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Calculation and Analysis of Carbon Emission in Construction Operation Stage and Prediction of Carbon Peak in Anhui Province

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Abstract

This paper uses the carbon emission coefficient method to calculate the carbon emission in the operation stage of Anhui Province from 2012 to 2019, takes this data as a sample, uses the GM (1,1) grey prediction model to predict and analyze the carbon emission in the construction operation stage from 2020 to 2035, and finally puts forward the corresponding emission reduction countermeasures for the operation stage of Anhui Province, so as to provide a certain reference for Anhui Province to achieve "carbon peak" in the construction field as soon as possible.

Keywords

Anhui Province; Construction Operation Stage; Carbon Emissions; Gray Prediction.

1. Introduction

In September 2020, China put forward a plan to reach the carbon peak by 2030 and achieve carbon neutrality by 2060 [1]. Looking back on the past, China's total energy consumption in 2019 increased by 706% from 1980 to 4.86 billion tons of standard coal. China's carbon dioxide emissions from related energy sources also increased rapidly. In 2019, the total carbon emissions ranked first in the world, reaching 9.8 billion tons. In 2021, China issued the outline of the 14th five year plan and long-term objectives for 2035 [2], which proposed the goal of "improving the research and efficient utilization of clean energy, and further promoting the transformation of industry, construction, transportation and other fields to low-carbon". Anhui Province has been actively responding to national policies. In order to contribute to energy conservation and emission reduction, Anhui Province plans to fully promote the development of green and low-carbon cycle and strive to improve energy efficiency. As a major energy province, with the rapid development of energy industry in Anhui Province, the total production also increases year by year, and the emissions of carbon dioxide and other greenhouse gases produced by energy enterprises also increase year by year. Therefore, it is necessary to study the current situation of carbon emission in Anhui Province, which is of positive significance for Anhui Province to reach the carbon peak before 2030.

Due to the proposal of the concept of low-carbon economy, scholars in relevant fields began to study the carbon emissions of the construction industry, mainly including carbon peak analysis, carbon reduction policies, accounting carbon emissions and so on. In the research on energy conservation and emission reduction strategies suitable for the construction industry, building materials and economic development, Chen Yuxin (2016) [3] used the grey prediction model to predict the direct and indirect carbon emissions of each region, summarize the carbon emission characteristics of these regions, and put forward the corresponding carbon reduction strategies according to their characteristics. Nakata (2009) [4] studied Japan's carbon tax policy and found that the implementation of the carbon tax policy has a significant effect on energy conservation and emission reduction, effectively increasing people's use of clean energy, such

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as electric energy and solar energy, and reducing people's use of energy with high carbon emissions such as coal and oil.

Taking Anhui Province as the research object, this paper calculates the carbon emission in the construction operation stage from 2012 to 2019, and constructs the GM (1,1) grey prediction model to predict the carbon emission from 2020 to 2035. By studying the peak value of carbon emission in the construction operation stage of Anhui Province, it is helpful to understand the progress and effectiveness of low-carbon development in Anhui Province, help Anhui Province formulate carbon emission reduction targets and measures, and provide help for Anhui Province to explore its own carbon emission reduction path. On the other hand, it provides a reference for provincial administrative departments to formulate carbon emission reduction strategies.

2. Model Construction of Carbon Emission Calculation and Carbon Peak Prediction in Construction Operation Stage

2.1. Calculation Model of Carbon Emission in Building Operation Stage

The Research Report on China's building energy consumption (2016) points out that the energy consumption of the construction industry refers to the energy consumption of the construction industry as the material production department of the national economy, and the building energy consumption refers to the energy consumption in the construction operation stage [5]. According to this definition concept, this paper adopts the carbon emission coefficient method [6] to establish the carbon emission calculation model in the construction operation stage according to the guidelines for the preparation of provincial greenhouse gas inventories. The model is as follows:

$$T = \sum_{i=1}^{5} \sum_{j=1}^{15} C_{ij} E_j$$

$TC_{ij}E_j$Among them,it is the total carbon emission in the construction and operation stage of Anhui Province,the j terminal energy consumption of category i, and the carbon emission coefficient of the j th energy. Domestic consumption, wholesale and retail industry, catering industry, transportation and storage, post and telecommunications industry and other industries are selected as the energy consumption sources in the construction operation stage, and 15 main energy consumption such as raw coal, briquette, coke, coke oven gas, crude oil, gasoline, kerosene, diesel, fuel oil, LPG, natural gas, other petroleum products, heat, electricity and other energy are selected. The carbon emission coefficients of thermal power, electric power and other energy sources are 0.709kgc/kgce, 0.24286kgc/kwh and 0.67kgc/kgce respectively. The carbon emission coefficients of the other 12 energy sources = carbon content × Average low calorific value × Carbon oxidation rate.

2.2. Construction of Carbon Peak Prediction Model in Building Operation Stage

Grey prediction model is a medium and long-term prediction of grey system, which is used to solve the problem of future development trend in some fields. Other relevant domestic scholars apply it to many fields, such as economic growth, traffic accident prediction and environmental pollution, mainly through the processing of raw data to find the law of system change, generate a strong regular data sequence, and establish a differential equation model on the basis of the generation and processing of raw data, so as to make a scientific and quantitative prediction of the future state of the system, which requires less modeling information, simple operation It is an effective tool to deal with the prediction problem of small samples. Therefore, this paper uses GM (1,1) grey prediction model to predict and analyze the carbon emission in the construction operation stage of Anhui Province.

1. Construct the original sequence: let the equal interval time T series have n observations, (t = 1, 2, 3, ..., n), $X_{(t)}^{(0)} = \{X_{(1)}^{(0)}, X_{(2)}^{(0)}, \ldots, X_{(n)}^{(0)}\}$.

2. Construct cumulative sequence: generate new sequence through accumulation, $X_{(t)}^{(1)} = \{X_{(1)}^{(1)}, X_{(2)}^{(1)}, \ldots, X_{(n)}^{(1)}\}$.

3. Conduct the quasi-smoothness test and the quasi-exponential test for the original and new sequences:first check whether the sequence can pass the quasi-smoothness test, $p(t) = \frac{X_{(t)}^{(0)}t}{X_{(t)}^{(0)}(t-1)}$, so that if t>3, if p(t)<0.5, the quasi-smoothness test is satisfied. Secondly, test whether the sequence $X_{(t)}^{(1)}$ meets the quasi-exponential rule, $d(t) = \frac{X_{(t)}^{(1)}t}{X_{(t)}^{(1)}(t-1)}$, when t>3, if 1 <d(t)<1.5, indicating that the data meets the quasi-exponential law, can use the gray prediction model for predict[6].

4. Establish the differential equation: GM (1,1) prediction model: $\frac{dX_{(t)}^{(1)}}{dt} + aX_{(t)}^{(1)} = u$, a is the development coefficient and u is the endogenous control coefficient.

5. Construct matrix B and data vector X:

$$B=\begin{bmatrix} -(1/2)(X_{(1)}^{(1)} + X_{(2)}^{(1)}) & 1 \\ -(1/2)(X_{(2)}^{(1)} + X_{(3)}^{(1)}) & 1 \\ \cdots & \cdots \\ -(1/2)(X_{(n-1)}^{(1)} + X_{(n-2)}^{(1)}) & 1 \end{bmatrix}, X = \begin{bmatrix} X_{(2)}^{(0)} \\ X_{(3)}^{(0)} \\ \cdots \\ X_{(n)}^{(0)} \end{bmatrix}$$

6. Construction of prediction equation: setaas the parameter variable to be evaluated, $\hat{a} = (\frac{a}{u})$, using the least squares method solution, and then obtain the prediction equation: $\hat{a} = (B^TB)^{-1}B^TX$, $X_{(t+1)}^{(1)} = (X_{(1)}^{(0)} - \frac{u}{a})e^{-at} + \frac{u}{a}$

7. Model test: calculate the variance ratio and small error probability of the standard deviation, and test the accuracy of the prediction model by comparing with the accuracy standard grade table of the prediction model (see Table 1). After the prediction model is established, the prediction accuracy shall be tested. It can be used only when the calculation accuracy of the prediction model meets the requirements. Otherwise, even if the prediction results are not realistic, it cannot be used. The specific formula is as follows:

Standard deviation of original sequence:

$$S_1 = \sqrt{\frac{\sum \left[X_{(t)}^{(0)} - \overline{X}_{(t)}^{(0)}\right]^2}{n-1}}$$

$$S_2 = \sqrt{\frac{\sum \left[\Delta_{(t)}^{(0)} - \bar{\Delta}_{(t)}^{(0)}\right]^2}{n-1}}$$

Variance ratio: $C = \frac{S_2}{S_1}$

Small error probability: $P = P\left\{\left|\Delta_{(t)}^{(0)} - \bar{\Delta}_{(t)}^{(0)}\right| < 0.6745S_1\right\}$

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Where, $\Delta_{(t)}^{(0)} = \left| X_{(t)}^{(0)} - \overline{X}_{(t)}^{(0)} \right|$, (t = 1, 2, 3, ..., n), $\overline{X}_{(t)}^{(0)} = \frac{1}{n}\sum_{t=1}^{n} X_{(t)}^{(0)}$ is the mean value of the original data and $\overline{\Delta}_{(t)}^{(0)} = \frac{1}{n}\sum_{t=1}^{n} \Delta_{(t)}^{(0)}$ is the mean value of the original data $\Delta_{(t)}^{(0)}$.

Table 1. Predicts the standard grade of the model accuracy

Model accuracy level	P	C
First level, excellent	$P \geq 0.95$	$C \leq 0.35$
Second level, good	$0.80 \leq P < 0.95$	$0.35 < C \leq 0.50$
Third level, qualified	$0.7 \leq P < 0.80$	$0.50 < C \leq 0.65$
Fourth level, unqualified	$P < 0.70$	$C > 0.65$

3. Empirical Analysis of Carbon Emission and Carbon Peak Prediction in the Construction Operation Stage of Anhui Province

3.1. Data Source and Processing

Table 2. The correlation coefficient of carbon emission calculation in Anhui Province

class	Carbon content (ton / too coke)	Average low heat generation rate (kJ / kg)	Carbon oxidation rate	Carbon emission coefficient (ten thousand tons of carbon / ten thousand tons)
raw coal	26.37	20908	0.94	0.5183
briquette	33.6	17563	0.9	0.5311
crude oil	20.1	41816	0.98	0.8237
gasoline	18.9	43070	0.98	0.7977
diesel oil	20.2	42652	0.98	0.8443
kerosene	19.6	43070	0.98	0.8273
fuel oil	21.1	41816	0.98	0.8647
coke	29.5	28435	0.93	0.7801
coal oven gas	13.58	16726	0.99	2.2487
natural gas	15.3	38931	0.99	5.8969
LPG	17.2	50179	0.98	0.8458
Other petroleum products	20	35125	0.98	0.6885

Note: The average low calorific value unit of natural gas and coke oven gas is one thousand coke / cubic meters, and the carbon emission coefficient unit is ten thousand tons of carbon / 100 million cubic meters

Referring to the China Energy Statistics Yearbook (2013-2020), we can get all kinds of energy consumption in the construction operation stage of Anhui Province. The carbon content and carbon oxidation rate of energy are derived from the guidelines for the preparation of provincial greenhouse gas inventories; The type of energy comes from the general rules for calculation of comprehensive energy consumption; The average low calorific value of energy comes from the reference coefficient of various energy converted into standard coal in Appendix 4 of China energy statistical yearbook. According to the table of average CO2 emission

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factors of power supply in China's regional power grid, the power carbon emission coefficient [8] can be calculated. Based on the above data, the correlation coefficient of carbon emission calculation in Anhui Province can be obtained. As shown in Table 2.

3.2. Analysis of Carbon Emission Calculation Process in Construction Operation Stage in Anhui Province

By referring to the China Energy Statistics Yearbook (2013-2020), we can get the energy consumption of Anhui Province in the construction operation stage. Combined with the carbon emission coefficient calculated in Table 2, we can calculate the carbon emission in the construction operation stage from 2012 to 2019 by using the carbon emission calculation model, that is, multiplying and summing the energy consumption and its carbon emission coefficient, as shown in Table 3:

Table 3. Carbon emissions during construction operation in Anhui Province (unit: 10000 tons)

a particular year	run phase
2012	3091
2013	2845.80
2014	2989.29
2015	3070.37
2016	3533.76
2017	3789.75
2018	4473.67
2019	4139.38

3.3. Analysis on the Prediction Process of Carbon Peak at the Construction Operation Stage in Anhui Province

The first step is to construct the original sequence from the carbon emission data generated in the construction operation stage of Anhui Province from 2012 to 2019:

$X_{(t)}^{(0)}$= (3091.00, 2845.80, 2989.29, 3070.37,3533.76,3789.75,4473.67, 4139.38)

In the second step, the sequence is accumulated once to obtain a new sequence:

$X_{(t)}^{(1)}$= (3091,5936.8,8926.09,11996.46,15530.22,19319.97,23793.64,27933.02)

The third step is to test the quasi smoothness of the original sequence and the quasi exponential test of the new sequence. The results are shown in Table 4. It can be seen from the table that when t> 3, p(t)< 0.5, 1 <d(t) < 1.5, indicating that the data meet the feasibility test conditions and can be predicted through the grey prediction model.

Table 4. Quasi-smooth tests $p(t)$ and quasi-exponential tests d(t)

t	1	2	3	4	5	6	7	8
$p(t)$	0	0.92	0.50	0.34	0.29	0.24	0.23	0.17
$d(t)$	0	1.92	1.50	1.34	1.29	1.24	1.23	1.17

The fourth step is to establish the differential equation based on the sequence data $X_{(t)}^{(1)}$:$\frac{dX_{(t)}^{(1)}}{dt} + aX_{(t)}^{(1)} = u$

The fifth step, construct the matrix B and the data vector X

$$B=\begin{bmatrix} -4513.9 & 1 \\ -7431.445 & 1 \\ -10461.275 & 1 \\ -13763.34 & 1 \\ -17425.095 & 1 \\ -21556.805 & 1 \\ -25863.33 & 1 \end{bmatrix}, X=\begin{bmatrix} 2845.8 \\ 2989.29 \\ 3070.37 \\ 3533.76 \\ 3789.75 \\ 4473.67 \\ 4139.38 \end{bmatrix}$$

The sixth step uses the least squares method to solve the prediction equation of carbon emission in the construction stage of Anhui Province: $X^{(1)}_{(t+1)} = 35429e^{0.076t} - 32338$

Step 7: model test. Calculated by Excel, the building operation stage: C=0.336, P=1, compared with the calculation accuracy standard grade table of the prediction model, C=0.336 <0.35, P=1>0.95, so it can be concluded that the accuracy grade of the prediction model is the first grade, excellent. At the same time, compared with the original data, it can be seen that the error between the value calculated by the grey prediction model and the actual value is small (refer to table 5). Therefore, it is feasible to take the data from 2012 to 2019 as the fitting data and use the grey prediction model for medium and long-term prediction after 2019.

Table 5. Calculation and analysis of carbon emission prediction model in construction operation stage of Anhui Province from 2012 to 2019

a particular year	run phase		
	original value	predicted value	fractional error
2012	3091.00	3091.0000	0.0000
2013	2845.80	2793.0173	0.0185
2014	2989.29	3013.2026	0.0080
2015	3070.37	3250.7460	0.0587
2016	3533.76	3507.0160	0.0076
2017	3789.75	3783.4889	0.0017
2018	4473.67	4081.7572	0.0876
2019	4139.38	4403.5393	0.0638

4. Result Analysis and Discussion

4.1. Analysis of Carbon Emission From Building Operation in Anhui Province

According to the carbon emission calculation model of construction operation stage established in Section 2.1, the carbon emission of construction operation stage in Anhui Province from 2012 to 2019 is obtained, as shown in Table 6.

As can be seen from table 6, the carbon emission in the construction operation stage generally shows an upward trend, reaching the peak value in the sample year in 2018 (44.7367 million tons), which is about 1.5 times that in 2012. Different from the construction stage, there are more types of energy consumption in the operation stage, and natural gas, fuel oil, kerosene and LPG begin to occupy a certain proportion. Among them, the consumption of kerosene and fuel oil increased steadily, but the consumption of LPG fell sharply in 2018, producing only 300 tons of carbon emissions. The consumption of gasoline and diesel increased steadily, and their carbon emissions accounted for roughly the same proportion, which also had a certain impact on the carbon emissions in the operation stage. From 2012 to 2019, the carbon emissions generated by electricity and heat fluctuated greatly, and the proportion of their consumption ranked first, which had the greatest impact on the carbon emissions of building operation.

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Overall, the main sources of carbon emissions affecting the construction operation stage are electricity and heat, followed by gasoline and natural gas. Raw coal, kerosene, fuel oil, LPG and briquette account for a small proportion and have little impact. It can be seen that the energy consumption structure has changed in the construction operation stage.

Table 6. Carbon emissions from construction and operation in Anhui Province from 2000 to 2019 (unit: 10000 tons)

a particular year	raw coal	gasoline	kerosene	diesel oil	fuel oil	LPG	natural gas	heating power	power	Operating carbon emissions
2012	111.48	172.67	8.55	342.46	2.59	42.34	98.07	1405.27	907.57	3091
2013	220.87	214.86	7.54	375.00	2.50	68.24	102.61	811.34	1042.84	2845.8
2014	181.65	240.55	8.49	405.17	3.07	78.24	133.56	907.47	1031.09	2989.29
2015	198.71	322.59	11.28	364.12	3.87	81.29	131.74	824.15	1129.18	3070.37
2016	122.67	363.12	12.96	367.08	4.69	84.92	135.63	1032.16	1331.02	3533.76
2017	127.78	412.47	12.61	372.25	8.81	91.97	161.58	1110.29	1457.48	3789.75
2018	58.33	452.73	12.60	388.35	13.23	0.03	197.96	1651.15	1699.29	4473.67

4.2. Prediction and Analysis of Carbon Peak in Construction Operation Stage in Anhui Province

Table 7. Predicted value of carbon emission in construction operation stage of Anhui Province from 2020 to 2035 (unit: 10000 tons)

particular year	Operation phase
2020	4750.6889
2021	5125.2057
2022	5529.2472
2023	5965.1411
2024	6435.3982
2025	6942.7278
2026	7490.0522
2027	8080.5246
2028	8717.5463
2029	9404.7872
2030	10146.2062
2031	10946.0743
2032	11808.9994
2033	12739.9526
2034	13744.2967
2035	14827.8174

According to the analysis of the prediction process of carbon peak in the construction operation stage of Anhui Province in Section 3.3, the grey GM (1,1) model can well predict the carbon emission in the construction operation stage of Anhui Province in the medium and long term, so as to judge whether the construction field of Anhui Province can achieve the carbon peak at a certain time point according to the predicted value. Using Excel software, based on the established grey GM (1,1) model, the construction operation stage of Anhui Province is predicted, and the predicted value of carbon emission from 2020 to 2035 is calculated by the model, as shown in Table 7.

The prediction results show that the construction operation stage shows an exponential growth trend, and the predicted carbon emissions have not reached the peak by 2035. According to table 7, the average annual growth rate of construction operation stage is 3.31%. By 2030, the carbon emission of construction operation stage in Anhui Province will reach 101.462062 million tons, about twice that of 2020. The energy used in the construction operation stage is mainly electricity and heat, so the carbon reduction in the construction operation stage should focus on reducing the demand for energy. Use renewable energy to realize self production and consumption of energy and promote the realization of net zero energy consumption in the operation stage of buildings. It can be seen that the carbon emission situation in the construction field of Anhui Province in recent decades is not optimistic. Building energy consumption accounts for more than 20% of the total social energy consumption, which is a large energy consumer. Energy conservation and carbon reduction in the construction field has become one of the key links to achieve China's carbon peak and carbon neutralization goals. Anhui Province, as a major province of coal, oil and natural gas energy production and consumption, should pay great attention to it.

5. Conclusion and Suggestions

5.1. Conclusion

In this paper, the carbon emission coefficient method mentioned in the provincial greenhouse gas inventory preparation guide is used to establish the carbon emission calculation model in the construction operation stage, and calculate the carbon emission generated in the construction operation stage from 2012 to 2019. Then build GM (1,1) grey prediction model to simulate the data of construction operation stage from 2012 to 2019. It is found that the data meet the feasibility test conditions and the accuracy of the model is excellent. Therefore, GM (1,1) grey prediction model can be used to predict the carbon emission of construction operation stage from 2012 to 2019, and the predicted value of carbon emission of operation stage from 2020 to 2035 can be obtained through model calculation. The analysis results show that the growth trend of carbon emissions in the construction operation stage is very obvious. Improving the energy consumption structure and reducing carbon emissions have become the goal of this stage. It is predicted that the carbon emission in the construction operation stage of Anhui Province has not reached the peak value until 2035. Therefore, Anhui Province should incorporate the requirements of green buildings into the engineering construction specifications, vigorously develop the green concept, promote the distributed renewable energy system, and turn the buildings from energy to new energy ecology.

5.2. Suggestions

The completion of the carbon peak in 2030 and the realization of the "double carbon" policy in carbon in 2060 have been written into the government work report for two consecutive years. However, according to the prediction results of carbon peak in Section 4.2, if the current situation is maintained, the construction operation stage of Anhui Province will still not be able to implement carbon peak by 2035, and the reform is imperative. The energy used in the construction operation stage is mainly electricity and heat. However, due to the more types of energy consumption and wide range involved in the construction operation stage, we can devote ourselves to formulating slow but far-reaching policies to realize the long-term reform plan of net zero energy consumption. In this regard, the following countermeasures are put forward:

(1) Promote the construction of new-type buildings per capita and control the construction area per capita

In recent years, due to the rise of real estate speculation, although the per capita housing area has increased, it has not met the rigid needs of people's housing, and the vacancy rate in Anhui Province has greatly increased. Anhui provincial government can issue relevant policies to reasonably reduce the number of vacant houses on the premise of ensuring the rigid demand of people's housing demand, so as to reduce the waste of heat, electricity and other energy. In addition, the growth of urbanization rate in Anhui Province will lead to the growth of carbon emissions from building operation. Therefore, Anhui provincial government should change the urbanization mode, advocate the development of new urbanization and improve the quality of urbanization in Anhui Province.

(2) Vigorously promote low-carbon environmental protection and make the concept of low-carbon deeply rooted in the hearts of the people

With the growth of population, the concept of green and low-carbon has not been popularized. The government can vigorously promote the concept of green and low-carbon, guide residents' consumption behavior and improve the overall quality of the people. For example, when decorating a new house, consider green and pollution-free decoration materials. When building entrepreneurs purchase energy, they should consider low-carbon and environment-friendly energy. Anhui provincial government can encourage residents to choose green and low-carbon energy by formulating preferential policies for the purchase of green and environmentally friendly materials and products, such as offsetting value-added tax and reducing relevant purchase costs.

(3) Carry out energy-saving transformation of existing buildings and enhance the cascade utilization of energy

The two most used aspects of buildings in operation are electricity and heating. Therefore, in terms of power, Anhui provincial government should actively promote the construction of smart grid, reasonably allocate power resources, and promote the use of clean energy such as hydropower, wind power and nuclear power in the construction industry. In terms of heating, the government can encourage heating enterprises to use energy cascade utilization technology. For example, biomass energy and natural gas complementary distributed energy structure, gas steam combined cycle, solar energy and fuel cell cogeneration system, etc., technically promote energy conservation and emission reduction in heating [9].

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