Simulation Prediction and Research of China Industrial Energy Related CO2 Emissions

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Abstract. This paper analyzes the industrial CO_2 emissions of China which consumption from energy from 2009 to 2019. The simulation forecast model for predict CO_2 emissions in 11 years' period has reached a very high precision, the mean error of predictive model logistic and GM of CO_2 emissions is 6.25% and 2.87%, and the industrial CO_2 emissions' growth from 2012 to 2016 is expected from 12.8% to 6.3%. China energy consumption per unit industrial added value in 2019 fell by 38.21% in comparison with 2009, carbon emission intensity fell 27.33%. The energy conservation illustrated by this, and a certain effect achieved by emission reduction work in China between 2009 and 2019, and its industrial structure got a better improvement.

Keywords: Simulation prediction, GM, logistic, CO2 emissions.

1. Introduction

In the past century, especially in the last three decades, the global climate has undergone significant changes, global warming is the greatest warning. More and more CO2 emissions have led to the series of questions [1]. Since reform and opening up in 1978, economy of China continues to grow which drives China to be the second largest economy the world's entity [2]. But at the same time, this also makes China surpassed the U.S. At the same moment, China gradually becomes the largest energy consumer and the biggest CO2 emitter of the world [3] [4], an increase from 1978's 1.424 billion tons to 2011's 7.955 billion tons [5].

As economy and the society develops, the energy demand of China was also growing which led to a large amount of CO2 emissions. And the energy consumption from industry accounting for 66.62% of the total. China will do all one can to achieve carbon peak and carbon neutrality in 2030 and 2060 respectively. With the existing energy and economic structure, energy abatement task is very arduous. So, it is significant to realize the significance of sustainable development and energy abatement under the premise without affecting economic development.

The grey system theory is used to model, analyze and forecast the gray system. The grey prediction model (GM) has been successfully used to predict carbon emissions by many scholars. [6]- [8].The Logistic model has been used in some areas of theoretical analysis and research for predict energy-related CO_2 emissions by many scholars at home and abroad. They made some preliminary results.[9] [10]

Through the literature search, it will be found that the current literature that is focused on the decomposition analyze of industries' CO2 emissions research, but there is analysis and relatively little research in predicting industrial energy-related CO2 emissions. So, take China's industry as an example, China industrial energy-related CO2 emissions will be forecasted by using two different models in the paper. At the same time some opinion and comments about the existing problem will also be put forward in the paper.

2. .Methodology and data sources

2.1. Energy-related carbon dioxide emissions calculation method

This paper studies on the CO_2 emissions of China industrial sectors which come from energy consumption, the main energy consumption data is regard as the foundation, uses the IPCC guidelines recommended method to calculate. It can be expressed by the formula (1):

$$C_n = \sum_j C_{i,n} = \sum_i EC_{i,n} \cdot ef_i \quad (1)$$

Where, C_n represents energy-related CO_2 emissions; i represents energy types; $EC_{i,n}$ represents i energy type consumption volume in the n year's; ef_i represents i energy type's carbon emission factor. The carbon dioxide emission factors for a variety of end-use energy referred to the relevant literature and obtained through a simple calculation.

2.2. The energy-related CO_2 emissions forecasting model

The logistic predict model have amount of successfully applied in predicting carbon emission, energy consumption and in explore disease control. The logistic model that used in predicting CO_2 emission show as formula (2):

$$\frac{dC}{dn} = \gamma C\left(1 - \frac{C}{K}\right), C_0 = C|_{n=0} \quad (2)$$

By transforming formula (2), Eq. (3) can be obtained as follows:

$$C = \frac{K}{1+(\frac{K}{C_0}-1)e^{-\gamma n}} \quad (3)$$

Where, C represents CO_2 emissions come from energy consumption; C_0 represents the base year CO_2 emissions come from energy consumption; K is the ultimate amount of CO_2 emissions; r is the growth factor.

Set $T = \ln(\frac{K-C}{C}), \frac{K}{C_0} - 1 = e^{\alpha}$,then convert the equation (3) to the linear equation (4):

$$T = \alpha - \gamma \quad (4)$$

The optimal α and γ values can be got according to formula (4), by using the method of alternating iterative [11]. In the paper, China's industrial CO_2 emissions are regarded as the value to be forecast. The data from 2009 to 2019 of energy consumption is the sample, and the year of 2009 is the base period.

2.3. . GM (1, 1) model

The original time series:
$C^{(0)} = (c^{(0)}(1), c^{(0)}(2), c^{(0)}(3) \ldots, c^{(0)}(n))$.

One-accumulate of the time-series:
$C^{(1)} = (c^{(1)}(1), c^{(1)}(2), c^{(1)}(3), \ldots, c^{(1)}(n))$, where $c^{(1)}(m)=\sum_{j=1}^{m} x^{(0)}(j)$,m=1,2,3…,n.

Neighbor sequences of the time-series:
$T^{(1)} = (t^{(0)}(1), t^{(1)}(2), t^{(1)}(3) \ldots, t^{(1)}(n))$, where $t^{(1)}(m)=0.5c^{(1)}(m) + 0.5c^{(1)}(m-1)$.

Differential GM equation show that:

$$\frac{dc^{(1)}}{dn} + dc^{(1)} = f \quad (5)$$

The predict model can be obtained:$\hat{c}^{(1)}(m-1)=\left[c^{(0)}(1) - \frac{f}{d}\right]e^{-dm} + \frac{f}{d}$, m=1, 2,3…, n (6)

The a , b could be obtained in using least square method. $\hat{d} = (d, f)^T$, $\hat{d} = (F^T F)^{-1} F^T Y_n$. Where

$$F = \begin{bmatrix} -t^{(1)}(2) & 1 \\ -t^{(1)}(3) & 1 \\ \dots & \dots \\ -t^{(1)}(n) & 1 \end{bmatrix}, Y_n = \begin{bmatrix} c^{(0)}(2) \\ c^{(0)}(3) \\ \dots \\ c^{(0)}(n) \end{bmatrix}$$

2.4. . Data source

The major basic data in the article according to China Industry economy Statistical and energy Statistical Yearbook. [12] [13] Electrical energy conversion coefficient is 4.04. All value mentioned above is equivalent value (special circumstances will give instruction).

In Logistic model with the average CO_2 emissions growth during the past ten years (10.06%) was taken as the higher bound limit value, and the average value (3.2%) was taken as the lower limit value. The CO_2 emissions scope in decade can be positioned [435371.6425,828171.6066] by using the computer select point calculation [11].

3. Results and discussion

3.1. Industrial energy consumption of China

Figure 1 shows that China's energy consumption in industry is going up continually from 2009's 3,203,896,788.29 standard coal tons to 2019's 4,470,564,755.5 standard coal tons, and 2019's industrial energy consumption has increased 39.53% over the 2009's level. Because of the rapid and sustained economic growth for the past years in China, total industrial energy consumption is also increasing. Which can be seen from the figure 1 that energy consumption per unit industrial added value of China in the same period from 2.32 standard coal tons / 10,000 RMB in 2009 drops to 1.44 standard coal tons /10,000 RMB in 2019, which is declined by 38.21%. That was mainly attribute to China Government adopted a collection of policies about energy conservation policies, making energy efficiency and energy technologies improved, thus contributing to the China's energy consumption per unit industrial added value sustained decline.

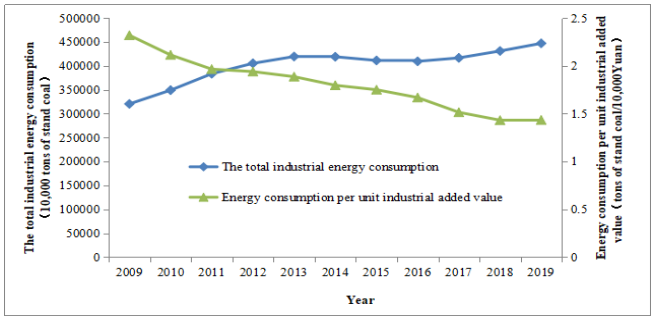


Fig. 1. Variation of China's industrial energy consumption per unit industrial added value and energy consumption from 2009 to 2019

3.2. Industrial energy-related CO_2 emissions of China

Figure 2 shows that the China industrial CO_2 emissions come from energy consumption is going up continually during the last eleven years from2009's 2,332,934,453.9 tons to 2019's 3,176,228,379.25 tons, and the CO_2 emissions in 2019 has increased 36.15% over the 2009 level, the mean yearly growth rate is 3.2%. Because of the China's rapid and sustained economic growth for the previous years, and the industrial energy-related CO_2 emissions are also increasing. As is visible from Figure 3 that at the same time, China's carbon emission intensity drops from 0.43 tons CO_2/ 10,000 RMB in 2009 to 0.30 tons CO_2/ 10,000 RMB in 2011, which is declined by 29.1%. This is mainly due to the fact that China accelerates the elimination of the backward and high energy consumption equipment, takes the adjustment of industry structure, and optimizes industrial structure

through transforming, introducing, improving industries has low-energy's, high outputs and less pollution's characteristic.

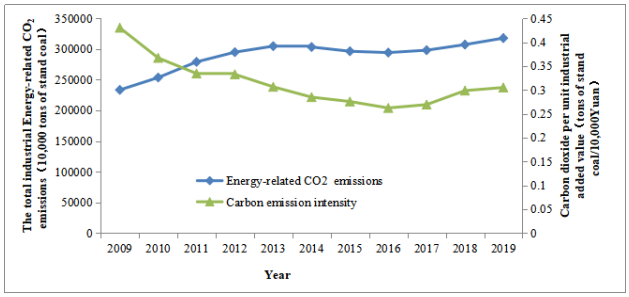


Fig .2. Variation of China's industrial energy-related $\mathbf{CO_2}$ emissions, Carbon emission intensity from 2009 to 2019

3.3. The Logistic model forecast results

According to relevant basic data and logistic predict model, the China total industrial CO_2 emissions come from energy consumption prediction formula can be got:

$$C = \frac{631770}{1+1.71e^{-0.0605n}} \tag{7}$$

According to the formula (7), the China total industrial CO_2 emissions come from energy consumption during 2009 to 2019 can be forecasted and calculated. The compare between the actual value and forecasted one during the same period show in Fig.3 and Table 1.

Table 1. The industrial $\mathbf{CO_2}$ of China actual and forecast error table (by Logistic model)

Year	Predicted $\mathbf{CO_2}$ emissions (10,000 tons)	Actual $\mathbf{CO_2}$ emissions (10,000 tons)	Relative errors
2009	233293.4	233293.4	0.00%
2010	253443.2	242460.1	-4.33%
2011	278934	251834.5	-9.72%
2012	294773.5	261409.6	-11.32%
2013	304610.9	271177.5	-10.98%
2014	303199.8	281129.3	-7.28%
2015	296242.9	291255.3	-1.68%
2016	294097	301545	2.53%
2017	297975.8	311987	4.70%
2018	307114.4	322569.1	5.03%
2019	317622.8	333278.4	4.93%

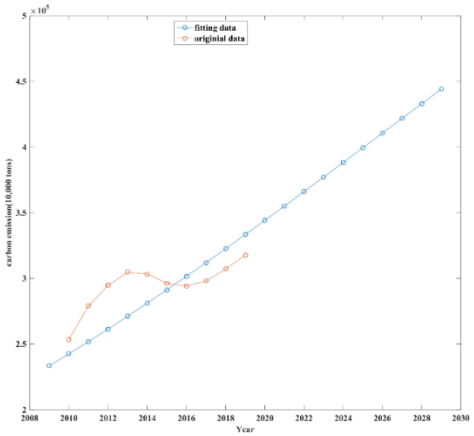


Fig. 3. China industrial energy-related $\mathbf{CO_2}$ emissions and predict fitting graph (Logistic model)

Table 1 shows that the max. error between forecast industrial CO_2 emissions which calculated by equation (7) and the actual value is -11.32% in 2012, the min. distortion is 0.00% in 2009, the mean relative distortion is 6.25 % in China from 2009 to 2019. That shows the high accuracy of the fitted logistic equation model.

According to the formula (7), the China industrial CO_2 emissions come from energy consumption from 2020 to 2029 are predicted in the paper, the results show in Table 2.

Table 2. The forecast for industrial energy-related $\mathbf{CO_2}$ emissions of China(10,000 tons), 2020-2029

Year	$\mathbf{CO_2}$ emissions	Year	$\mathbf{CO_2}$ emissions
2020	**344101.3**	**2025**	**399403**
2021	**355023.5**	**2026**	**410591.6**
2022	**366030.2**	**2027**	**421785.4**
2023	**377106.2**	**2028**	**432967.9**
2024	**388235.8**	**2029**	**444122.9**

3.4. The GM model forecast results

According to relevant basic data and GM predict model, the China total industrial CO_2 emissions come from energy consumption prediction formula can be got:

$$\hat{c}^{(1)}(k-1)=\left[c^{(0)}(1)-269370\right]e^{-0.0152m}+269370,\ m=1,\ 2,3\ldots,\ n \tag{8}$$

According the formula (8), the China total industrial CO_2 emissions come from energy consumption during 2009 to 2019 can be forecasted and calculated. he compare between the actual value and forecasted one during the same period show in Fig.4 and Table 3.

Table 3. The industrial $\mathbf{CO_2}$ of China actual and forecast error table (GM model)

Year	predicted energy-related $\mathbf{CO_2}$emissions (10,000 tons)	Actual energy-related $\mathbf{CO_2}$ emissions (10,000 tons)	Relative errors
2010	**253443.2**	**275016.3**	**8.51%**
2011	**278934**	**279236.4**	**0.11%**
2012	**294773.5**	**283521.2**	**-3.82%**
2013	**304610.9**	**287871.9**	**-5.50%**
2014	**303199.8**	**292289.2**	**-3.60%**
2015	**296242.9**	**296774.4**	**0.18%**
2016	**294097**	**301328.4**	**2.46%**
2017	**297975.8**	**305952.3**	**2.68%**
2018	**307114.4**	**310647.1**	**1.15%**
2019	**317622.8**	**315413.9**	**-0.70%**

Figure 4 shows that the max. error between forecast CO_2 emissions which calculated by GM model and the actual value is 8.51% in 2010, the min distortion is 0.11% in 2011, the mean relative distortion is 2.87 % in China from 2010 to 2019. Compared to the results of Logistic model, the results of GM model have a higher precision. However, the GM model only has the advantages in a short term predict, so GM model is just use to forecast CO_2 emissions from 2020 to 2024 and make a compare with the results of Logistic model.

As is visible from Table 4, the difference of industrial energy-related CO_2emissions of China predicted by two models from 2020 to 2024 is very small, and so the result of prediction has very high credibility. The growth of CO_2 emissions from 2020 to 2024 can be calculated according to table 3 and table 4, and it is projected at 1.5%-3.2%.

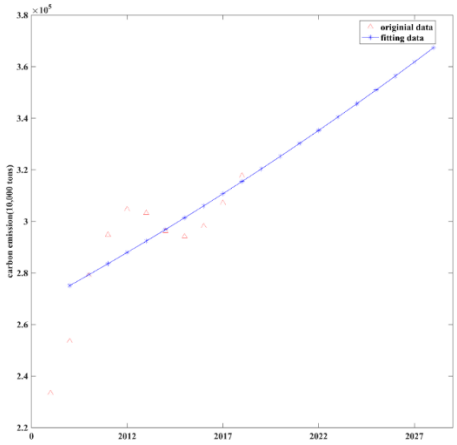


Fig. 4. China industrial energy-related CO_2 emissions and predict fitting graph (GM model)

Table 4. The forecast results of the industrial CO_2 emissions of China by the two model

Year	Predicted energy-related CO_2 emissions of Logistic (10,000 tons)	Predicted energy-related CO_2 emissions of GM (10,000 tons)	The difference between two predictions
2020	**344101.3**	**320253.9**	**23847.4**
2021	**355023.5**	**325168.2**	**29855.3**
2022	**366030.2**	**330157.9**	**35872.3**
2023	**377106.2**	**335224.2**	**41882**
2024	**388235.8**	**340368.2**	**47867.6**

4. Conclusions and suggestions

4.1. Conclusions

(1) Due to the rapidly development of economy, China industrial energy consumption raise 39.53% in 2019 over 2009 level; owe to energy-saving policies' measures and development of energy saving technologies, China energy consumption per unit industrial added value of declined to 38.21 % from 2009 to 2019.

(2) China total industrial CO_2 emissions come from energy consumption grow year by year; growth's mean annual rate is 3.2% from 2009 to 2019; and carbon emission intensity fell by 29.1% from 2009 to 2019.

(3) With the two model's calculation result, the growth rate of China total industrial CO_2 emissions come from energy consumption from 2020 to 2024 can be forecast and that is at 1.5%-3.2%.

4.2. Suggestions

To achieve the goal of achieve carbon peak and carbon neutrality in 2030 and 2060 respectively, and energy structure adjustment, based on the paper results and the status quo of China's industrial development, this paper proposes the following recommendations:

(1) Improve the portion of quality energy we used, cut the number of raw coal burned. Developing renewable energy vigorously, such as geothermal energy, solar energy, biomass energy, so that it can further optimize the energy consumption structure.

(2) Accelerate the high technology and low-energy consumption industries develop for further optimize the industrial structure. Firstly, control from the resource. Secondly, apply high and new technology actively, and transform traditional heavy energy-intensive industries, which turns the “high put, low output, high consumption” into ”low input, high output, low consumption”, so that it improves the quality of industrial development.

(3) Make good use of some mechanisms such as carbon emissions exchange, and use market mechanisms to reach the development of low carbon and green with lower the cost.

(4) Government functional departments at all levels should work together, strengthen the supervision of the implement efficiency policy. Firstly, promote energy conservation efforts of energy consumption monitoring institutions. Secondly, law enforcement departments perform their respective duties to strength oversight of energy saving. Ensure energy conversation and environmental protection policy execution by strengthening supervision, performing regulatory responsibilities earnestly and accelerating energy conservation and emission reduction work.

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