Carbon Emission Prediction of Civil Buildings in China based on Improved Grey Prediction Method

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Abstract: Civil construction is an important source of carbon emissions. The implementation of total carbon emission control for civil buildings is an important means to achieve energy conservation and emission reduction in China. The study divides civil buildings into urban residential buildings, rural residential buildings, public buildings, and northern urban heating. The study calculates and predicts the total carbon emissions of China's civil buildings. Firstly, according to the statistical method of IPCC, the calculation model of carbon emissions of civil buildings is constructed, and the total amount of carbon emissions of civil buildings in China from 2005 to 2016 is calculated by using the energy balance table. Further, based on the improved grey prediction method, the national civil use from 2017 to 2025 is predicted. Total carbon emissions from construction. The forecast results show that in 2017-2025, the annual average carbon emission growth rate of buildings is about 4.65%, and by 2025, the total emission is expected to reach 298.176 million tons of CO₂. In order to achieve the 2030 emission reduction target, it is necessary to further optimize the energy structure, improve the energy efficiency of the building, and increase the carbon emission reduction in civil construction.

Since the reform and opening up, the process of urbanization in China has been continuously promoted, and the proportion of building energy consumption in total social energy consumption has been increasing. At present, the energy consumption of China's civil buildings has reached 20% of the total social energy consumption [1]. According to the experience of developed countries, the proportion of energy consumption of civil buildings over the life of the building will be at 40% [2], while foreign researchers have shown that the energy consumption of civil buildings in the operational phase accounts for up to 80% of the whole life period [3]. The large amount of CO₂ generated by civil buildings makes China's energy conservation and emission reduction work face severe challenges. The energy saving of civil buildings will be a key area for China to achieve the 2030 carbon emission reduction target. Therefore, it is necessary to calculate the carbon emission data of civil buildings in the past and predict the carbon emission scale of civil buildings in China in the future. It can provide reference and basis for the relevant government departments to formulate and implement carbon emission policies.

1 Research review
In the field of carbon emission prediction, domestic and foreign scholars have proposed a variety of prediction models and methods for application in specific practice. Xu Li and Qu Jiansheng (2019) used the ARIMA model to predict the carbon emissions of China's residents' energy consumption in the next decade [4]. Zhao Yatao (2018) established a regression model of China's power consumption...
through multivariate statistical analysis. Based on the scenario analysis method, the carbon emissions of China's coal-fired power industry in 2018-2030 were predicted\textsuperscript{[5]}. He Yonggui (2018) analyzed the four major factors affecting carbon emissions in Hebei Province through the STIRPAT model, and predicted the future carbon emissions in Hebei Province based on the gray GM (1,1) model\textsuperscript{[6]}. Based on the gray prediction method widely used in energy, production, design and other fields\textsuperscript{[7]}, this paper chooses the gray prediction method to study the problem, and through the improvement method, to make up for the existing vulnerabilities of the gray method.

2 China's civil construction carbon emissions accounting

2.1 Carbon emission accounting range

According to the function of building use, China divides civil buildings into residential buildings and public buildings\textsuperscript{[8]}, among which residential buildings are divided into urban residential buildings and rural residential buildings. The main commodity energy types used in the three types of civil buildings (excluding heating in the northern regions) are coal, gas, liquefied petroleum gas, natural gas and electricity. Since the energy types and heating methods in the north and south regions, rural areas and urban areas in China are obviously different when heating in winter, the carbon emissions from heating in the north are separately accounted for. Therefore, this paper divides the national construction carbon emission accounting scope into four parts: public buildings (excluding northern heating), urban residential buildings (excluding northern heating), rural residential buildings and northern urban heating.

2.2 Carbon emission accounting method

Since there is no universal accounting system for CO\textsubscript{2} emissions Internationally, the IPCC proposes to estimate CO\textsubscript{2} emissions based on energy consumption and energy carbon content, energy carbon emissions = energy consumption × energy carbon emission factors

Among them, energy carbon emission factor = energy fuel calorific value × energy unit calorific value carbon content × energy combustion carbon oxidation factor

All data are based on the values specified by the relevant government in China. The energy carbon emission factors are shown in Table 1.

| Energy type               | Carbon emission factor | Energy type               | Carbon emission factor |
|---------------------------|------------------------|---------------------------|------------------------|
| 1 raw coal                | 1.90kgCO\textsubscript{2}/kg | 6 gasoline               | 2.93kgCO\textsubscript{2}/kg |
| 2 Briquette               | 1.86kgCO\textsubscript{2}/kg | 7 kerosene               | 3.04kgCO\textsubscript{2}/kg |
| 3 coke                    | 2.86kgCO\textsubscript{2}/kg | 8 diesel                 | 3.1kgCO\textsubscript{2}/kg |
| 4 liquefied petroleum gas | 3.10kgCO\textsubscript{2}/kg | 9 standard coal          | 2.77kgCO\textsubscript{2}/kg |
| 5 natural gas gas         | 1.98kgCO\textsubscript{2}/m3 | 10 electricity           | 0.60-0.96kgCO\textsubscript{2}/KWh |

Therefore, the calculation of carbon emissions in China's civil buildings can be expressed as a formula:

\[ C = \sum_{i=1}^{4} C_i = \sum_{i=1}^{4} \sum_{j=1}^{10} E_{ij} \times G_j \quad (i=1,2,3,4; j=1,2,3,\ldots,10) \]  

\[ C \quad \text{—— Total carbon emissions of all national buildings} \]

\[ C_i \quad \text{—— The total carbon emissions of the i-type buildings} \]

\[ E_{ij} \quad \text{—— Class j energy consumed by Class i buildings} \]

\[ G_j \quad \text{—— Class j energy carbon emission factors} \]
2.3 Calculation of carbon emissions

Except for Tibet, Hong Kong, Macao and Taiwan, the energy consumption of urban residential buildings, rural residential buildings and public buildings can be obtained from the Energy Balance of the National Energy Statistics Yearbook. Since most of the oil products are consumed in transportation, only 5% of the gasoline in the public buildings, 35% of the kerosene and diesel consumption are calculated; 5% kerosene and diesel consumption. The sources of energy consumption data for civil buildings are shown in Table 2.

Table 2. Energy consumption of civil buildings

| Building energy consumption type   | Energy balance table department                  | Types of energy consumption and their proportion                                      |
|-----------------------------------|-------------------------------------------------|--------------------------------------------------------------------------------------|
| public building                   | Wholesale, retail and accommodation, catering;  | All raw coal, briquette, coke, liquefied petroleum gas, natural gas and electricity;   |
|                                  | other                                           | 5% gasoline, 35% kerosene and diesel                                                 |
| Urban residential building        | Urban sub-items in daily consumption             | All raw coal, briquette, coke, liquefied petroleum gas, natural gas and electricity;   |
| Rural residential building       | Rural sub-items in life consumption              | 5% kerosene and diesel                                                                |
| Northern town heating             | Taken from the "China Building Energy Conservation Annual Development Research Report" |

The carbon emissions of civil buildings in 2006-2016 are calculated according to formula (1). The results are shown in Table 3.

Table 3. Carbon emission of civil buildings in China from 2005 to 2016 (Unit: ten thousand tons)

| Year | 2016 | 2015 | 2014 | 2013 | 2012 | 2011 | 2010 | 2009 | 2008 | 2007 | 2006 | 2005 |
|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Total carbon emissions            | 1969 | 1875 | 1830 | 1853 | 1710 | 1603 | 1495 | 1448 | 1365 | 1315 | 1239 | 1123 |
| Annual growth rate(%)             | 5.02 | 2.44 | -1.22 | 8.33 | 6.72 | 7.17 | 3.28 | 6.11 | 3.74 | 6.15 | 10.3 |

Although the carbon emissions of our civil buildings continue to grow, the growth rate is gradually decreasing. The average annual growth rate has decreased from 5.92% during the 11th Five-Year Plan period to 4.69% during the 12th Five-Year Plan period. The consumption of energy by residents is gradually increasing, and the quality of life is gradually improving. On the other hand, the effect of emission reduction in China has been significantly improved. It is worth noting that the carbon emissions of civil buildings in 2014 showed a downward trend for the first time. The reasons are as follows: China issued the “Twelfth Five-Year Plan” for energy development in 2013, and included carbon emissions per unit of GDP into the inspection system, which intensified the implementation of energy saving and emission reduction; secondly, due to advances in technology, the carbon emission factor of electricity in 2014 was significantly lower than that in 2013. Although the total electricity consumption showed an increasing trend, the final carbon emission decreased.

3 China’s civil construction carbon emissions forecast

In 1982, Deng Julong proposed the grey method theory, and the gray GM (1,1) prediction model is the core of the grey method theory. The grey prediction model accumulates the existing data to make the unordered initial data into exponentially increasing data, and uses the least squares method to fit the data through the differential equation to form a prediction model. The model has high accuracy and is suitable for forecasting total carbon emissions.
3.1 Traditional Grey GM (1,1) Model

The total carbon emissions of civil buildings in 2005-2016 is the original data sequence $X^{(0)}$:

$$X^{(0)}=(X^{(0)}(1),X^{(0)}(2),X^{(0)}(3),\ldots,X^{(0)}(12))$$

(2)

Where, $X^{(0)}(i)$ is the carbon emissions of urban buildings in the i-th year, and $X^{(0)}$ is formed by accumulating columns $X^{(1)}$:

$$X^{(1)}=(X^{(1)}(1),X^{(1)}(2),X^{(1)}(3),\ldots,X^{(1)}(12))$$

(3)

$$X^{(1)}(k)=\sum_{i=1}^{k}X^{(0)}(i), k=1,2,3,\ldots,12.$$  

Find the immediate mean column $Z^{(1)}$ on the basis of $X^{(1)}$:

$$Z^{(1)}=(Z^{(1)}(2),Z^{(1)}(3),Z^{(1)}(4),\ldots,Z^{(1)}(12))$$

(4)

$$Z^{(1)}(k)=\frac{1}{2}(X^{(1)}(k)+X^{(1)}(k-1)), k=2,3,4,\ldots,12.$$  

Through the above data processing, the corresponding differential equation of the GM(1,1) model is defined as:

$$\frac{dX^{(1)}}{dt}+aX^{(1)}=\mu$$

(5)

Where, $a$ is the development gray number, the change trend of the predicted value can be judged; $\mu$ is the endogenous control gray scale, which can reflect the change relationship of the data.

Let $A=(a, \mu)^T$ be the estimated parameter vector and solve it by least squares method to get $A=(B^TB)^{-1}B^TY_n$.

$$B=[-Z^{(1)}(2) 1 \ \ -Z^{(1)}(3) 1 \ \ -Z^{(1)}(12) 1], \ Y_n=[X^{(0)}(2) \ \ X^{(0)}(3) \ \ \vdots \ \ X^{(0)}(12)]$$

The corresponding sequence of time is:

$$X^{(1)}(k+1)=(X^{(0)}(1)-\frac{\mu}{a})e^{-ak}+\frac{\mu}{a}$$

(6)

Perform a subtraction on equation (6) to get the predicted value of the original sequence:

$$X^{(0)}(k+1)=X^{(1)}(k+1)-A^{(1)}(k)=(1-e^a)(X^{(0)}(1)-\frac{\mu}{a})e^{-ak}$$

(7)

Calculated $a=0.04655$, $\mu=11.80529$

$$X^{(0)}(k)=[12.3959, 13.1578, 13.6505, 14.4849, 14.9595, 16.0322, 17.1094, 18.5339, 18.3086, 18.7562, 19.6971)$$  

3.2 Gray GM (1,1) model optimization

Through the above process of solving the model, it can be found two problems in its existence. First, in the process of solving the parameters $a$ and $\mu$, the background value $Z^{(1)}(k)$ needs to be calculated. In the traditional GM (1, 1) model, the background value $Z^{(1)}(k)$ is solved by the immediate value, and the trapezoidal area is used.

However, as the index increases, the error of the algorithm will also become larger and larger, so the background value should be avoided in the optimization process. Second, the traditional GM (1,1) model default point $(1, X^{(0)}(1))$ is on the fitting curve $X^{(1)}(k)$, but according to the principle of least
squares, the data starting point is not always on the fitting curve, so it is necessary the initial point raw data is processed to make the calculation more accurate.

(1) Avoiding background value optimization
In terms of avoiding background values, Xu Tongle (2018) proposed a formula for avoiding background values by combining Euler's formula:

\[
X^{(0)}(k+1) = -X^{(1)}(k) \frac{ah}{1+ah} + \frac{\mu h}{1+ah}
\]

(8)

Where, \( h \) is the step size, generally taking \( h=1 \).

Equation (8) can be expressed as \( CA = Y \)

Since the matrices \( C \) and \( Y \) relate only to \( X^{(1)}(k) \) and \( X^{(0)}(k) \), both can be obtained by known conditions. In this case, the values of \( M \) and \( N \) can be obtained to obtain \( a \) and \( \mu \), and the avoidance of the background value is completed.

The calculation can be obtained: \( a=-0.0455 \), \( \mu=11.5398 \)

(2) Initial point optimization
In the initial point of raw data processing, using \( \lambda X^{(0)}(1) \) instead of \( X^{(0)}(1) \), substituting \( \lambda X^{(0)}(1) \) into equation (7):

\[
X^{(0)}(k+1) = X^{(1)}(k+1) \cdot X^{(1)}(k) = (1+e^a)(\lambda X^{(0)}(1) - \frac{\mu}{a})e^{-ak}
\]

(9)

The model makes up the impact of the fixed initial value on the prediction accuracy by giving the initial value parameter. Based on this, the model is further improved. The improvement process is shown in Figure 1:

![Flow Chart of Improved Model](image)

**Figure 1.** Flow chart of the improved model

The average relative error between the predicted value and the actual value of \( \lambda=1 \) is calculated by the equation (9). On this basis, increase or decrease a small amount of \( \Delta \lambda (\Delta \lambda = 0.01) \), both \( \lambda = \lambda + \Delta \lambda \) or \( \lambda = \lambda - \Delta \lambda \). Then select the \( \lambda \) when the average relative error is...
the smallest, and substitute the equation (9) for gray prediction. So far, the improvement process of the gray method is completed.

The calculation is available: $\lambda = 1.46$

According to the above improved gray GM (1,1) method, the carbon emission forecast of China's civil buildings can be calculated. The forecast results are shown in Table 4.

Table 4. Table of predicted values and error comparison

| Year | Total carbon emissions | Traditional gray method prediction value | Relative error(%) | Improve the gray method prediction value | Relative error(%) |
|------|------------------------|------------------------------------------|------------------|------------------------------------------|------------------|
| 2006 | 123959                 | 126198                                   | 1.81             | 125691                                   | 1.39             |
| 2007 | 131578                 | 132212                                   | 0.48             | 131538                                   | -0.03            |
| 2008 | 136505                 | 138513                                   | 1.47             | 137656                                   | 0.84             |
| 2009 | 144849                 | 145209                                   | 1.63             | 145114                                   | 0.77             |
| 2010 | 160322                 | 159275                                   | 0.65             | 157773                                   | -1.58            |
| 2012 | 171094                 | 166865                                   | 2.47             | 165112                                   | -3.49            |
| 2013 | 185339                 | 174817                                   | 5.68             | 172972                                   | -6.76            |
| 2014 | 183086                 | 183148                                   | 0.03             | 180830                                   | -1.23            |
| 2015 | 187562                 | 191877                                   | 2.30             | 189241                                   | 0.89             |
| 2016 | 196971                 | 201021                                   | 2.05             | 198044                                   | 0.54             |
| Average relative error |                         |                                          | 1.71             |                                          | 1.64             |

3.3 Gray model test

To ensure that the established improved grey model can be used for actual predictions, the following tests are required:

$$e(k) = X^{(0)}(k) - \bar{X}^{(0)}(k), \Delta_k = \left| \frac{e(k)}{X^{(0)}(k)} \right| \times 100\%, \Delta = \frac{1}{n} \sum_{k=1}^{n} \Delta_k$$

Where, $e(k)$ is the residual value, $\Delta_k$ is the relative error, and $\Delta$ is the average relative error. The results are shown in Table 4.

According to Table 4 we can calculate:

The average of the raw data is $\bar{X}^{(0)} = \frac{1}{n} \sum_{k=1}^{n} X^{(0)}(k) = 156934$

The average of the residual values is $\bar{e} = \frac{1}{n-1} \sum_{k=2}^{n} e^{(0)}(k) = -0.1578$

The raw data variance is $S_1^2 = \frac{1}{n} \sum_{k=1}^{n} (X^{(0)}(k) - \bar{X}^{(0)})^2 = 7.1492$

The variance of the residual is $S_2^2 = \frac{1}{n-1} \sum_{k=2}^{n} (e^{(0)}(k) - \bar{e})^2 = 0.1706$

Mean variance ratio $C = S_2/S_1 = 0.1545$
The small probability error is \( p = P \left( e^{(k)} - e \right) \leq 0.6745 s_{ij} = 82\% \).

Comparing the mean square error ratio with the small probability error value with Table 5, it can be seen that the improved gray model we constructed can be used for practical prediction.

| Accuracy level          | good | general | qualified | unqualified |
|------------------------|------|---------|-----------|-------------|
| Mean variance ratio    | ≤0.35| ≤0.50   | ≤0.65     | > 0.65      |
| Small error probability| ≥0.95| ≥0.80   | ≥0.70     | < 0.70      |

At the same time, based on Table 4, it can be seen that the improved gray method effectively reduces the average relative error from 1.71% to 1.64% compared to the traditional gray method. Therefore, it can be predicted 2017 more accurately through the improved gray method. Carbon emissions from civil buildings in 2025, the results are shown in Table 6:

| Year | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 |
|------|------|------|------|------|------|------|------|------|------|
| Total carbon emissions | 20725 | 21689 | 22698 | 23754 | 24859 | 26015 | 27225 | 28492 | 29817 |

According to the calculation results of Table 2 and Table 6, we can get a graph about the carbon emissions of our civil buildings, as shown in Figure 2.

As shown in Figure 2, the carbon emissions of our civil buildings have been increasing from 2005 to 2025, from 112.35 million tons in 2005 to 298.17 million tons in 2025, with a growth rate of 165.40%. The average annual growth rate is 5.03%, and the growth rate has not decreased since 2018. This is because the premise of the grey forecasting method is that there is no major change in the overall environmental background of the forecast. The predictions made above are based on the growth of China's residents' energy consumption levels, the adjustment of China's energy policy, and the progress of low-carbon technologies. Great changes, so we can conclude that under the current environmental background, China's civil construction carbon emissions will continue to maintain low and medium-speed growth, and China will not be able to complete the 2030 carbon emissions peak target signed on the Paris Agreement. Therefore, in order to successfully complete the 2030 emission reduction target, China needs to increase the implementation of emission reduction policies and the development of low-carbon technologies.
4 Conclusion
Based on the IPCC inventory method, this paper calculates the carbon emissions of civil buildings in China from 2005 to 2016, and predicts the carbon emissions of civil buildings in China from 2017 to 2025 through the improved grey prediction method. The following conclusions are obtained through the analysis of the above calculation results:

1) The average annual growth rate of carbon emissions during the “Eleventh Five-Year Plan” period is lower than the “Twelfth Five-Year Plan” period, indicating that the effect of China's energy conservation and emission reduction policies is obvious.

2) Based on the background of the grey forecasting method, China's existing emission reduction policies are insufficient to ensure the completion of the 2030 emission reduction target, and the carbon emissions of civil buildings will continue to maintain low and medium-speed growth, so we need more effective measures to reduce carbon emissions growth trend. Based on China's national conditions, for one thing, we must continue to promote the energy-saving renovation of existing building, for another thing, we must greatly increase the proportion of green buildings and passive buildings in new buildings, especially public buildings, and consider the needs of residents' comfort and health.

3) From the first reduction of carbon emissions in 2014, we can see that the carbon emission factors of electricity can continue to decline under the existing technical conditions, and contribute greatly to the reduction of carbon emissions. Therefore, we should adjust the civil buildings. The energy consumption structure advocates the use of electricity to replace other energy sources and strives to achieve “0” emissions.

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