Influencing factors and forecast of carbon emissions from transportation - Taking Shandong province as an example

Heng Zhang, Xue Kong and Chuanxiang Ren*
College of Transportation, Shandong University of Science and Technology, Qingdao, Shandong, 266590, China

*Corresponding author e-mail: ren_chx@sina.com

Abstract. Under the severe situation of global warming, reducing carbon emissions is an important trend in today's society. Based on the 2003-2015 Shandong Province transportation energy consumption data, this paper uses the top-down method to calculate the carbon emissions of transportation in Shandong Province. On this basis, the grey relational degree analysis method is used to study the impact of seven factors, namely per capita GDP, total population, energy consumption per unit GDP, private car ownership, tourism income, freight turnover and passenger turnover, on the carbon emissions of transportation in Shandong Province. According to the analysis results, the above influencing factors are closely related to the carbon emissions of transportation in Shandong Province. The impact degree is from large to small: passenger turnover > freight turnover > per capita GDP > total population > energy consumption per unit > tourism income > private car ownership. At the same time, using the gray prediction GM(1,1) model to predict the carbon emissions of transportation in Shandong Province from 2016 to 2021, it is concluded that the carbon emissions of transportation in Shandong Province will continue to grow in the next few years.

1. Introduction
With the rapid development of the social economy, the problem of global warming has become increasingly serious, and the increase in carbon emissions is the main cause of this problem. Related studies have shown that transportation is one of the main sources of carbon emissions. Therefore, it is imperative to find the influencing factors of transportation carbon emissions and reduce carbon emissions from the source.

Relevant scholars at home and abroad have conducted a lot of research on the influencing factors and predictions of carbon emissions in the transportation industry. Scholars use Kaya's identity [1], LMDI decomposition method [2], LEAP model [3], data envelopment analysis [4] and other methods to calculate and analyze the influencing factors of carbon emissions in the transportation industry. It is concluded that factors such as per capita GDP, energy intensity, vehicle full load rate, economic growth, energy structure and emission efficiency are the main factors of carbon emissions in transportation. Scholars use linear regression analysis [5], Logistic model [6], and other methods to predict carbon emissions.

Based on the transportation energy consumption data of Shandong Province from 2003 to 2015, this paper uses the top-down method to calculate the carbon emissions of transportation in Shandong
Province. The grey correlation analysis method was used to study the influencing factors of transportation carbon emissions in Shandong Province. At the same time, the grey prediction GM(1,1) model is used to predict and analyze the carbon emissions of transportation in Shandong Province from 2016 to 2021.

2. Calculation of carbon emissions from transportation
This paper calculates the data related to carbon emissions from transportation in Shandong Province according to the top-down calculation method. The top-down calculation method is to multiply and multiply the various energy consumptions within the scope of the study with the carbon emission factors of the corresponding energy. The energy consumption data of the transportation industry in this paper comes from the China Energy Statistical Yearbook and the Shandong Statistical Yearbook.

In order to reduce the error of forecast data, this paper uses nine types of energy consumption data: coal, coke, crude oil, fuel oil, gasoline, kerosene, diesel, natural gas, electricity. In the calculation of carbon emissions, firstly, each type of energy consumption needs to be converted into standard coal, and then multiplied by the carbon emission coefficient corresponding to each type of energy. The carbon emission calculation formula is shown in formula (1).

\[ C_t = \sum_{i=1}^{n} E_i \cdot F_i \cdot A_i \]  

(1)

In formula (1), \( C_t \) represents the traffic carbon emissions of the t-year in Shandong Province, and \( E_i \) represents the usage of the i-th traffic energy in the t-year. \( F_i \) is the coefficient of the i-type transportation energy converted to standard coal, and \( A_i \) is the carbon emission coefficient corresponding to the i-type transportation energy.

Reference coefficient of various types of energy discount standard coal: coal:0.71, coke:0.97, crude oil:1.43, fuel oil:1.47, gasoline:1.47, kerosene:1.46, diesel:1.46, natural gas:13.3, electricity:1.23. Carbon emissions coefficient of various types of energy (t carbon / t standard coal): coal:0.75, coke:0.11, crude oil:0.59, fuel oil:0.62, gasoline:0.55, kerosene:0.34, diesel:0.59, natural gas:0.45, electricity:2.2.

The raw data of various types of transportation energy use were brought into the formula(1) to calculate the total carbon emissions and carbon emissions of each transportation energy consumption in Shandong Province from 2003 to 2015. The results are shown in Table 1.

### Table 1. Carbon emissions from transportation energy consumption in Shandong Province(10^4 tons).

| Year | Coal | Coke | Crude Oil | Gasoline | Kerosene | Diesel | Fuel Oil | Natural Gas | Electricity | Total carbon emissions |
|------|------|------|-----------|----------|----------|--------|----------|-------------|--------------|------------------------|
| 2003 | 809.86 | 14.46 | 632.50 | 34.10 | 1.43 | 89.77 | 42.56 | 11.45 | 759.27 | 2395.44 |
| 2004 | 975.64 | 27.07 | 913.27 | 38.03 | 2.18 | 100.33 | 49.26 | 13.95 | 921.38 | 3041.15 |
| 2005 | 1348.26 | 43.66 | 942.97 | 80.67 | 2.21 | 195.11 | 51.95 | 21.31 | 1039.92 | 3726.10 |
| 2006 | 1548.69 | 37.56 | 1108.09 | 88.00 | 2.40 | 210.39 | 53.66 | 26.92 | 1236.01 | 4311.75 |
| 2007 | 1692.96 | 56.83 | 1164.50 | 93.24 | 3.21 | 221.76 | 64.80 | 27.80 | 1412.26 | 4737.39 |
| 2008 | 1836.44 | 57.23 | 1322.01 | 95.81 | 3.08 | 216.72 | 62.71 | 41.11 | 1483.48 | 5118.65 |
| 2009 | 1858.09 | 64.04 | 1469.42 | 104.33 | 3.55 | 229.88 | 71.44 | 47.95 | 1599.95 | 5448.71 |
| 2010 | 1993.34 | 67.22 | 1598.14 | 130.62 | 3.88 | 249.53 | 227.06 | 56.02 | 1794.37 | 6120.22 |
| 2011 | 2078.42 | 72.66 | 1664.71 | 131.28 | 3.98 | 286.78 | 258.79 | 62.99 | 1977.59 | 6537.21 |
| 2012 | 2148.48 | 76.83 | 1791.89 | 132.12 | 7.74 | 312.64 | 299.13 | 80.11 | 2064.27 | 6913.25 |
| 2013 | 2012.33 | 80.65 | 1933.18 | 114.83 | 0.45 | 217.62 | 377.47 | 81.98 | 2221.22 | 7039.77 |
| 2014 | 2112.63 | 82.43 | 2233.15 | 114.82 | 0.45 | 217.91 | 436.29 | 89.32 | 2297.59 | 7584.64 |
| 2015 | 2185.54 | 81.16 | 2459.19 | 118.19 | 9.90 | 230.08 | 572.96 | 98.09 | 2783.69 | 8538.85 |
According to the data in Table 1, it can be seen that during the period of 2003-2015, the carbon emissions of the transportation industry in Shandong Province continued to grow, and the total amount of carbon emissions from transportation increased from 2,935,400 tons to 8,538,800 tons. It has increased by 2.56 times and the average annual growth rate is 19.7%. It can be concluded that the carbon emissions from transportation of kerosene, natural gas and coke are small, the carbon emissions from transportation of coal, electricity and crude oil are more. And the total carbon emissions of transportation showed a steady growth.

3. Gray correlation analysis of transportation carbon emissions

3.1. Selection of indicators for influencing factors of carbon emissions from transportation

By reading relevant literature and combining with the development of transportation in Shandong Province, this paper selects seven factors of per capita GDP, total population, energy consumption per unit of GDP, private car ownership, tourism revenue, freight turnover and passenger turnover as influencing factors of transportation carbon emissions. The raw data of the above seven factors are derived from the Shandong Statistical Yearbook from 2003 to 2015. The detailed raw data is shown in Table 2.

| Year | Per capita GDP /yuan | Total population /10^4 people | Unit GDP energy consumption (t standard coal / 10^4 yuan) | Private car ownership /10^4 units | Tourism income /100 million yuan | Freight turnover /million tons kilometers | Passenger turnover /million passenger kilometers | Total carbon emissions /10^4 tons |
|------|----------------------|-------------------------------|-------------------------------------------------------|----------------------------------|---------------------------------|------------------------------------------|------------------------------------------|-----------------------------|
| 2003 | 9256                 | 9108                          | 1.51                                                  | 89.86                            | 574.43                          | 1034.71                                  | 304075                                   | 2395.44                     |
| 2004 | 10165                | 9163                          | 1.6                                                    | 117.10                           | 467545                          | 304075                                   | 90314                                    | 3041.15                     |
| 2005 | 11320                | 9212                          | 1.63                                                   | 136.07                           | 403315                          | 304075                                   | 82778                                    | 3726.10                     |
| 2006 | 13233                | 9282                          | 1.58                                                   | 199.24                           | 1294.66                         | 342906                                   | 93014                                    | 4311.75                     |
| 2007 | 16359                | 9346                          | 1.5                                                    | 254.06                           | 1654.62                         | 478309                                   | 106879                                   | 4737.39                     |
| 2008 | 19857                | 9392                          | 1.41                                                   | 315.72                           | 2001.24                         | 558286                                   | 141867                                   | 5118.65                     |
| 2009 | 23531                | 9449                          | 1.35                                                   | 433.94                           | 2453.2                          | 665521                                   | 158713                                   | 5448.71                     |
| 2010 | 27521                | 9536                          | 1.32                                                   | 577.11                           | 3068.8                          | 642854                                   | 164471                                   | 6120.22                     |
| 2011 | 32847                | 9591                          | 1.3                                                    | 708.53                           | 3746.6                          | 1010234                                  | 172751                                   | 6537.21                     |
| 2012 | 35779                | 9580                          | 1.24                                                   | 877.56                           | 4521.7                          | 1095569                                  | 183196                                   | 6913.25                     |
| 2013 | 40889                | 9612                          | 1.19                                                   | 1039.55                          | 5183.9                          | 1174705                                  | 189285                                   | 7039.77                     |
| 2014 | 47067                | 9747                          | 1.13                                                   | 1191.62                          | 6191.5                          | 1258364                                  | 114056                                   | 7584.64                     |
| 2015 | 51641                | 9822                          | 1.07                                                   | 1351.83                          | 7052.5                          | 1099119                                  | 112745                                   | 8538.85                     |

3.2. Gray correlation calculation

Taking the total carbon emissions of transportation $X_o$ as the reference series, per capita GDP, total population, energy consumption per unit of GDP, private car ownership, tourism revenue, freight turnover, passenger turnover $X_i$ $(i = 1, 2, 3, 4, 5, 6, 7)$ is a comparison sequence, and the calculation steps of grey relational degree are shown below.

**Step 1:** All the original data sequences are dimensionless. In this paper, the initial value method is used to dimensionless the data to obtain new data columns $X_i'(n) = X_i(n) / X_i(1)$ $(i = 1, 2, \ldots, 7, n = 1, 2, \ldots, 13)$.  

Step 2: Solving the absolute difference sequence $\Delta_i(n)$ according to formula (2). Find the maximum absolute difference $\Delta_{max}$ and the minimum absolute difference $\Delta_{min}$ in the calculation result. The calculation process of the gray correlation degree is shown in formula (3).

$$\Delta_i(n) = |X_i(n) - X_{i,0}(n)|$$

$$\gamma_0 = \frac{1}{N} \sum_{n=1}^{N} q_0(n) = \frac{1}{N} \sum_{n=1}^{N} \frac{\Delta_{min} + \rho \Delta_{max}}{\mu}$$

In formula (3): $\gamma_0$ is the gray correlation degree, $N$ is the total number of related factor sequences, and $q_0(n)$ is the correlation coefficient of the correlation factor sequence at time $n$. $\rho$ is called resolution, $0 < \rho < 1$, and the larger the $\rho$ is, the smaller the resolution is; the smaller the $\rho$ is, the larger the resolution is. Take $\rho = 0.5$ in this article. The data in Table 5 is brought into the formula (2) and the formula (3) to calculate the gray correlation degree.

3.3. Grey correlation analysis

Sorting the gray correlation degree of the calculated factors affecting the carbon emissions of transportation in Shandong Province, we can get: passenger turnover (0.9464) > freight turnover (0.9255) > GDP per capita (0.9016) > total population (0.8289) > energy consumption per unit of GDP (0.8170) > tourism revenue (0.7230) > private car ownership (0.6895). The above results show that the influencing factors of transportation carbon emissions in Shandong Province are mainly the traffic itself (passenger turnover, freight turnover). Reducing the passenger traffic volume, freight turnover, per capita GDP, total population, energy consumption per unit of GDP, tourism revenue, and the growth rate of private car ownership can all reduce the carbon emissions of transportation in Shandong Province.

4. Forecast of transportation carbon emissions based on GM(1,1) model

4.1. Gray prediction GM (1,1) model establishment and testing

The establishment of the grey prediction GM(1,1) prediction model is as follows. Set $x_i^{(0)} = (x_{i1}, x_{i1}, x_{i1}, \cdots, x_{i1})$ be the raw data of the indicator to be predicted, and add a sequence of $x_i^{(0)}$ to generate a sequence $x_i^{(1)} = (x_{i1}, x_{i2}, x_{i3}, \cdots, x_{in})$. And meet the following conditions: $x_i^{(1)} = \sum_{k=0}^{n} x_{i(k)}(k = 1, 2, \cdots, n)$, $x_i^{(1)} = \frac{1}{2}(x_{i(k)} + x_{i(k-1)})(k = 1, 2, \cdots, n)$. The formula (4) is called the basic form of the GM(1,1) model. The least squares estimation parameter column of the formula (4) needs to satisfies the formula (5).

$$x_{i(k)} + a_{i(k)} = b$$

$$\hat{p} = (a, b)^T = (BB^{-1})B^TY$$

In the formula (5), $P = (a, b)^T$ is a parameter column, $Y$ is a data column, and $B$ is a data matrix.

$$Y = \begin{bmatrix} x_{i(0)}^{(1)} \\ \vdots \\ x_{i(n)}^{(1)} \end{bmatrix}, B = \begin{bmatrix} -z_{i1}^{(1)} & 1 \\ \vdots & \vdots \\ -z_{in}^{(1)} & 1 \end{bmatrix}$$

Set $x^{(0)}$ to be a non-negative sequence, $x^{(1)}$ to a one-time cumulative sequence of $x^{(0)}$, and $z^{(i)}$ is a sequence of adjacent mean generations of $x^{(1)}$. Establish an approximate differential equation model as shown in equation (7). This equation is the whitening equation of equation (4). In the formula, $a$ is the development coefficient, and $b$ is the gray action amount. The time response function is solved as
equation (8), the time response sequence is equation (9), and the predicted value of the original data sequence \( \hat{x}^{(0)} \) is equation (10).

\[
\frac{dx^{(1)}}{dt} + ax^{(1)} = b \tag{7}
\]

\[
x^{(1)}(t) = (x^{(0)}(1) - \frac{b}{a}) e^{-at} + \frac{b}{a}, \tag{8}
\]

\[
x^{(0)}(k+1) = (x^{(0)}(1) - \frac{b}{a}) e^{-a(k-1)} + \frac{b}{a} \quad (k = 1, 2, \ldots, n) \tag{9}
\]

\[
x^{(0)}(k+1) = x^{(0)}(k+1) - x^{(0)}(k) = (1 - e^{-a}) (x^{(0)}(1) - \frac{b}{a}) e^{-a(k-1)} \tag{10}
\]

Where \( x^{(0)}(k)(k = 1, 2, \ldots, n) \) is the original data sequence, \( \hat{x}^{(0)}(k)(k = 1, 2, \ldots, n) \) is the fitted value of the original data sequence; \( \hat{x}^{(0)}(k)(k > n) \) is the predicted value of the original data sequence.

Diagnosis of the model: In order to analyze the reliability of the model, the model needs to be diagnosed. First, set the residual sequence \( q^{(0)} = \{q(1), q(2), \ldots, q(n)\} \) as the subtraction value between the original sequence value and the prediction model simulation sequence, and then calculate the variance \( s_1 \) of the data and the variance \( s_2 \) of the residual.

\[
s_1^2 = \frac{1}{n} \sum_{k=1}^{n} (x^{(0)}(k) - \hat{x})^2 \tag{11}
\]

\[
s_2^2 = \frac{1}{n} \sum_{k=1}^{n} (q^{(0)}(k) - q)^2 \tag{12}
\]

Finally, the reliability of the model is judged based on the mean square error ratio of \( c = s_2/s_1 \), and the small error probability of \( p = P(|q(k) - \hat{q}| < 0.6745s_2) \). In general, when \( c < 0.35 \), the model is the mean square error ratio qualified model. When \( p > 0.95 \), the model is a small error probability qualified model.

4.2. Calculation and analysis of the model

Based on the traffic carbon emissions of Shandong Province from 2003 to 2015, the carbon emissions of transportation in 2016-2021 are predicted. After the gray GM (1,1) prediction model correlation calculation, the model parameter \( a = -0.077631 \), the parameter \( b = 3311.8341 \), and the prediction model of transportation carbon emission in Shandong Province is \( x(t+1) = 45056.4356e^{0.076631t} - 42660.95629 \). After the test calculation, the mean square error ratio \( c = 0.1494 < 0.35 \) and the small error probability \( p = 1.00 > 0.95 \), so the accuracy of the prediction model is very high.

The results of the carbon emissions from transportation by the gray GM (1, 1) prediction model are shown in Figure 1.

![Figure 1. Distribution line chart of transportation carbon emission in Shandong Province.](image)
According to the analysis results of Figure 1, the carbon emissions of transportation in Shandong Province will continue to grow steadily in the next few years. As can be seen from the trend of the line in Figure 1, the prediction accuracy of this method is relatively high. The predicted values of transportation carbon emissions in Shandong Province from 2016 to 2021 are shown in Table 3.

| Year | 2016   | 2017   | 2018   | 2019   | 2020   | 2021   |
|------|--------|--------|--------|--------|--------|--------|
| 2016 | 9232.93| 9978.26| 10783.74| 11654.25| 12595.03| 13611.76|

### 5. Conclusion

Based on the 2003-2015 Shandong Province transportation energy consumption data, this paper uses the top-down method to calculate the carbon emissions of transportation in Shandong Province. Correlation analysis was conducted on the seven influencing factors affecting the carbon emissions of transportation in Shandong by grey correlation analysis. At the same time, the grey prediction GM(1,1) model is used to predict and analyze the carbon emissions of transportation in Shandong Province from 2016 to 2021.

According to the calculation results of transportation carbon emissions, coal, electricity and crude oil generate more carbon emissions from transportation. The government should increase financial support for new energy and new technologies, reduce the use of energy such as coal and crude oil, and reduce the carbon emission rate of carbon transportation.

According to the results of grey correlation analysis, the key to reducing traffic carbon emissions is to reduce passenger turnover and freight turnover, and secondly to reduce per capita GDP, total population, energy consumption per unit of GDP, and tourism revenue. Reducing the growth rate of private car ownership is also a measure that cannot be ignored to reduce carbon emissions.

According to the prediction of the carbon emissions of transportation in Shandong Province in 2016-2021, the carbon emissions of transportation in Shandong Province increased by an average of 10.13% per year, and the carbon emissions in 2021 will reach 136.1176 million tons, which is 5.68 times that of 2003. It can be concluded that the carbon emissions of transportation in Shandong Province still show a steady growth trend in the next few years. The realization of carbon emission reduction in Shandong Province still requires all parties to make more effective measures to reduce the amount of carbon emissions from transportation.

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