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Carbon Emission Prediction and Strategy based on GM

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Abstract

Global warming is the most serious global environmental problem faced by mankind so far. Reducing CO_2 emissions and developing a low-carbon economy with low energy consumption and low emissions have become an urgent task for countries all over the world. This paper adopts the LMDI decomposition method to quantitatively analyze the impact of energy structure, energy efficiency and economic development on carbon emissions in China. The model is realized from the degree of influence of energy structure, economic development and energy efficiency on per capita carbon emissions, and the contribution values of the three factors to per capita carbon emissions are analyzed. A gray prediction model is used to establish a carbon emission time series to make a better prediction of carbon emission in China. Thus, emission reduction strategies on these three influencing factors are proposed.

Keywords

LMDI Decomposition; Gray Projection; Carbon Emissions.

1. Introduction

With the rapid development of the world economy, the global carbon emission is increasing, which not only appears a series of environmental problems, but also has a significant impact on the global economic development. The increase of CO_2 emissions in the atmosphere is the root cause of global warming, so reducing CO_2 emissions and developing a low-carbon economy with low energy consumption and low emissions has become an urgent task for all countries in the world. The growth momentum of CO_2 emissions in China is slowing down, but the total amount has jumped to the first place in the world, and the energy consumption keeps rigid growth, so the task of energy conservation and emission reduction is very difficult.

2. Study of Influencing Factors

2.1 Modeling

In this paper, considering that the LMDI decomposition method can decompose multiple factors and the residuals of the decomposed results are 0. Therefore, the LMDI decomposition method is used to quantitatively analyze the influence of energy structure, energy efficiency and economic development on China's carbon emissions.

$$Ln(D_{tot}) = ln(D_{x1}) + ln(D_{x2}) + \dots + ln(D_{xn})$$

The LMDI decomposition method is an effective method for analyzing the drivers of energy and GHG emissions. It has no unexplained residuals after decomposing the object and can use conversion expressions for additive and multiplicative decompositions. The results using multiplicative decomposition have the following additive properties:

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There is a simple correspondence between additive and multiplicative decomposition: for all k, there is

$$\frac{\Delta V_{tot}}{\ln(D_{tot})}=\frac{\Delta V_{xk}}{\ln(D_{xk})}$$

The results obtained by applying additive decomposition or multiplicative decomposition can be transformed into each other in this way.

The total carbon emissions are decomposed as follows.

$$C=\sum_i C_i=\sum_i \frac{C_i}{E_i}\times\frac{E_i}{E}\times\frac{E}{Y}\times\frac{E}{P}\times P$$

C is the carbon emissions, C_i is the carbon emissions of the i energy source, E is the consumption of primary energy, E_i is the consumption of the i energy source, Y is the gross domestic product (GDP), P is the population. The emission intensity of each type of energy F_i is the carbon emission per unit of energy consumed, the energy structure factor S_i is the share of energy in primary energy consumption, the energy efficiency factor I is the energy consumption per unit, and the economic development factor R is the per capita. Therefore, the per capita carbon emissions can be expressed as

$$A=\frac{C}{P}=\sum_i F_i S_i IR$$

The equation indicates that the change in per capita carbon emissions A comes from changes in energy intensity, energy mix, energy efficiency, and economic development.

2.2 Model Solving

The change in per capita carbon emissions in period t relative to the base period can be expressed as

$$\Delta A=A^t-A^0=\sum_i S_i^t F_i^t I_i^t R_i^t-\sum_i S_i^0 F_i^0 I_i^0 R_i^0$$
$$=\Delta A_S+\Delta A_F+\Delta A_I+\Delta A_R+\Delta A_{rad}$$

$$D=\frac{A^t}{A^0}=D_S D_F D_I D_R D_{rad}$$

Where,ΔA_S, $D_S$is the energy structure factor, ΔA_F, D_F is the energy emission intensity factor, ΔA_I, D_I is the energy efficiency factor, ΔA_R, D_R is the economic development factor, and ΔA_{rad}, D_{rad} is the decomposition residual.

ΔA_S, ΔA_F, ΔA_I,and ΔA_R, are the contribution of the change of each factor to the change of per capita carbon emissions, respectively, and they are real values with units. And D_S,D_F, D_I and D_R, are the contribution of the change of each factor to the change of carbon emission per capita, respectively.

The decomposition is carried out according to the LMDI method, and the decomposition results of each factor are as follows.

$$\Delta A_S=\sum_i W_i'\ln\frac{S_i^t}{S_i^0}\ ;\ \Delta A_F=\sum_i W_i'\ln\frac{F_i^t}{F_i^0}$$

$$\Delta A_I=\sum_i W_i'\ln\frac{I_i^t}{I_i^0}\ ;\ \Delta A_R=\sum_i W_i'\ln\frac{R_i^t}{R_i^0}$$

$$W_i'=\frac{A_i^t-A_i^0}{\ln(\frac{A_i^t}{A_i^0})}$$

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$$\begin{aligned}\Delta A_{rad} &= \Delta A-\left(\Delta A_S+\Delta A_F+\Delta A_I+\Delta A_R\right)\\ &= A^t-A^0-\sum_i W_i'(\ln\frac{S_i^t}{S_i^0}+\ln\frac{F_i^t}{F_i^0}+\ln\frac{I_i^t}{I_i^0}+\ln\frac{R_i^t}{R_i^0})\\ &= A^t-A^0-\sum_i W_i' \ln\frac{A_i^t}{A_i^0}\\ &= A^t-A^0-\sum_i\left(A_i^t-A_i^0\right)\\ &= 0\end{aligned}$$

Taking the logarithm of both sides, we get that

$$\ln D=\ln D_S+\ln D_F+\ln D_I+\ln D_R+\ln D_{rad}$$

The items can be set to correspond to a proportion, is

$$\frac{\ln D}{\Delta A}=\frac{\ln D_S}{\Delta A_S}=\frac{\ln D_F}{\Delta A_F}=\frac{\ln D_I}{\Delta A_I}=\frac{\ln D_R}{\Delta A_R}=\frac{\ln D_{rad}}{\Delta A_{rad}}$$

Here, it is assumed $\frac{0}{0}$ that it can be an arbitrary constant.

$$\frac{\ln D}{\Delta A}=\frac{\ln A^t-\ln A^0}{A^t-A^0}=W$$

$$D_S=e^{(W\Delta A_S)};D_F=e^{(W\Delta A_F)};D_I=e^{(W\Delta A_I)};D_R=e^{(W\Delta A_R)};D_{rad}=1$$

The model is implemented in terms of the degree of influence of energy structure, economic development, and energy efficiency on per capita carbon emissions, so the contribution values of the three factors to per capita carbon emissions are analyzed.

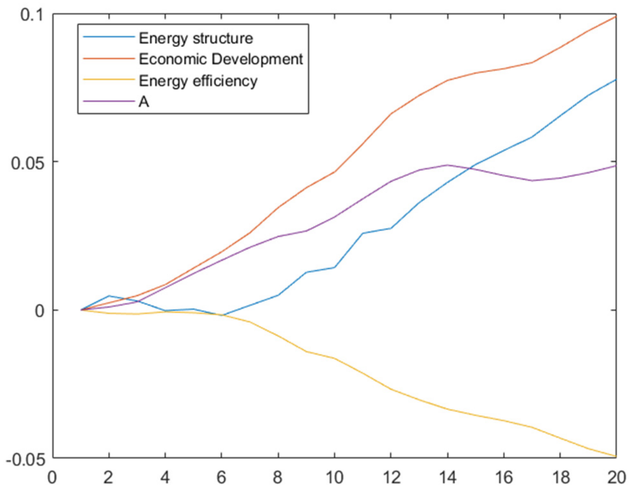

Fig 1. Trend of contribution value from 2000-2019

It is clear from Figure 1 that the main factor leading to the rapid growth of carbon emissions per capita in China in the past two decades is the rapid economic development, and the energy structure is also one of the main factors leading to the growth of carbon emissions in China after 2015, while the optimization of the energy structure before 2015 is one of the inhibiting factors of carbon emissions in China, and the improvement of energy efficiency has always been the inhibiting factor. The reasons for the changes in China's per capita carbon emissions presented in each period can be clearly seen by the figure.

 Volume 9 Issue 2, 2023
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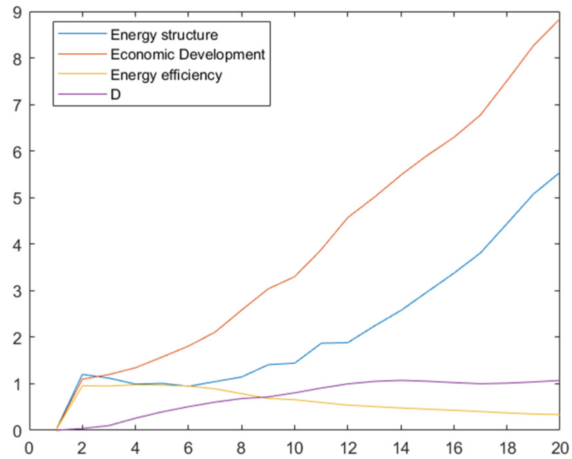

Fig 2. Trend of the contribution of change 2000-2019

Combined with the trend graph of contribution rate, we further analyze the main factors influencing the overall change of carbon emissions per capita in China. During the period 2003-2019, the gap between the suppression contribution of energy efficiency and the pull rate of economic development becomes larger and larger, which leads to the rapid growth of per capita emissions in China during this period.

3. Carbon Emission Projections

3.1 Modeling

In this paper, a gray prediction model is used to establish the carbon emission time series, find the level ratio, and judge the series can be GM(1,1) modeling, so as to make a better prediction of China's carbon emission.

The gray model is a method to generate an approximate exponential law by accumulating the original data and then modeling it. A differential model is built to fit the given time series data through the data series to predict the trend of the data.

3.2 Model Solving

A time series of China's carbon emission data is established as follows.

$$x^{(0)} = (x^{(0)}(1), x^{(0)}(2), \dots, x^{(0)}(7)) \\ = (6111.098826, 6624.055704, \dots, 10434.84476)$$

$$\lambda(k) = \frac{x^{(0)}(k-1)}{x^{(0)}(k)}$$

$$\lambda = (\lambda(2), \lambda(3), \dots, \lambda(14)) \\ = (0.9226, 0.9594, 0.9124, 0.8982, 0.9084, 0.9407, 0.9718, 1.0131, 1.0245, 1.0182, 0.9820, 0.9705, 0.9652)$$

$$\lambda(k) \in [0.8982, 1.0245], k = 2, 3, \dots 14$$

The original data column is summed once to obtain

$$x^{(0)} = (6110, 12740, 19640, 27210, 35630, 44910, 54770, 64910, 74920, 84700, 94300, 104070, 114140, 124580)$$

Construct the data matrix B and the data vector Y, with

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$$B=\begin{bmatrix} -\frac{1}{2}(x^{(1)}(1)+x^{(1)}(2)) & 1 \\ -\frac{1}{2}(x^{(1)}(2)+x^{(1)}(3)) & 1 \\ \vdots & \vdots \\ -\frac{1}{2}(x^{(1)}(13)+x^{(1)}(14)) & 1 \end{bmatrix}, Y=\begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(14) \end{bmatrix}$$

$$\hat{u}=\begin{bmatrix} \hat{a} \\ \hat{b} \end{bmatrix}=(B^TB)^{-1}B^TY=\begin{bmatrix} 0.8982 \\ 1.0245 \end{bmatrix}$$

$$\frac{dx^{(1)}(t)}{dt}+ax^{(1)}(t)=b$$

Get

$$\hat{x}^{(1)}(k+1)=\left(x^{(0)}(1)-\frac{\hat{b}}{\hat{a}}\right)e^{-\hat{a}k}+\frac{\hat{b}}{\hat{a}}=250010e^{0.0298556k}-243899$$

Taking k=1,2,3...13, we get,

$$\hat{x}^{(0)}=(\hat{x}^{(0)}(1),\hat{x}^{(0)}(2),...,\hat{x}^{(0)}(13)) \\ =(6111,7577,7806,8043,8287,8538,8797,9063,9338,9621,9912,10213,10522,10841)$$

Residual tests were performed and the errors obtained are shown in Fig. 3.

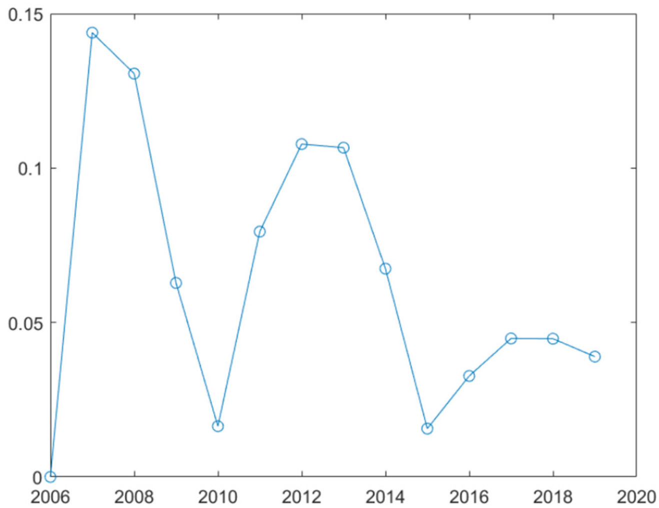

Fig 3. Relative error curve in residual test

From Figure 3, it can be seen that the error in the first few years is large, while the error in the latter years is small. Then, from the model test table in Table 2 below, it can be seen that the model has a high accuracy and can be predicted.

Table 1. GM(1,1) model test table

Serial number	Year	Original value	Predicted value	Residual deviation(10^3)	Relative error (10^3)	Grade ratio deviation
1	2006	6111	6111	0	0	

 Volume 9 Issue 2, 2023
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2	2007	6624	7577	-0.9527	0.1438	0.0495
3	2008	6904	7806	-0.9017	0.1306	0.0116
4	2009	7567	8043	-0.4753	0.0628	0.0599
5	2010	8425	8287	-0.4753	0.0164	0.0745
6	2011	9274	8538	0.1383	0.0794	0.0641
7	2012	9858	8797	0.7367	0.1078	0.0308
8	2013	10144	9063	1.0624	0.1066	-0.0013
9	2014	10013	9338	1.0814	0.0674	-0.0438
10	2015	9773	9621	0.6752	0.0156	-0.0555
11	2016	9598	9912	0.1529	0.0327	-0.0491
12	2017	9774	10213	-0.4382	0.0448	-0.0118
13	2018	10071	10522	-0.4507	0.0447	0.0001
14	2019	10434	10841	-0.4064	0.0389	0.0056

The carbon emissions from 2006-2019 are projected as well as compared with the original data, and the results are shown in Fig. 4.

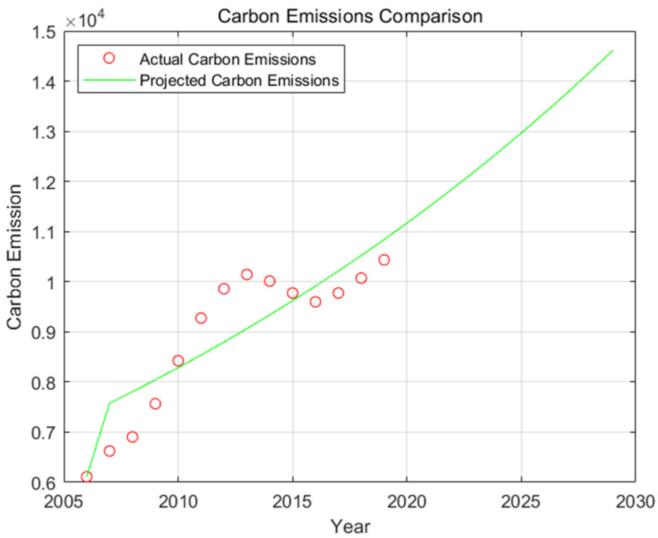

Fig 4. Comparison of real data and original data

In turn, the carbon emissions of China from 2021-2029 are projected in billion tons, and the data are shown in Table 2.

Table 2. Carbon emission projections

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Value	11170	11508	11857	12216	12587	12968	13361	13766	14183	16413

4. Conclusion

By the main factors of carbon emissions: energy structure, economic development, energy efficiency, and then proposed to reduce emissions on these three influencing factors strategy.

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(1) Change the structure of energy consumption. Energy is an important factor in promoting economic growth, but also an important factor in causing environmental pollution and greenhouse gas emissions. The carbon emission coefficients of different types of energy in the energy consumption structure are different, resulting in different carbon emissions generated per unit of energy consumption. Coal combustion has the highest CO_2 emission factor, followed by oil and natural gas, while nuclear energy, wind energy, solar energy, etc. are clean energy sources whose production process does not emit CO_2. For a long time, China's energy consumption structure is dominated by coal, and in recent years, although the proportion of coal consumption in total energy consumption has decreased, it is still greater than 50%. Therefore, optimizing the energy consumption structure, reducing the proportion of coal consumption, strengthening the construction of clean energy, and developing clean energy are the keys to reduce carbon emissions.

(2) Change the mode of economic growth and improve the quality of economic growth. The growth of GDP per capita means the rapid growth of national economy and the continuous improvement of people's living standard, which will drive the rapid growth of total energy consumption, thus prompting the growth of carbon emissions and increasing the pressure of carbon emission reduction. In the process of maintaining rapid economic growth, try to maintain or reduce carbon emissions.

(3) Improve energy use efficiency. Energy efficiency degree is the ratio of GDP to energy consumption. The lower the energy efficiency, that is, the higher the efficiency of energy use, the smaller the per capita carbon emissions. The country can improve energy use efficiency by developing science and technology to reduce the energy consumption of minerals in the process of converting them into usable energy.

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