Carbon Emission and Sustainable Development of the city Coupling in Shandong Province

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Abstract: Based on the three-stage DEA model, the carbon emission efficiency of 17 prefectures and cities in Shandong province from 2005 to 2016 was measured, and the carbon emission efficiency was further decomposed into 7 three-level indicators including carbon emission efficiency and carbon emission status, so as to further build a coupled and coordinated evaluation system for regional carbon emission and sustainable development. The results show that the coordination degree of the three synergetic coupling degrees in Shandong province is on the rise. In terms of region, the coupling coordination degree of the eastern coastal cities led by Qingdao and Yantai are relatively high, while the mid-western inland cities, such as Jining city, Dezhou city, Liaocheng city, are relatively low.

1. Introduction
For now, the coordinated analysis of energy consumption and coupling mechanism at home and abroad mainly includes the following aspects: ①Coupling of carbon emissions and urbanization. Niu Honglei (2018) found that the energy structure of Jiangsu has been improved, but it is difficult to get fundamental changes in the short term. The acceleration of urbanization has brought great pressure on carbon emission growth [1]. ②Coupling of carbon emissions and economic development. Li Tao (2013) estimated the economic efficiency and carbon environmental efficiency of 29 provinces in China from 1998 to 2010, and integrated them in a unified joint efficiency framework to measure the coupling degree between carbon emissions and economic growth. The policy has achieved a "level effect" of significant efficiency improvement [2]. ③Coupling of environmental protection, carbon emissions and economic development. Fu Qiang (2017) conducted a study on the two-way coupling relationship between environmental pollution and economic growth, energy consumption, FDI and urbanization. The study found that the dynamic relationship of five variables is the most significant among carbon emissions, and economic growth, energy consumption and urbanization. There is a significant two-way coupling relationship with pollutant emissions [3]-[4]. ④For the choice of the measurement method of carbon emission efficiency, You Heyuan (2010) calculated the land-use carbon emissions of the total efficiency, technology efficiency, scale efficiency and scale efficiency based on input-oriented CCR and BCC models[5]-[7].

2. Research methods and data sources

2.1 Calculation of carbon emissions
There is no official data on carbon dioxide emissions. The current mainstream method in which is based on the calculation methods of IPCC (2006). This paper learns previous research methods of carbon emissions. Formula for calculating carbon dioxide emissions from fossil energy combustion:

$$FEC = \sum_{i=1}^{n} FE_{i} = \sum_{i=1}^{n} FE_{i} \times CF_{i} \times CC_{i} \times COF_{i} \times \frac{24}{12} \quad (1)$$

In the formula (1), $FEC$ is the total amount of carbon dioxide emissions in Shandong Province; $FE_{i}$ is the consumption of i-th energy in each city of Shandong Province; $CF_{i}$ is the calorific value of i-th energy; $CC_{i}$ is the fossil energy-bearing carbon corresponding to i-th energy Amount; $COF_{i}$ is an oxidation facto.

The amount of carbon dioxide emitted during cement production is that:

$$CC = EF_{j} \times Q_{c} \quad (2)$$

$EF_{j}$ is the carbon dioxide emission coefficient when cement is produced, and $Q_{c}$ is the production quantity of cement.

2.2. Measurement of carbon emission efficiency - three-stage DEA model

This paper uses a three-stage DEA model that filters out exogenous factors to measure carbon emission efficiency, and the results are relatively objective.

The first stage: using the traditional DEA model to measure the efficiency, this paper chooses to use the DEA-BBC model in the first stage. The DEA-BCC model is constructed based on the modified DEA-CCR model, and calculates the efficiency value of the decision-making unit considering the variable scale returns.

The second stage: In order to further improve the accuracy of the calculation, after the first stage of measurement, this paper use the SFA model to calculate the management inefficiency of the decision-making unit. The SFA model can eliminate environmental factors and random error factors, improve the estimation reliability for the third stage DEA calculation, and make the results more objective.

The third stage: after removing the influence of environmental factors and random factors, continue to first stage, to obtain new efficiency results, using the information contained in the slack variable, the efficiency results at this time have excluded the role of the environment and random factors, and can calculate the actual objective efficiency value.

2.3. Coupling model

Carbon emissions and sustainable development have an interactive effect. Therefore, the principle of capacity coupling in physics can be used to conduct coupling analysis between the two. The degree of coupling is $C$, and its function expression is:

$$C = \left\{ \frac{SD(x)CE(y)}{\|SD(x)\|+\|CE(y)\|} \right\}^{1/i} \quad (3)$$

In the above formula, $SD(x)$ is the sustainable efficiency value, $CE(y)$ is the carbon emission efficiency value, $C$=1, indicating that the system is in optimal coupling, and $C$=0 indicate that the various elements within the system are irrelevant.

2.4. Variables and data sources

2.4.1. Indicators for measuring carbon emission efficiency

The emission factors of various energy and products in this cultural stone fuel and industrial production process are derived from the values published by the IPCC, and are converted into standard coal according to the “Reference Coefficient of Various Energy Standard Coals” given in the 2008 China Energy Statistical Yearbook. The raw data of energy emissions and the raw data of input and output of each city are derived from the Statistical Yearbook of Shandong Province in 2005-2016 and the statistical yearbooks of various cities.
2.4.2. Indicators of carbon emissions and sustainable development
Based on the research mechanism of carbon emission and sustainable development and the reference of the relevant research results, this paper calculates the carbon emission comprehensive index from the current situation of carbon emission efficiency and carbon emission using six indicators; this paper uses 17 indicators to measure the level of environmental composite index from the aspect of economic sustainability, ecological sustainability and social livelihood from a continuous perspective. The main indicators of the two major systems are shown in Table 1.

| First indicators   | Secondary indicators          | Third indicators                         | Power  |
|--------------------|--------------------------------|------------------------------------------|--------|
| Carbon emission    | carbon emission efficiency    | Carbon emission technology efficiency    | 0.194  |
|                    |                                | Carbon emission pure technical efficiency| 0.084  |
|                    |                                | Scale efficiency of carbon emissions     | 0.083  |
|                    | Carbon emissions status        | Per capita carbon emissions              | 0.224  |
|                    |                                | The density of carbon emissions          | 0.176  |
| Sustainable        | Economic sustainability       | The intensity of carbon emissions        | 0.240  |
| development        | GDP per capita                 |                                          |        |
|                    | the proportion of the tertiary industry in the GDP | 0.022  |
|                    | Financial expenditure on science and technology | 0.113  |
|                    | Annual Disposable Income of Urban | 0.040  |
|                    | Per capita fixed asset investment | 0.080  |
|                    | Fiscal expenditure as a proportion of GDP | 0.043  |
| Ecological         | Industrial Waste Water Discharged | 0.035  |
| sustainability     | life garbage treatment rate   |                                          |        |
|                    | Environmental expenditure     |                                          |        |
|                    | Total energy consumption      |                                          |        |
|                    | Residential power consumption |                                          |        |
|                    | electricity consumption per 10 000 GDP | 0.052  |
| Social and people's| Number of people employed at the end of the year | 0.077  |
| livelihood         | living area                   |                                          |        |
|                    | Number of beds per 10,000 people | 0.061  |
|                    | Per capita possession of public library | 0.077  |
|                    | Education expenditure as a share of fiscal expenditure | 0.118  |

The above is from the "Statistical Yearbook of Shandong Province" from 2005 to 2016 and the statistical yearbooks of various cities.

3. Empirical results

3.1. Empirical Analysis of Carbon Emission Efficiency in Shandong Province
This paper uses DEAP2.1 and Frontier4.0 software to measure the carbon emission efficiency in Shandong Province. The results are shown in Table 1. From Table 2, it can find that the carbon emission efficiency of the first phase of most cities is significantly better than the carbon emission efficiency of the third phase as a whole, when the environmental variables and other random influencing factors are not considered. It indicates that environmental factors and random factors have a significant impact on CO2 emissions in each city which means carbon emission has decreased after taking out environment variable.

Through Table 2, it can find that the carbon emission efficiency of the traditional industrial cities changes a lot after the environmental factors and random factors are removed which carbon emission efficiency of these cities declines in the third state. After these environmental factors removing, the changes of Eastern coastal cities are relatively stable. Comparing the result of the first stage, this paper found that the carbon emission efficiency of the third stage consistent with the actual situation in Shandong Province.

Table 2. Carbon emission efficiency measurement results of the first and third stages of each city in Shandong province from 2005 to 2016

| Cities      | The results of the first stage DEA (2005-2016 mean) | The results of the third stage DEA (2005-2016 mean) |
|-------------|-----------------------------------------------------|---------------------------------------------------|
|             | TE        | PTE     | SE        | TE        | PTE     | SE      |
| Jinan City  | 0.853     | 0.908   | 0.941     | 0.844     | 0.907   | 0.929   |
| Qingdao City| 1.000     | 1.000   | 1.000     | 1.000     | 1.000   | 1.000   |
| Zibo City   | 0.644     | 0.869   | 0.742     | 0.476     | 0.610   | 0.773   |
| Zaozhuang City | 0.343     | 0.536   | 0.630     | 0.334     | 0.535   | 0.624   |
| Dongying City | 1.000     | 1.000   | 1.000     | 0.887     | 0.979   | 0.906   |
| Weifang     | 0.847     | 0.967   | 0.877     | 0.817     | 0.944   | 0.869   |
| Yantai      | 0.711     | 0.757   | 0.948     | 0.680     | 0.725   | 0.939   |
| Jining City | 0.472     | 0.658   | 0.733     | 0.442     | 0.742   | 0.593   |
| Tai'an City | 0.518     | 0.704   | 0.736     | 0.540     | 0.705   | 0.766   |
| Weihai      | 0.954     | 0.971   | 0.983     | 0.995     | 0.997   | 0.998   |
| Rizhao City | 0.668     | 0.733   | 0.928     | 0.548     | 0.595   | 0.920   |
| Laiwu City  | 0.584     | 0.746   | 0.782     | 0.530     | 0.731   | 0.725   |
| Linyi City  | 0.582     | 0.734   | 0.792     | 0.565     | 0.695   | 0.820   |
| Dezhou City | 0.587     | 0.708   | 0.839     | 0.548     | 0.694   | 0.790   |
| Liaocheng   | 0.527     | 0.647   | 0.838     | 0.495     | 0.626   | 0.791   |
| Binzhou City| 0.576     | 0.680   | 0.862     | 0.520     | 0.677   | 0.769   |
| Heze City   | 0.622     | 0.794   | 0.784     | 0.577     | 0.730   | 0.790   |

3.2. The analysis of Coupling coordination

According to formulas (3), this paper calculated the coupling degree of carbon emission and sustainable development in 17 cities of Shandong Province from 2005 to 2016. Referring to the relevant scholars [8], the degree is divided into ten levels. According to the results of calculation, this paper gets the map of the coupling and coordination of carbon emissions and sustainable development in Shandong Province in 2005, 2011 and 2016. The degree of coupling coordination in various cities and counties in Shandong Province has been improved to varying degrees from the Figure 1. And the fastest is the Qingdao city. Qingdao has been in a stable development momentum in recent years. The slowest is in Tai'an City. In 2005-2016, the coupling degree only increased by 0.082. From the spatial dimension: the degree of coordination in the east is
high, the degree of inland coupling coordination in the central and western regions is low, and the degree of polarization is deepened.

![Figure 1. Coupled and coordinated spatial distribution of carbon emission and sustainable development in Shandong province in 2005, 2011 and 2016](image)

It can be seen that the degree of coupling coordination of the northeastern part of Shandong Province as the core, Qingdao Yantai, is better than other cities. And the radiation belts of these two cities are also stronger. The coupling coordination degree of Jinan, Weihai, Weifang and Zibo is at an intermediate level. In, the regional GDP of these cities is above the average. However, there is still room for improvement in the rational use and exploitation of resources. For the cities of Dezhou, Heze Laiwu, Jining, Zaozhuang and other cities, the degree of coupling coordination is lower than the average level. These cities are located in the inland areas of the central and western parts of Shandong Province. The energy consumption of the cities is high, while the economic development level of several other cities is low. The coupling and development potential of these cities is great.

4. Conclusion

This paper measures the carbon emission efficiency of various cities in Shandong Province from 2005 to 2016 through three-stage DEA. After the influence of environmental factors and random errors is proposed, the carbon emission efficiency of Shandong Province has responded. After constructing the binary coupling coordination model of carbon emission and sustainable development in Shandong Province, it can find that the degree of binary coupling in various regions of Shandong Province shows an upward trend, but there are gaps in coupling coordination in each region. It is mainly characterized by higher coastal cities in the east and lower inland cities in the central and western regions. The results prove that the carbon emission efficiency based on the three-stage DEA model is applied to the coupling coordination model, which is consistent with the actual situation in Shandong Province and has high credibility.

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