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ORIGINAL RESEARCH ARTICLE

Quality evaluation of low carbon ecological city based on development stage—Take Shandong Province as an example

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ABSTRACT

Aiming at the problems existing in the current evaluation of low-carbon ecological city, based on the comprehensive interpretation of the scientific law of the development of low-carbon ecological city, this paper distinguishes the path index and evaluation index, constructs the evaluation index system of low-carbon ecological city according to the evaluation index, adopts the quadrant method, establishes a set of technical methods for the evaluation of low-carbon ecological city based on the development law and development stage, and makes an empirical analysis with Shandong Province as an example. The results show that Shandong has crossed the peak of the inverted U-shaped curve of carbon emission intensity, but it is still in the rising period on the left of per capita carbon emission and total carbon emission; According to the situation of each city, there are 10 cities of high-carbon development type. Most cities have entered the critical period of low-carbon ecological transformation and development. The high low-carbon index of some cities has a great relationship with the low level of economic development, and they are in the primary development stage of low-carbon and low economy.

Keywords: low carbon ecological city; index system; quality evaluation; Shandong Province

1. Introduction

Accelerating the transformation of cities to low-carbon ecology is an important way to deal with global climate change. In the practical experience of low-carbon ecological city construction at home and abroad, it has gradually become a consensus to lead the construction of low-carbon ecological city with index system. At present, the research on low-carbon eco city index system at home and abroad mainly focuses on eco city index system, low-carbon city index system, low-carbon economy index system, low-carbon competitiveness, etc. The United Nations has proposed six evaluation criteria for eco-cities. The “Eco-Province, Eco-City, and Eco-County Construction Indicators” formulated by the former State Environmental Protection Administration includes 22 indicators in three consists of 22 control indicators (quantitative) and 4 guiding indicators (qualitative), and the Tangshan Caofeidian International Eco-City indicator system consists of 141 indicators, which are divided into two sub-systems: management indicator system and planning indicator system[1].

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In the construction of most indicator systems, the proportion of added value of the tertiary industry and the ownership of public transport vehicles by 10,000 people are taken as the evaluation indicators to measure the degree of “low carbon” between cities. Zhang, Wen, et al. designed an index system for the sustainable development of China’s eco city from the perspectives of economics, ecology and socio-political science[2]. On the basis, the qualitative and quantitative information of expert consultation was used to construct the evaluation index system of Yangzhou Eco-City[3]. Chang et al.[4] constructed an ecological city index system in terms of vitality, organization and resilience, and proposed the standard values and evaluation methods for each index factor. In terms of low-carbon city indicator system research, in 2010, the Chinese Academy of Social Sciences announced the first standard system for evaluating low-carbon cities, including 12 items in four categories, including low-carbon productivity, low-carbon consumption, low-carbon resources, and low-carbon policies relative indicators. Tan[5] divided the low-carbon city evaluation index system into three levels and 13 indicators, and gave a comprehensive evaluation from the generation, processing and final results of carbon emissions. Zhang[6] and Shao[7] constructed a low-carbon city construction and evaluation index system based on the model principle of “driving force-pressure-state-influence-response”. In the research of low-carbon economy index system, Liang [8] proposed a regional low-carbon economy development index system based on the model of “support-input-response-output”. Tang[9] used the AHP and K-means clustering method to construct a set of evaluation index system for the development level of low-carbon economy at the provincial scale in China. Based on fuzzy rough set theory, Xie[10] constructed a low-carbon economic development evaluation index system and model including five aspects: Economic system, technical system, social system, energy consumption and emission system, and environmental system. In terms of research on low-carbon competitiveness index system, Li[11] constructed an inter-provincial low-carbon economic competitiveness evaluation index system on the basis of exploring the connotation of low-carbon economic competitiveness, including low-carbon basic competitiveness and low-carbon efficiency competitiveness. 20 specific indicators in three aspects: Low-carbon potential competitiveness. Zhang[12] constructed a low-carbon competitiveness evaluation system from four aspects: Low-carbon energy, low-carbon industry, low-carbon output, and low-carbon environment based on the concept of low-carbon competitiveness.

Overall, the research on the index system of low-carbon ecological city has made important progress and made important contributions to guiding and leading the construction of low-carbon ecological city. However, most studies confuse path indicators and level indicators in the selection of indicators, which affects the fairness and scientificity of the evaluation. In the construction of most indicator systems, the proportion of added value of the tertiary industry and the ownership of public transport vehicles by 10,000 people are taken as the evaluation indicators to measure the degree of “low carbon” between cities. The higher the value, the higher the degree of low carbon. However, most of these indicators are path indicators rather than horizontal indicators for the construction of low-carbon ecological cities. Taking the proportion of added value of tertiary industry as an example, from the perspective of a single city, increasing the proportion of service industry and reducing the proportion of industry or secondary industry is undoubtedly an effective measure to reduce carbon. However, from the perspective of horizontal comparison, it is obviously unfair to measure the low-carbon development level by the proportion of added value of the tertiary industry. For example, in 2010, the energy consumption of RMB 10,000 GDP in Shanghai and Dongying City was 712 tons of standard coal and 742 tons of standard coal respectively, with little difference, but the proportion of added value of tertiary industry in the same period was 57.3% and 23.7% respectively, with a wide gap. Taking 17 districts and cities in Shandong Province in 2010 as a sample, the correlation coefficient between the energy consumption of RMB 10,000 GDP and the proportion of added value of the tertiary industry is only -0.169, with little correlation. There is no significant relationship between the low-carbon industrial structure and the level of urban ecological development. Therefore, there is no scientific evaluation of the proportion of low-carbon industries, and there is no significant relationship between the low-carbon industrial structure and the level of urban ecological development. Secondly, in the evaluation method, the periodicity of low-carbon ecological city is ignored. Low carbon is the product of economic and social development to a certain stage. In the early stage of urban development, due to the weak industrial foundation and low carbon emission intensity, it is in a low-level low-carbon development stage. With the continuous development of industry, the extensive urban development model is gradually emerging, and the carbon emission intensity will be significantly improved. When the city develops to a certain stage, especially technological and management innovation will gradually reduce the urban carbon emission intensity. Therefore, the evaluation of low-carbon ecological city must consider the phased characteristics of low-carbon. However, most current studies ignore this problem and simply measure the low-carbon development level by the level of carbon emission.

In order to make up for the defects of the above research, this paper attempts to build scientific and reasonable horizontal indicators, innovate relevant evaluation methods, and scientifically evaluate the development level of low-carbon ecological city in combination with the urban development stage on the basis of distinguishing path indicators and horizontal indicators.

2. Scientific basis of low-carbon ecological city evaluation

2.1. Empirical study on the relationship between carbon emission and economic development stage

As mentioned above, there are three "inverted U-shaped" curve peaks in the evolution of the relationship between economic development and carbon emission in a country or region, that is, the evolution process needs to go through the inverted U-shaped curve peak of carbon emission intensity, the inverted U-shaped curve peak of per capita carbon emission and the inverted U-shaped curve peak of total carbon emission. According to the three "inverted U" curve laws of carbon emission, the evolution process of carbon emission can be divided into four stages, namely, the stage before the peak of carbon emission intensity, the stage from the peak of carbon emission intensity to the peak of per capita carbon emission, the stage from the peak of per capita carbon emission to the peak of total carbon emission, and the stage of stable decline of total carbon emission. Research shows that the peak of carbon emission intensity is relatively easy to span, while it is difficult to span the peak of per capita carbon emission and the peak of total carbon emission[13]. To this end, we use the relevant data of Shandong Province for empirical analysis, as shown in **Figure 1** and **Figure 2**. Overall, Shandong Province has crossed the peak of the inverted U-shaped curve of carbon emission intensity, but it is still in the rising period on the left of per capita carbon emission and total carbon emission, which is the most basic scientific basis for the evaluation of green and low-carbon cities and towns in Shandong Province.

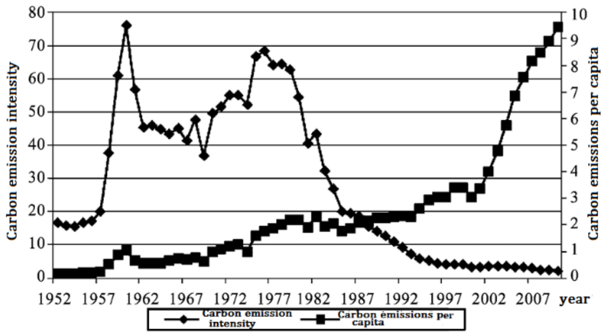

Figure 1. Schematic diagram of the evolution of carbon emission intensity and per capita carbon emission in Shandong Province since 1952.

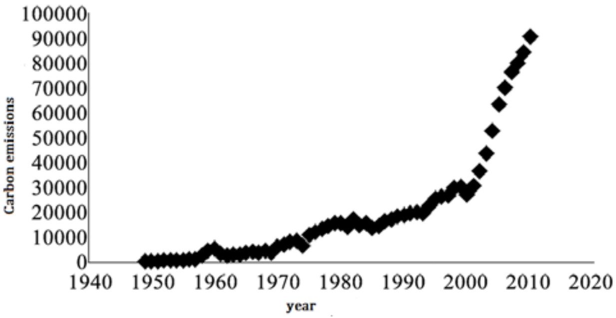

Figure 2. Evolution of total carbon emissions in Shandong Province since 1952.

2.2. Empirical analysis of industrial structure and green and low carbon

Industrial structure adjustment is an effective way to realize urban green and low-carbon transformation. Most scholars have confirmed that industrial structure adjustment has a significant impact on reducing carbon emission intensity[14,15] and total carbon emission[16]. Especially from the perspective of a single city, adjusting the industrial structure and increasing the proportion of the tertiary industry is obviously an effective way and means to reduce carbon emissions. Taking Shandong Province as an example, since 1952, with the continuous upgrading and improvement of industrial structure, the carbon emission intensity has been declining. The scatter diagram of the two indicators is constructed by using the proportion of added value of the tertiary industry in 1952 and 2010 and the carbon emission intensity index of RMB 10,000 GDP. The results show that there is a significant negative correlation between the two indicators, that is, with the continuous development of the tertiary industry, the carbon emission intensity shows a gradual downward trend, as shown in **Figure 3**.

However, the industrial structure index is an indirect index to measure the development level of green and low-carbon cities and towns, which needs to have a significant linear correlation with the development level of green and low-carbon cities and towns. However, from the cross-sectional data, this is not the case. The scatter diagram of the proportion of tertiary industry added value and carbon emission intensity index of 17 cities in Shandong Province (**Figure 4**) shows that there is no significant correlation between them, and the correlation coefficient is only -0.169.

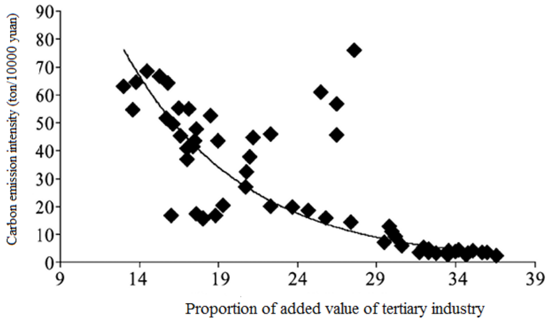

Figure 3. Relationship between the proportion of tertiary industry and carbon emission intensity in Shandong Province in 1952 and 2010.

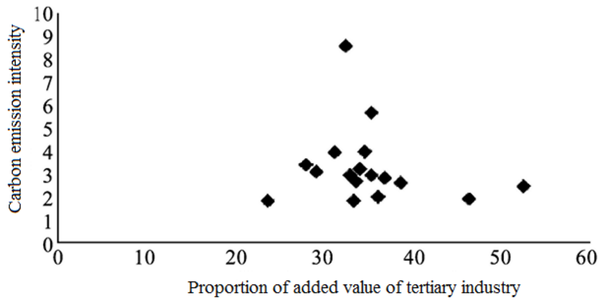

Figure 4. Scatter chart of tertiary industry proportion and carbon emission intensity in 17 districts and cities of Shandong Province in 2010.

In general, industrial structure adjustment is an effective way to reduce carbon emissions, but it is not a scientific index to measure the level of urban green and low-carbon development. The differences between urban individuals lead to different levels of industrial structure, and the carbon emission level may converge. There is no significant linear relationship between the level of industrial structure and carbon emission level.

2.3. Technology rebound effect of energy consumption

Khazzoom pointed out for the first time that the improvement of energy efficiency does not necessarily lead to the decline of energy demand. The improvement of energy efficiency may lead to the increase of energy services, so that the actual reduction of energy consumption is not in the same proportion with the reduction of energy consumption per unit of energy services[17]. Brookes believes that the improvement of energy efficiency will lead to economic growth, which in turn will increase energy consumption[18]. That is, when the real energy price remains unchanged, the improvement of energy efficiency caused by technological progress will increase rather than reduce energy consumption. This is the rebound effect of energy consumption, that is, technological progress leads to the improvement of energy efficiency, but the benefits brought by technological progress will cause individual behavioral reactions in the economy, so that the potential energy savings generated by technological progress can not be fully realized[19]. The rebound effect of technology has forced us to re-examine and reflect on the impact of technological progress on green low-carbon cities and towns, reminding us that we should not only take technological progress and improving energy efficiency as the only way to realize urban low-carbon ecological development, especially when evaluating the development level of green low-carbon cities and towns, we should carefully select relevant indicators of technological progress. The evaluation of the development level of green low-carbon cities and towns should not be limited to the relatively low-carbon level such as carbon emission intensity, but also pay attention to the absolute low-carbon indicators such as total carbon emission.

3. Construction of evaluation index system of low-carbon ecological city

3.1. Construction of low carbon ecological index database

Referring to the relevant research results of index systems such as ecological city, low-carbon city and green city at home and abroad, classify and list the indicators in the existing index system results, exclude the repeated and similar indicators, and build the existing green and low-carbon index set. The indicator set contains 137 indicators, covering the research results of indicator systems related to low-carbon ecology in 15 regions and cities at home and abroad. Combined with the actual situation of Shandong, the research group repeatedly discussed 137 specific indicators and solicited the opinions of relevant experts, selected 67 indicators with high frequency, and abandoned indicators with high similarity and certain repeatability. Retain more advanced indicators that represent future development trends. Through the internal discussion of the research group, expert discussion, sending e-mail and other forms to solicit the opinions and suggestions of relevant experts in various fields, and through statistics and discussion, the index database of low-carbon ecological city is finally established.

3.2. Screening and optimization of evaluation indicators

Primary selection of evaluation indicators

According to the above research, first distinguish the path indicators and evaluation indicators, and determine that there is a deterministic linear relationship between the alternative evaluation indicators and the evaluation objectives, so as to ensure the scientificity and accuracy of the evaluation. Secondly, according to the essential connotation of low-carbon ecological city, deeply study the basic requirements of various systems of low-carbon ecological city, and select the indicators that can best reflect the essential connotation and development trend of low-carbon ecological city according to the construction principle of quality evaluation index system, so that the selected indicators can represent the comprehensive development level of a certain field and fundamentally reduce the number of indicators. Third, carry out expert consultation. After the preliminary selection of low-carbon ecological city evaluation indicators, widely solicit the opinions of experts from all aspects on the scientificity, integrity and operability of the indicators, and further adjust and optimize the preliminarily established index system according to the opinions of experts. Through the above three steps, the screening of the evaluation index system of low-carbon ecological city has been basically completed.

Optimization of evaluation indicators

Based on the preliminary selection of indicators, the evaluation index system of low-carbon ecological city is optimized by quantitative method. First, distinguish the inspection index. The low-carbon ecological city quality evaluation system requires that each index should have a high degree of discrimination. If there is no difference between the evaluation objects, it will not play any role in the evaluation results, so it is impossible to judge the advantages and disadvantages of each evaluation object. The coefficient of variation method is used to test the differentiation of indicators. Indicators with small coefficient of variation and low degree of differentiation can be deleted directly. In the study, some data of Shandong Province in 2010 are used to calculate the coefficient of variation of each primary index, and the indexes with coefficient of variation less than 0.4 and obvious insufficient discrimination are deleted. Secondly, check the "redundancy" of indicators. In order to eliminate the duplication between indicators and ensure the independence of indicators and the simplification of the indicator system, the correlation coefficient between indicators is calculated, the correlation coefficient greater than 0.95 is defined as true correlation, and the best of the true correlation indicators is selected as the evaluation index. Through the above steps and methods, the index system of low-carbon ecological city is preliminarily selected and optimized, and the evaluation index system of low-carbon ecological city is formed. See **Table 1** for details.

Table 1. Evaluation index system of low carbon ecological city

Primary index	Secondary index	Serial number	Tertiary indicators	Unit	Weight (%)
Low carbon ecological city	Carbon emission	1	Elasticity coefficient of carbon emission growth	%	10.18
		2	RMB 10,000 GDP carbon emission	Ton/RMB 10,000	18.35
		3	Per capita carbon emissions	Tons of carbon dioxide	12.52
	Carbon sink	4	Forest coverage	%	9.01
		5	Per capita park green space area	m^2	5.20
	Resource environment	6	RMB10,000 GDP water intake	m^3	8.26
		7	RMB10,000 GDP emission of major pollutants	kg/RMB 10,000	8.78
		8	Rate of air in good quality	%	8.81
		9	Harmless treatment rate of domestic waste	%	9.47
		10	Centralized treatment rate of sewage treatment plant	%	9.42

4. Quality evaluation method of low-carbon ecological city

According to the basic scientific basis of low-carbon eco city evaluation, reasonably determine the weight of evaluation indicators, select appropriate data standardization methods, incorporate the economic development stage into the low-carbon eco city evaluation according to the relationship between low-carbon and economic development, and conduct the low-carbon eco city evaluation based on the economic development stage and level, so as to evaluate the low-carbon eco city more scientifically and objectively and enhance the practical guidance.

4.1. Determination of evaluation index weight

The methods of index weighting mainly include subjective weighting, objective weighting and combined weighting based on the two. Considering the advantages and disadvantages of subjective, objective and combined weighting methods, the research group believes that analytic hierarchy process is more suitable to determine the weight of low-carbon ecological city quality evaluation indicators. Analytic hierarchy process has the following advantages. 1) Combination of qualitative and quantitative. 2) Can digitize the evaluation thinking process of complex system. c. It has strong logic, practicability and systematicness. Using this method to determine the weight of each index can not only fully absorb and learn from the opinions of relevant experts and decision makers in the field of low-carbon ecology, but also avoid the subjective randomness of other subjective weighting methods to the greatest extent, ensure the scientificity of weight determination, and play a correct guiding role in the construction of low-carbon ecological city. According to the evaluation index system of low-carbon ecological city, build a judgment matrix, and invite experts inside and outside the province to judge the relative importance of each index by using the 5/5–9/1 grading scale method (as shown in **Table 2**). Check the consistency of the judgment matrix and finally calculate the weight of each index, as shown in **Table 1**.

Table 2. Proportional scale of importance comparison of two elements in judgment matrix

Value meaning	5/5–9/1 grading scale
The two elements are of equal importance	5/5 = 1
Compared with the two elements, the former is slightly more important than the latter	6/4 = 1.5
Compared with the two elements, the former is obviously more important than the latter	7/3 = 2.333
The former is more important than the latter	8/2 = 4
Compared with the two elements, the former is extremely important than the latter	9/1 = 9
Represents the intermediate value of the above adjacent judgment	6.5/3.5, 5.5/4.5, 7.5/2.5, 8.5/1.5
If the importance ratio of element *i* to element *j* is m, then the importance ratio of element *j* to element *i* is	1/*m*

4.2. Determination of evaluation model

Comprehensive evaluation model of low-carbon ecological city

Since low-carbon ecology is the product of urban development to a certain stage, and at the same time, the relationship between low-carbon development level and economic development conforms to the law of inverted U curve, the scientificity and accuracy of evaluation only with low-carbon ecological city index are affected, so it is necessary to make a comprehensive evaluation with two indicators of low-carbon ecological index and economic development stage. Therefore, the quadrant method is used for comprehensive evaluation, that is, the horizontal axis represents the level or stage of economic development, expressed in per capita GDP, the vertical axis represents the low-carbon development level, and expressed in urban low-carbon ecological index. There is an obvious inverted U-shaped curve relationship between carbon emissions and per capita GDP in developed countries, and the income level corresponding to the inflection point of the inverted U-shaped curve is basically about US $3,000 per capita GDP (the price in 1990). Considering the price factor, we choose the origin of the coordinate axis at US $5,000 per capita GDP and the zero point of the low-carbon ecological index. Thus, four quadrants can be formed and correspond to different levels of low-carbon ecological development. The first quadrant is high economic and low carbon, the second quadrant is high economic and high carbon, the third quadrant is low economic and high carbon, and the fourth quadrant is low economic and low carbon, as shown in **Figure 5**. Generally speaking, the development of low-carbon cities generally goes through four development stages: Low economic and low-carbon, low economic and high-carbon, high economic and high-carbon and high economic and low-carbon. Therefore, in the same quadrant, it is sorted according to the low-carbon development level.

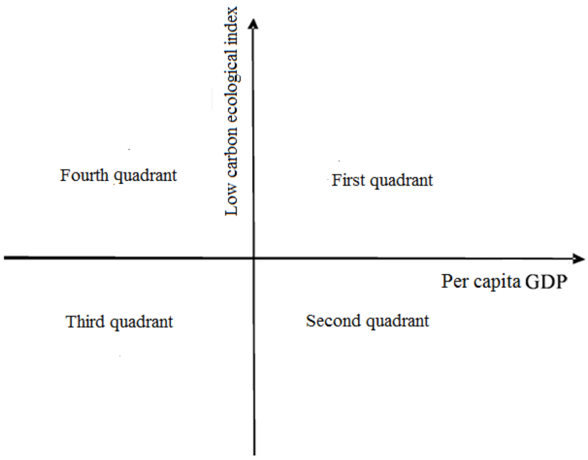

Figure 5. Quadrant diagram of low carbon ecological city evaluation.

Low carbon ecological index synthesis model

In multi-index comprehensive evaluation, synthesis refers to combining the evaluation values of multiple indexes on different aspects of things through a certain formula to obtain an overall evaluation. The comprehensive evaluation models of multi index synthesis mainly include the following types: Weighted linear sum method, multiplication synthesis method, addition and multiplication mixed method, substitution method, principal component analysis method[20,21].

Based on the analysis of the advantages and disadvantages of various evaluation models, the research group believes that the weighted linear sum method can fully highlight the role of weight, so as to give play to the guiding role of evaluation results, and the existing linear compensation problem of evaluation results can also be solved to a great extent through data standardization processing. It is a more suitable method for low-carbon ecological city quality evaluation.

The calculation formula of low carbon city ecological index is:

$$y = \sum_{i=1}^{n} w_i x_i \tag{1}$$

Where y is the urban low-carbon ecological index, w_i is the weight of index i, x_i is the standardized value of index i, and n is the number of evaluation indicators.

Raw data processing

Data standardization is the core of data preprocessing. It is a method to eliminate the dimensional influence of the original index through mathematical transformation. It can be divided into linear and nonlinear, of which linear method is the most widely used. The commonly used linear dimensionless forms include the following: standardized treatment method, extreme value treatment method, exponential standardization method, normalization treatment method, and efficacy coefficient method[22]. Since the four quadrant method is adopted for the overall evaluation, the characteristic of standard deviation standardization is that the sample mean value is 0, and the standardized data are distributed on both sides of 0, which is convenient for us to set the origin of the quadrant. Therefore, the standard deviation standardization method is used to dimensionless process the original data.

As follows, for positive indicators:

$$x'_{ij} = \frac{x_{ij} - \bar{x}_j}{s_j} \tag{2}$$

For negative indicators:

First of all, the indicators shall be consistent. To convert a negative indicator into a positive indicator:

$$x^* = \frac{1}{x} \tag{3}$$

Secondly, dimensionless processing.

$$X'_{ij} = \frac{X^*_{ij} - \bar{X}^*_j}{S_j} \quad (4)$$

Where $\bar{x}_j, s_j (j = 1,2,\cdots,m)$ are the (sample) average value and (sample) mean square deviation of the j-th index observation value respectively, which x_{ij} are the actual observation x'_{ij} value and the standardized value.

5. Evaluation on the development quality of low-carbon ecological city in Shandong Province

5.1. Quality evaluation results

Using the relevant data of 17 cities in Shandong Province in 2010, according to the above low-carbon ecological city evaluation index system and quality evaluation method, calculate the low-carbon development index of each city. The results are shown in **Table 3**. Combined with the level of economic development, the quadrant method is used for analysis and evaluation, and the results are shown in **Figure 6**.

Table 3. List of low carbon ecological development index of Shandong Province and 17 cities in 2010

City	Low carbon ecological development index	GDP per capita (USD)
Shandong Province	-0.28	6,072
Jinan City	-0.06	8,560
Qingdao	0.61	9,722
Zibo City	-0.23	9,363
Fengzhuang City	-0.66	5,439
Dongying City	0.15	17,195
Yantai City	0.88	9,196
Weifang City	0.32	5,061
Jining City	-0.31	4,659
Tai'an City	0.25	5,521
Weihai City	0.88	10,220
Rizhao City	-0.14	5,447
Laiwu	-0.45	6,262
Linyi City	0.33	3,555
Dezhou City	-0.12	4,411
Liaocheng	-0.04	4,202
Binzhou City	-0.43	6,152
Heze	-0.71	2,191

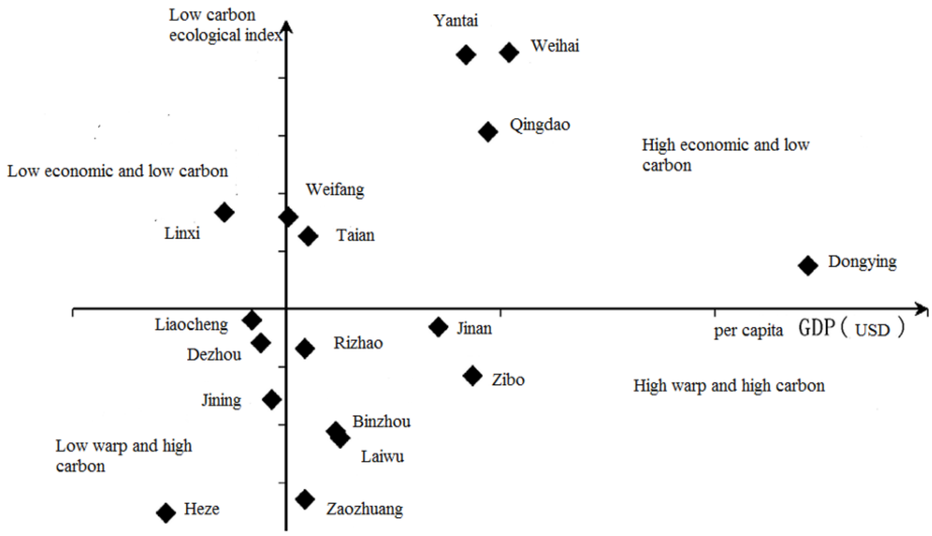

Figure 5. Evaluation results of low carbon ecological development level of 17 districts and cities in Shandong Province in 2010.

5.2. Development pattern of low-carbon ecological cities in the province

According to the evaluation results, the development level of low-carbon ecological cities in the province can be divided into four types:

First, high economic and low-carbon types, including Weihai, Yantai, Qingdao, Weifang, Tai'an and Dongying, are mainly distributed in the eastern coastal areas, with a per capita GDP of more than US $5,000 and a low-carbon eco city index of more than

0.15, representing the high level of low-carbon eco city development in our province. On the whole, these cities have crossed the peak of the inverted U-shaped curve of carbon emission intensity. In recent years, the carbon emission intensity has gradually decreased, and the carbon emission level is in the lead in the province. For example, the energy consumption per unit of GDP of Yantai, Dongying and Qingdao has fallen below 8 tons of standard coal, ranking the top three in the province; The water intake of RMB 10,000 GDP in Qingdao and Weihai has decreased to less than 20 cubic meters, and the resource utilization rate is high. The ecological construction of such cities has achieved remarkable results at the same time. For example, the harmless treatment rate of domestic waste in the six cities has reached 100%, and the good rate of air quality is more than 90%. In the next step, these cities should gradually cross the peak of the inverted U-shaped curve of per capita carbon emission while continuing to lead the province's low-carbon ecological construction and reduce the intensity of carbon emission.

Second, there are high economic and high carbon types, including Jinan, Rizhao, Zibo, Binzhou, Laiwu and Zaozhuang. The per capita GDP of these cities has exceeded US $5,000. Entering a new development period, the characteristics of high-carbon development are still very obvious. Except Jinan, the energy consumption of RMB 10,000 GDP of other cities is higher than the average level of the whole province, of which Laiwu is the highest, reaching 351 tons of standard coal. In terms of per capita carbon emission, all six cities are higher than the average level of the whole province, Laiwu and Zibo have 1,476 and 1,022 tons of carbon dioxide respectively. Therefore, in the future, while maintaining appropriate economic development, such cities should focus on improving resource and energy utilization, reducing carbon emission intensity, and actively leap in the direction of high economy and low carbon.

Third, low economic and high carbon types, including Liaocheng, Dezhou, Jining and Heze, are mainly distributed in the western region of our province. These cities are underdeveloped areas of our province. There is an obvious gap between economic development and the eastern coast, the level of industrialization and urbanization is not high, the economic and social development model is still extensive, the utilization efficiency of resources and energy is not high, and the energy consumption of RMB 10,000 GDP of the four cities is between 12–14 tons of standard coal. However, the per capita carbon emission intensity is significantly lower than the average level of the eastern coastal areas and the whole province. Therefore, the four cities will face the pressure of double increase of carbon emission intensity and per capita carbon emission in the future.

Fourth, low economy and low carbon, which represents the city of Linyi. Generally speaking, the development type of low economy and low carbon corresponds to cities with a per capita GDP of less than US $3,000. From the situation of the whole province, basically all 17 cities in our province have entered more than US $3,000, especially Linyi has reached US $3,555. Therefore, Linyi, as a low economy and low carbon type, is a special case in our province, indicating that Linyi attaches great importance to resource conservation and environment-friendly construction in the process of development and tries to avoid repeating the old road of pollution first and treatment later. It has laid a solid foundation for realizing low-carbon ecological development in the next step. But at the same time, we should also be soberly aware that Linyi is in a period of rapid development of industrialization and urbanization, and the rapid economic development needs a large space for carbon emission. The key in the future is to coordinate the relationship between economic development and low-carbon ecological construction. We should not affect economic and social development because of the excessive pursuit of low-carbon, but we should not waste the current good situation of low-carbon ecological construction.

Overall, the characteristics of urban high-carbon development in our province are still obvious. From the situation of the whole province and 17 cities, the total carbon emission of our province still shows an accelerated increasing trend. The growth elasticity coefficient of carbon emission of all 17 cities in the province is greater than 1, indicating that the carbon emission of all cities showed an increasing trend in 2010, which is larger than that in 2009. Among them, Heze is the highest, reaching 159, with the largest growth rate. Therefore, at present, the focus of low-carbon ecological construction in our province is still relative decoupling development rather than absolute decoupling development. From the perspective of the whole province, our province is still in the development stage of high economy and high carbon. From the perspective of 17 districts and cities, there are 10 cities of high carbon development type, accounting for 58.8% of all districts and cities. Secondly, most cities in our province have entered a critical period of low-carbon ecological transformation and development. The per capita GDP of 12 cities divided into districts in our province has reached more than US $5,000, entering a key transition period of development of US $5,000 and US $10,000. This period is both a period of major development opportunities and a period of frequent contradictions. If handled properly, we can quickly cross the US $10,000 mark. If handled improperly, we may fall into the trap of middle-income countries and face the severe challenge of low-carbon ecological construction. According to the evaluation results, half of the 12 cities have not achieved obvious results in low-carbon ecological construction after crossing the US $5,000 mark, and are still in an obvious high-carbon development stage, and the pressure of decoupling development is still great.

6. Conclusions

The construction of low-carbon ecological city is a long-term systematic project, which requires long-term scientific monitoring and evaluation of its construction effect. The evaluation of the development level of low-carbon ecological city must be based on its own development law. There are three inverted U-shaped curve laws in the development of low-carbon ecological city, which is not a simple linear relationship. The development of low-carbon ecological evaluation must be based on this scientific fact. Simply focusing on the investigation of low-carbon ecological development level and ignoring the evaluation of specific development stages may lead to wrong conclusions. Secondly, the selection of evaluation indicators for low-carbon ecological cities must reflect fairness. In some studies, the fairness of indicator selection is simply understood as the selection of relative indicators without in-depth analysis and research, which is easy to cause the illusion of fairness. Only paying attention to vertical fairness and ignoring horizontal fairness will also lead to the unfairness of evaluation results. The index fairness must achieve vertical and horizontal fairness.

Conflict of interest

The authors declare no conflict of interest.

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