.51	1.26	35.4	58.2	13.06	84.98	2.31	170430	2.40	65.24
2014	2.65	1.24	45	58.69	14.13	96.37	2.39	179953	2.67	67.62
2015	2.84	1.20	34.8	58.88	36.99	90.98	2.47	241176	2.72	68.02
2016	2.98	1.22	28.2	58.98	27.78	87.42	2.53	259032	2.52	73.52

Data sources: Shandong Statistical Yearbook (2011-2016).

Entropy weight method is a kind of objective weight method with mature principle. The weight is calculated according to relevant information. The specific calculation process is as follows: Let the entropy of the j-th index be $H_j = -k\sum_{i=1}^{m} f_{ij} \ln f_{ij}$, where $H_j = -k\sum_{i=1}^{m} f_{ij} \ln f_{ij}$, $k = 1/\ln n$ (assuming $f_{ij} = 0$ is $f_{ij} \ln f_{ij} = 0$), then the entropy weight of the j-th index is $w_j = (1 - H_j)/(n - \sum_{j=1}^{n} H_j)$. The weight value of each evaluation index after calculation is shown in Table 4.

Table 4. Shandong Province's weight table of low carbon economic evaluation indexes (2012-2016)

index	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4
weight	0.0668	0.0428	0.0503	0.0525	0.0451	0.0389	0.0651	0.0531	0.0485	0.0502
index	B5	B6	C1	C2	C3	C4	D1	D2	D3	D4
weight	0.0360	0.0407	0.0609	0.0547	0.0323	0.0683	0.0456	0.0422	0.0701	0.0359

From the information given in the above table, we can draw the conclusion that there is little difference in the weight of indicators; after ranking, we can find that indicators D3 (proportion of low-carbon technology input), C4 (effective utilization rate of industrial solid waste), A1 (GDP per capita), B1 (total energy consumption) have relatively large weight values, which are 7.01%, 6.83%, 6.68% and 6.51% respectively, indicating the level of low-carbon technology and carbon. Foreign exchange construction, energy endowment and human lifestyle will have a greater impact on the development of low-carbon economy.

After the weight is calculated by the entropy weight method, the grey correlation degree and Euclidean distance between the evaluation unit and the positive and negative ideal solution are calculated, and the most dimensionless treatment is carried out：

$$R^+ = \{0.6523, 0.7358, 0.8172, 0.8235, 1.0000\},$$
$$R^- = \{1.0000, 0.7726, 0.6348, 0.6703, 0.6351\},$$
$$D^+ = \{1.0000, 0.8501, 0.7086, 0.6813, 0.6052\},$$
$$D^- = \{0.5892, 0.6726, 0.7083, 0.7877, 1.0000\}$$

When α = β = 0.5, the grey correlation degree and Euclidean distance are combined to obtain:

$$S^+ = \alpha R_i^+ + \beta D_i^- = \{0.6208, 0.7042, 0.7628, 0.8056, 1.0000\},$$
$$S^- = \alpha R_i^- + \beta D_i^+ = \{1.0000, 0.8114, 0.6717, 0.6758, 0.6202\}$$

According to the proximity degree formula, the following equation can be calculated:

$$C^+ = \{0.3830, 0.4646, 0.5318, 0.5438, 0.6172\}$$

The criterion for the closeness evaluation of this model is that the greater the closeness, the higher the level of low carbon development; thus, the ranking of each evaluation unit can obtain the low carbon economic development level of each year: 2012-2016.The conclusion is that the economic development of Shandong Province is changing from the traditional extensive mode of high energy con-

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sumption and high carbon emission to the mode of low energy consumption and low carbon emission. The development of low carbon economy is moving forward in a good direction with obvious progress.

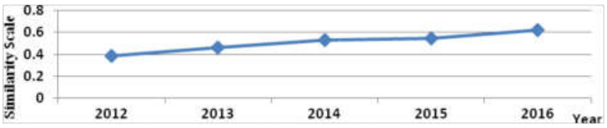

Figure 1. Shandong 'development trend of low carbon economy

5.Conclusion

This study establishes a comprehensive evaluation index system for low-carbon economy, and empirically analyzes the development of low-carbon economy in Shandong Province. The conclusions are as follows: Firstly, the development of low-carbon economy in Shandong Province is moving in a good direction and the progress is obvious. Secondly, the overall situation is still relatively backward. The energy consumption is too high, the industrial structure is unbalanced, and the low-carbon ecological benefits are poor. These low-carbon inputs have constrained the continued growth of the province's low-carbon economy and should be the focus of relevant work in Shandong Province in the future. With reference to the advantages and problems of low-carbon economic development in Shandong Province, combined with the development status of low-carbon economy in other advanced provinces and cities, this paper proposes relevant countermeasures in order to provide a reference for the better growth of Shandong's low-carbon economy and the coordinated development of other provinces.

Firstly, the government should implement effective policy guidance and establish a legal system to ensure the development of low-carbon economy. The government has issued policies and guided funds to lean towards low-carbon industries, which can be given preferential policies in tax, water, electricity, land and other aspects to ensure the steady development of low-carbon economy. At the same time, we can strictly limit the development of high energy consumption and high pollution industries and reduce emissions by means of laws. Moreover, the whole society advocates low-carbon consumption, creates a low-carbon atmosphere, enhances the public awareness of low-carbon consumption, and realizes the coordinated development of regional low-carbon economy.

Secondly, implement the low-carbon policy and ensure the input of resources. In terms of funds, ensure the implementation of various plans related to low-carbon economic development, overcome difficulties and ensure the timely availability of funds in the process of project implementation. In terms of human resources, the government can train its own excellent talents, or jointly train with scientific research institutes, enterprises and institutions to meet the needs of relevant projects for talents.

Thirdly, develop or introduce advanced low-carbon technologies and strengthen regional low-carbon technology strength. Shandong Province should make its own low-carbon technology development direction according to the sustainable development strategy. Enterprises, scientific research institutes and other organizations are encouraged to fully cooperate, actively carry out research and development and strive to promote demonstration application projects by taking advantage of the characteristics of the organization, gradually establish a low-carbon technology system focusing on green energy technology, energy conservation and emission reduction technology, and provide support for high-quality economic development.

Fourthly, strengthen the promotion of low-carbon economy and promote exchanges and cooperation between regions. The government is an important force to promote the development of a low-carbon economy, but the development of a low-carbon economy requires full participation, using the Internet, television, self-media, newspapers and other media to do a good job of propaganda, so that the masses can recognize the importance of tackling climate change. In addition, the current low-carbon economy development has become the consistent goal of development in various regions. In order to develop a low-carbon economy more efficiently, it is necessary to strengthen cooperation and exchanges between provinces and actively learn the mature measures and measures of advanced provinces, with a view to provide valuable experience for low carbon economy development in our province.

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