Analysis of coupling coordination degree between transportation and carbon emission in Beijing-Tianjin-Hebei region

Yuliang Cao, Fei Qu*
Tianjin University of Technology, Tianjin 300384, China

*Corresponding author e-mail: qufei@tjpu.edu.cn

Abstract. Under the background of China's energy conservation and emissions reduction pressure increasing, the Beijing-Tianjin-Hebei region have sharp contradiction in the economic development and energy consumption, transportation is important in the development of the national economy industry, is one of the biggest, the energy consumption of the carbon emissions of the second largest industry, the development of transportation will inevitably increase carbon emissions, for the transportation and the coordinated development of the carbon emissions. In this paper, the coupling coordination degree of the two was measured. Based on the data of Beijing-Tianjin-Hebei region from 2011 to 2018, the coupling model was used to measure the coupling coordination degree of the transportation system and the carbon emission system.Finally, it is concluded that the coupling coordination degree between transport and carbon emissions is the highest in Beijing, and the coupling coordination degree in Beijing-Tianjin-Hebei region is at the primary level or above. The variation trend of the coupling coordination degree in Beijing-Tianjin-Hebei region is firstly increased and then decreased, and there is a strong interaction between the two systems.

1. Introduction
With the acceleration of urbanization and rapid economic development in China, the industrial structure dominated by heavy chemical industry and the energy consumption structure dominated by petrochemical energy, such as coal, the pressure of carbon emission reduction is increasing in China.In recent years, China's carbon emissions rank first in the world, exceeding the combined emissions of the United States and the European Union [1].In order to actively deal with global climate change, China has made a commitment to the international community to reduce carbon emission intensity by 45% and 60% to 65% in 2020 and 2030, respectively, compared with 2005, and to "achieve national carbon emission peak by 2030" [2].The Beijing-Tianjin-Hebei region is one of the regions with the most dynamic economy and the largest population in China, which plays a very important role in China's development strategy.Data in 2018 showed that the GDP of the Beijing-Tianjin-Hebei region reached 8.5 trillion yuan, accounting for 9.44 percent of the country's total.However, there is a sharp contradiction between economic development and resource consumption in Beijing-Tianjin-Hebei region.With iron and steel, chemical industry, building materials and automobile as the main industries, the Beijing-Tianjin-Hebei region is a major heavy industry base in China, which leads to the region becoming one of the regions with the highest energy consumption intensity and the most serious air...
pollution in China \[3\]. These energy consumption leads to excessive carbon emissions, which leads to environmental problems. As an important industry in the development of national economy, the transportation industry accounts for the largest proportion of carbon emissions and the second largest industry in energy consumption, the development of transportation is bound to aggravate carbon emissions and lead to the destruction of the ecological environment. Therefore, in order to coordinate the development of transportation and carbon emissions, the coupling coordination degree of transportation and carbon emissions should be calculated. Based on the data of Beijing-Tianjin-Hebei region from 2011 to 2018, this paper calculates the coupling coordination degree between the transportation system and the carbon emission system by using the coupling model.

2. Data and Methods

2.1. Data sources
The research data in this paper are limited to 2011-2018, and the data are from China Energy Statistical Yearbook and the statistical Yearbook of Beijing, Tianjin and Hebei Province.

2.2. Index system
Based on the coupling between carbon emissions and transportation combined with the related research results, in the transportation system, from transport supply and demand of transportation energy efficiency three aspects selected 8 rating indicators, because of the air transport and pipeline transport data acquisition is difficult, and a smaller effect on carbon emissions, not be considered. In the carbon emission system, seven evaluation indexes are selected from the two aspects of carbon emission quantity and carbon emission efficiency. Therefore, the comprehensive evaluation system of transportation and carbon emission is constructed, as shown in Table 1.

| System                  | First level indicator | Secondary indicators | The index type | System                  | First level indicator | Secondary indicators | The index type |
|-------------------------|-----------------------|----------------------|----------------|-------------------------|-----------------------|----------------------|----------------|
| Transportation          | Transport supply      | Railway mileage      | +              | Carbon emissions        | Quantity status of carbon emissions | Carbon emissions per capita | -              |
|                         |                       | Highway mileage      | +              |                         | Emission density      | Emission intensity   | -              |
|                         |                       | Miles of inland waterways | +           |                         | Emissions intensity  |                        |                |
|                         | Transport demand      | Passenger traffic    | +              | Carbon emissions        | Carbon productivity   |                        | +              |
|                         |                       | Passenger turnover   | +              |                         | Comprehensive technical efficiency |                        | +              |
|                         |                       | freight              | +              |                         | Pure technical efficiency |                        | +              |
|                         | Energy efficiency     | Cargo turnover       | +              | Carbon emission efficiency status | Scale efficiency |                        | +              |
|                         |                       | Energy intensity     | -              |                         |                        |                      |                |

Note: + means the bigger the better type, - means the smaller the better type; The data came from the statistical yearbook of provinces and cities, China Energy Statistical Yearbook and the statistical data of the National Bureau of Statistics.
Energy intensity refers to the energy consumption per unit of gross domestic product, that is, the ratio of standard coal consumed by the transportation industry to gross domestic product of the transportation industry; The total carbon emissions can be calculated by summing the carbon emissions of each energy source according to the energy consumption data and the carbon emission factors published by IPCC. Carbon emission = energy consumption* energy carbon emission factor

2.3. Research methods

2.3.1. Entropy method weighting. Since the addition units of each index in the original data studied are not uniform, the data should be standardized before the entropy value method is weighted. The calculation formula is as follows:

- Standardized positive index processing: \[ x_{ij} = \frac{x_{ij} - \min x_i}{\max x_i - \min x_i} \]

- Standardized reverse index processing: \[ x_{ij} = \frac{\max x_i - x_{ij}}{\max x_i - \min x_i} \]

After data standardization, the index weights of the Beijing-Tianjin-Hebei transportation system and the carbon emission system were respectively calculated by the entropy method. The specific steps are as follows:

Assuming there are \( n \) evaluation indicators, and each indicator has \( m \) samples, a matrix \( Y = (y_{ij})^{m \times n} (0 \leq i \leq m, 0 \leq j \leq n) \) is formed. \( y_{ij} \) is the \( i \) sample and the index value of the \( j \) index. The weight \( w_j \) can be obtained by the following steps:

\[ p_{ij} = y_{ij} / \sum_{i=1}^{m} y_{ij} \]

\[ e_j = -k \sum_{i=1}^{m} p_{ij} \ln p_{ij}, \quad f_j = 1 - e_j \]

\[ k = 1 / \ln m \]

\[ w_j = f_j / \sum f_i \]

After the specific index weight of the subsystem is obtained, Linear weighting method is used to measure the contribution degree of the subsystem to the total system, that is, the comprehensive evaluation index. Suppose \( X_{ij} \) is the \( j \) index of \( i \) province in the transportation system. Then the comprehensive evaluation index \( f(x_i) \) of the transportation system of \( i \) province is through the following formula:

\[ f(x_i) = \sum_{j=1}^{n} W_j \cdot X_{ij} \]

2.3.2. Coupling Model. Coupling refers to the phenomenon that two or more systems or motion forms influence each other and even collaborate through various interactions. It is a dynamic correlation relationship that is interdependent, mutually coordinated and mutually promoted under the benign interaction between subsystems [4], coupling degree describes the degree to which system elements interact with each other. In this article, \( f(x) \) and \( f(t) \) as a comprehensive evaluation index of the transportation system and carbon emission system, it can be calculated by linear weighting. \( C \) is the coupling degree, \( C \in [0, 1] \). The larger the value, the greater the degree of coupling between the systems, and the greater the degree of mutual influence between the two systems. The relationship between the transportation system and the carbon emission system is to construct the coupling degree model of the two systems as follows:
2.3.3. Coupling coordination degree model. The coupling degree subsystem cannot directly measure the coordination degree between the transportation system and the carbon emission system, so the coupling degree model is introduced to measure the interaction coordination level between transportation and carbon emissions, and the coupling degree model is further built, as shown below:

\[
D = \sqrt{C \times F(x, t)}
\]

\[
F(x, t) = af(x) + bf(t)
\]

D is coupling coordination degree; C is the coupling degree; \(F(x, t)\) is the comprehensive development evaluation index of transportation system and carbon emission system. This represents the overall synergy effect of the dual system. \(a\) and \(b\) is the undetermined coefficient, \(a+b=1\). Considering that transportation and carbon emission coordination have the same status, and the role of the same degree, Then \(a=b=0.5\).

After calculating the coupling coordination degree of the system, According to the partition standard of coupling coordination degree (Table 2), the coordination level of the two systems is determined.

| Coupling degree of compatibility C | Coordination level          | Coupling degree of compatibility C | Coordination level          |
|-----------------------------------|-----------------------------|-----------------------------------|-----------------------------|
| 0.00–0.09                         | Extreme imbalance           | 0.50–0.59                         | Barely coordination        |
| 0.10–0.19                         | Severe imbalance            | 0.60–0.69                         | Primary coordination       |
| 0.20–0.29                         | Moderate imbalance          | 0.70–0.79                         | Medium coordination        |
| 0.30–0.39                         | Mild imbalance              | 0.80–0.89                         | Well coordination          |
| 0.40–0.49                         | approximate imbalance       | 0.90–1.00                         | Quality coordination       |

2.3.4. Calculation of carbon emission efficiency. In a broad sense, carbon emission efficiency refers to the production benefit brought by unit carbon emission. Considering that the evaluation of carbon emission efficiency from the perspective of single factor is not comprehensive, it should be calculated from the perspective of total factor. DEA method can be used to evaluate the efficiency of multiple inputs and multiple outputs, which is not affected by the dimension of input and output, and is widely used in efficiency evaluation. However, the traditional DEA ignores the problem of the slack of input and output variables, and cannot deal with the problem of undesired output (carbon dioxide). Therefore, a Super-SBM model considering undesired output is constructed:

\[
\min \rho = \frac{1 - \frac{1}{m} \sum_{i=1}^{m} s_i}{1 + \frac{1}{s_1 + s_2} \left( \sum_{r=1}^{g_1} s_{r}^a + \sum_{r=1}^{g_2} s_{r}^b \right)}
\]

\[
x_{ik} = X\lambda + s^-
\]

\[
y_{rk}^a = Y^a\lambda - s^a
\]

\[
y_{tk}^b = Y^b\lambda + s^b
\]

\[
s^-, s^a, s^b, \lambda \geq 0
\]

In the formula, \(\rho\) is the carbon emission efficiency, \(s^-\) and \(s^b\) is the redundancy of input and undesired output, \(s^a\) is insufficient expected output. With labor force and energy as input variables,
regional GDP as expected output, carbon dioxide emissions as unexpected output. The labor force is the year-end number of employees in each province and city; Energy is the total amount of energy consumption; expected output GDP is adjusted to actual GDP by deflator conversion; Undesired output carbon dioxide emissions can be obtained by the method described in Section 2.2.

3. Results and analysis

3.1. Calculation and analysis of carbon emission efficiency

The comprehensive technical efficiency is a comprehensive index to indicate the efficiency of the decision making unit, which is affected by the management, technical level and scale of the decision making unit. The pure technical efficiency refers to the efficiency affected by its own management and technical level at a certain scale. The scale efficiency refers to the efficiency affected by production scale [5]. As can be seen from Figure 1, the pure technical efficiency has been hovering around 1 since 2013, and the comprehensive technical efficiency and scale efficiency are both below the pure technical efficiency. The pure technical efficiency drives the comprehensive technical efficiency, which also shows that technological progress is the key to improve the carbon emission efficiency. In the years when the pure technical efficiency declined, the scale efficiency and the comprehensive technical efficiency also showed a similar downward trend, indicating that the pure technology limited the carbon emission efficiency, and the carbon emission efficiency could be improved by improving management ability and technical level. The trend of scale efficiency is similar to that of comprehensive technical efficiency, indicating that scale efficiency limits carbon emission efficiency, and expanding scale is beneficial to the development of carbon emission.

![Fig. 1. Beijing, Tianjin and Hebei carbon emission efficiency](image)

3.2. Comprehensive level of transportation and carbon emissions

Based on the data of Beijing-Tianjin-Hebei from 2011 to 2018, the index weight was determined by the entropy weight method. The comprehensive index of the transportation system and carbon emission system of Beijing-Tianjin-Hebei from 2011 to 2018 was obtained by the formula in 2.3.1, as shown in Figure 2 and Figure 3.

As can be seen from Figure 2, from 2011 to 2016, the comprehensive index of Tianjin's transportation system was higher than that of Beijing and Hebei. In 2016, Tianjin began to decline. Beijing has been in a stage of steady rise from 2011 to 2018; Although the comprehensive level of Hebei is low, it has been rising steadily and reached a level similar to that of Tianjin in 2017 and 2018.

The comprehensive index of the carbon emission system in Beijing-Tianjin-Hebei is analyzed in Figure 3. The comprehensive index of the carbon emission system in the three regions shows a steady rising trend, with Beijing at a relatively high level, followed by Tianjin and Hebei. From 2011 to 2016, the level of Hebei and Tianjin was similar, and the change trend was almost synchronous. However, in 2017 and 2018, Hebei's carbon emission development was not as good as that of Tianjin, which had a significant gap with Tianjin. However, Tianjin has narrowed the gap with Beijing through development.
The comprehensive index of the transportation system and the carbon emission system both belong to the type of the bigger the better, that is, the bigger the comprehensive index is, the higher the development level of the transportation industry and the lower the carbon emissions, or when the benefits of the transportation industry are greater, the lower the carbon emissions. As can be seen from the calculation results in Fig 2 and Fig 3, the comprehensive index of the transportation system in the Beijing-Tianjin-Hebei region is rising steadily, developing continuously, and the level is getting higher and higher. The carbon emission system composite index level of Tianjin and Hebei is low. For these two regions, the situation of low carbon emission reduction is grim.

![Fig. 2. Comprehensive index of Beijing-Tianjin-Hebei transportation system](image1)

![Fig. 3. Composite index of Beijing-Tianjin-Hebei carbon emission system](image2)

3.3. Coupling coordination degree result analysis

According to the formula in 2.3.3, the coupling coordination degree between the transportation system and the carbon emission system in the Beijing-Tianjin-Hebei region from 2011 to 2018 is calculated, and the results are shown in Figure 4. As can be seen from the figure, there is little difference in the coupling coordination degree among Beijing, Tianjin and Hebei. Looking at the overall change trend, the coupling degree of Beijing is the largest, followed by Tianjin and Hebei is slightly lower. This indicates that the degree of coordination between transportation and carbon emissions in Hebei is relatively low, and the development is in an unstable state. The two cannot achieve a good coordinated development state. Among the three regions, Beijing has the best degree of coordination, and the coordinated development of transportation system and carbon emission system is the best.
4. Conclusions and recommendations

Based on the data of Beijing-Tianjin-Hebei region from 2011 to 2018, the coupling coordination degree of transportation and carbon emissions was calculated and analyzed. The following conclusions were drawn:

(1) The carbon emission efficiency level of Beijing-Tianjin-Hebei region was significantly different, and the scale efficiency and comprehensive efficiency were low. The carbon emission efficiency could be improved by improving the scale and technology.

(2) In the development of transportation industry in the Beijing-Tianjin-Hebei region, Tianjin is the most outstanding and its overall level is higher than that of the other two regions. Beijing and Hebei are also in the stage of steady rise. The comprehensive index of the carbon emission system in Beijing, Tianjin and Hebei is also on the rise. The development level of Beijing is slightly higher than that of the other two regions. Tianjin and Hebei still need to strengthen low-carbon emission reduction and other related measures.

(3) The coupling coordination degree between transport and carbon emissions is the highest in Beijing, and the coupling coordination degree in Beijing-Tianjin-Hebei region is at the primary level or above. The coupling coordination degree in Beijing-Tianjin-Hebei region increases first and then decreases, and there is a strong interaction between the two systems. In order to protect the environment and reduce carbon emissions, transportation should adjust its structural mode, take green transportation as the development direction, change the transportation structure, take clean energy as the transportation energy, accelerate the innovation and research of energy saving and emission reduction technology, so as to promote the coordinated development of transportation and carbon emissions.

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