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Research on Carbon Emission Forecast for Residential Buildings in Anhui Province in 2024 Based on SARIMA

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Abstract

In the context of China's commitment to achieving the "dual carbon" objectives for green, healthy, and sustainable development—specifically, reaching peak carbon emissions by 2030 and achieving carbon neutrality by 2060—the construction industry, a cornerstone of the national economy, confronts multifaceted challenges including elevated carbon emissions, environmental pollution, excessive resource depletion, and a scarcity of specialized personnel. These impediments not only curb the industry's structural transformation and upgrading but also obstruct the progression towards a low-carbon economy. Consequently, in harmony with contemporary trends, the promotion of industrialization in low-carbon building practices emerges as a pivotal pathway and strategic choice for the construction industry to advance towards green and efficient development paradigms. Despite China's nascent strides in the industrialization of low-carbon buildings, it still lags behind in global comparisons, characterized by a late inception and a relatively low overall level of development, thereby encountering a multitude of obstacles and challenges. Within this framework, this academic endeavor focuses intently on residential buildings within Anhui Province. By meticulously amassing data pertaining to carbon emissions from residential buildings in Anhui Province spanning from 2016 to 2022, and employing the Seasonal Autoregressive Integrated Moving Average (SARIMA) model to forecast carbon emissions for the year 2023, it is discerned that the growth rate of carbon emissions has markedly decelerated in recent years, approaching a plateauing trend. Furthermore, this study contributes insightful recommendations tailored to the current trajectory of green building development in Anhui Province.

Keywords

Residential buildings; carbon emission forecasting; SARIMA model.

1. Introduction

Since 2020, China has established the "dual carbon" targets, aiming to balance carbon emissions with economic and social development, build a low-carbon circular economy system, and strive for parallel progress in economic development and environmental protection. The construction industry, as a major emitter of carbon emissions, accounted for nearly half of the national total in 2020[1], playing a crucial role in achieving the "dual carbon" targets. The effectiveness of energy conservation and emission reduction in this industry directly impacts the successful accomplishment of these targets. The 14th Five-Year Plan for the construction industry explicitly proposes to promote green construction methods, reduce resource and energy consumption, decrease carbon emissions, and achieve sustainable development[2]. Green innovation, as a core means of energy conservation and emission reduction, will inject strong

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vitality into the high-quality development of the construction industry and the modernization process of harmonious coexistence between man and nature.

Anhui Province, as a key member of the Yangtze River Delta, is not only a strategic hub for national economic development but also an important transportation node connecting the north and south and linking the east and west. Its construction industry ranks in the middle to upper tier domestically. Since 2015, through the transformation of development models and the deepening of industrial restructuring, Anhui has achieved steady growth in its construction industry. Even under the impact of the COVID-19 pandemic in 2022, the total output value of Anhui's construction industry reached RMB 1,170.3 billion, with a year-on-year increase of 10.6%, demonstrating robust growth momentum. Meanwhile, the industry employed 2.116 million people, highlighting its large market size and promising employment prospects[3]. However, with the continuous expansion of the residential construction industry market scale in Anhui Province, the pressure for emission reduction has also increased dramatically. Therefore, vigorously promoting energy conservation, emission reduction, and low-carbon development in the construction industry is particularly important. Nevertheless, relevant research on predicting and analyzing future carbon emissions from residential buildings in Anhui Province is relatively scarce[4]. Based on data from 2016 to 2023 related to residential buildings in Anhui Province, this paper predicts carbon emissions from residential buildings in Anhui Province for 2024, filling this research gap to some extent.

In addition, given the need for accurate predictions of carbon emissions throughout the construction process in Anhui Province in 2024, and considering that the carbon emissions of residential buildings in a region are highly sensitive to seasons. For instance, during extreme temperatures in summer and winter, residents use air conditioning more frequently, leading to increased carbon emissions, while during the milder climates of spring and autumn, carbon emissions are relatively lower. Therefore, we plan to use the SARIMA model, a branch of the ARIMA model, for predictive analysis.

2. Model Construction

The SARIMA model is an ARIMA model with the incorporation of seasonal factors. As a type of time series model, it can be used for short-term forecasting of time series data that exhibit seasonality and trends[5]. $SARMA(p,d,q)x(P,D,Q)s$ is its basic structure, and its general form is:

$$\Phi(B)U(B^S)(1-B)^d(1-B)^D X_t = \Theta(B)V(B^S)a_t$$

$$U(B^S)=1-\Gamma_1 B^S-\Gamma_2 B^{2S}-\ldots-\Gamma_P B^{PS}$$

$$V(B^S)=1-H_1 B^S-H_2 B^{2S}-\ldots-\Gamma_Q B^{QS}$$

$$\Phi(B)=1-\phi_1 B-\ldots-\phi_p B^p$$

$$\Theta(B)=1-\theta_1 B-\ldots-\theta_q B^q$$

There are many functions and variables involved, which are described here.

Table 1. Terminology

Parameters	Practical significance
p	Autoregressive order
q	Moving average order
P	Seasonal autoregressive order
Q	Seasonal moving average order
s	Cycle length
d	The number of differentials to make it run smoothly

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D	The number of times the seasonal differential is made to run smoothly
$\Gamma_j(j=1,2,\ldots,P)$	Coefficients
$H_j(j=1,2,\ldots,Q)$	Coefficients
$\phi_i(i=1,2,\ldots,p)$	Coefficients
$\theta_i(i=1,2,\ldots,q)$	Coefficients
$\Phi(B)$	Autoregressive polynomial
$\Theta(B)$	Moving average polynomials
$U(B^S)$	Seasonal autoregressive polynomials
$V(B^S)$	Seasonal moving average polynomial

3. Empirical Analysis

3.1. Data source

This data comes from China Carbon Accounting Database, Anhui Province Statistical Yearbook and relevant research literature. Finally, the carbon emissions from residential buildings in Anhui Province from 2016 to 2023 were obtained, and the specific data are shown in the following figure.

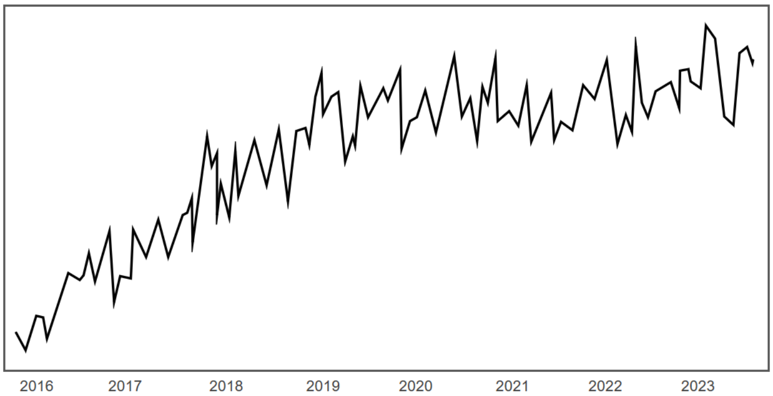

Figure 1. Time series diagram of carbon emissions from the whole life cycle of residential buildings in Anhui Province, 2015-2022

3.2. Smoothness test

According to the original time series image we can find that there is a general upward trend, while the growth rate is slowing down, but it is not smooth. The ACF test is carried out after the first differencing, and the results are as follows.

Table 2. ACF test for the first difference

Type	lag	ADF	Pvalue
Nodriftnotrend	0	-2.43	0.017
	1	-1.11	0.233
	2	-0.61	0.512
Withdriftnotrend	0	-4.02	0.013
	1	-3.11	0.121
	2	-2.43	0.133
Withdriftandtrend	0	-4.32	0.011
	1	-3.51	0.052
	2	-5.78	0.011

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According to the results, it can be seen that the nine P-values are not exactly less than 0.05, so we believe that the series after the first difference is still not smooth, and it is subjected to a second difference, the results of which are shown in the table.

Table 3. ADF test for second difference

Type	lag	ADF	Pvalue
	0	-5.12	0.001
Nodriftnotrend	1	-3.66	0.012
	2	-6.23	0.001
	0	-5.24	0.011
Withdriftnotrend	1	-3.54	0.025
	2	-5.32	0.010
	0	-5.01	0.016
Withdriftandtrend	1	-4.21	0.001
	2	-5.33	0.001

According to the results, it can be seen that the P-value of the data after second differencing is less than the significance level of 0.05, which can be considered that the series is significantly smooth, and we plotted the smoothed differenced time series graphs as well as the seasonal decomposition graphs with the help of Python.

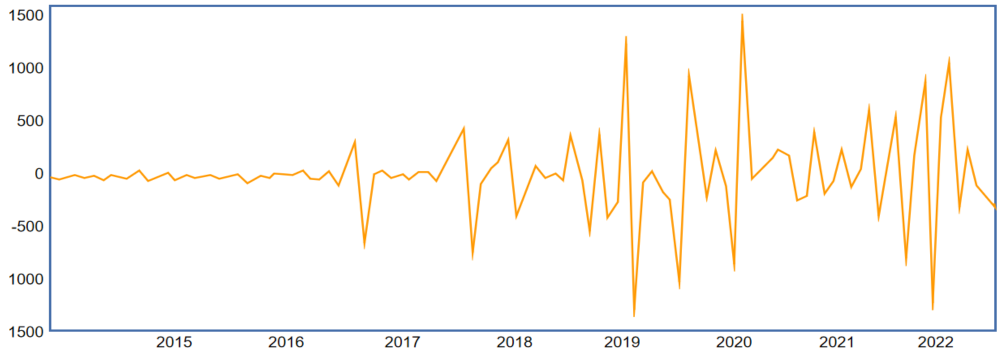

Figure 2. Differential time series of carbon emissions from whole life cycle residential buildings in Anhui Province, 2015-2022

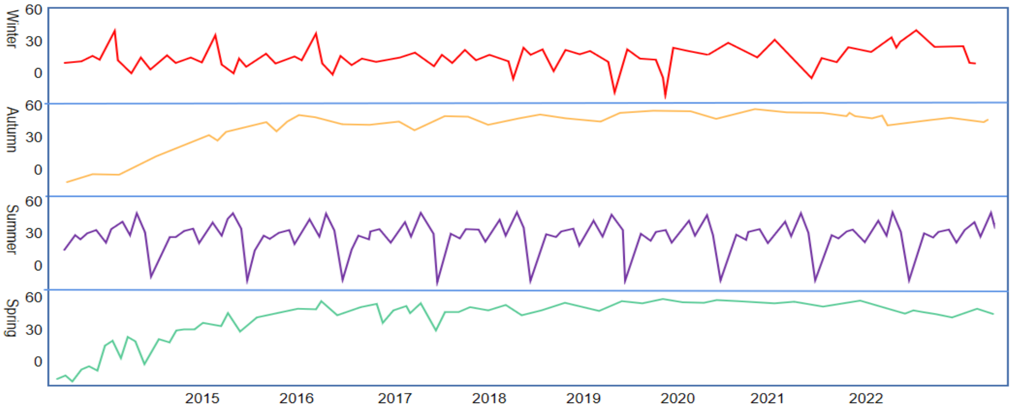

Figure 3. Seasonal Breakdown

3.3. Model Identification and Order Fixing

In order to be able to make a rough estimation of the structural parameters of the model, we made autocorrelation (ACF) plots as well as partial autocorrelation (PACF) plots of the differenced time series.

ISSN: 2710-0170

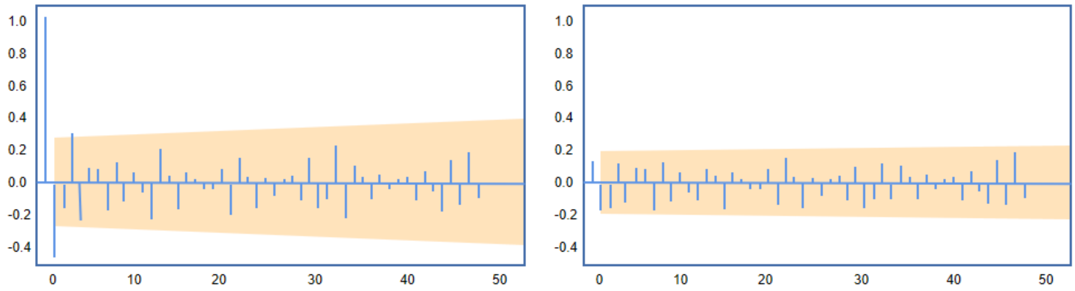

Figure 4. Autocorrelation plot (left) and partial autocorrelation plot (right) after differencing

Based on the autocorrelation and partial autocorrelation plots we understand that the values of the covariates that can be determined are d=1,D=1,s=12. For the structural parameters p, q, P and Q only rough calculations can be made, and the rough estimations are 2, 1, 3, and 0, respectively.

In order to obtain more accurate values for the structural parameters p, q, P and Q, we output a variety of AIC and BIC values to determine the model order based on the AIC and BIC criteria[6], as shown in the following table.

Table 4. AIC and BIC values for some alternative parameters

Model Parameter	AIC	BIC
$(2,1,0)\times(2,1,0)_{12}$	2387.293	2401.234
$(2,1,1)\times(2,1,0)_{12}$	2391.034	2423.457
$(2,1,0)\times(3,1,0)_{12}$	2390.523	2435.426
$(2,1,1)\times(3,1,0)_{12}$	2393.125	2404.947
$(2,1,2)\times(2,1,0)_{12}$	2389.738	2495.117

When the value of AIC and BIC is smaller, the model has the best fit for the combination of parameters[7]. Therefore, we choose *SARIMA(2,1,0)×(2,1,0)*$_{12}$ as our prediction model, at this time$p$=2,q=0,P=2 and Q=0.

Based on this, we obtained the coefficients of the relevant variables of model *SARIMA(2,1,0)×(2,1,0)*$_{12}$, as shown in the following table.

Table 5. Estimated coefficients of SARIMA(2,1,0)×(2,1,0)12 model correlation

Variables Coefficients	Coefficients	$P>\|z\|$
AR(1)	-0.5318	0.000
AR(2)	-0.4132	0.007
SAR(12)	-0.2348	0.001
SAR(24)	-0.3704	0.000

Accordingly, we obtain the estimated equation for model *SARIMA(2,1,0)×(2,1,0)*$_{12}$:

$$\left(1+0.5318\,B+0.4132\,B^{2}\right)\left(1+0.2348\,B^{12}+0.3704\,B^{24}\right)(1-B)\left(1-B^{12}\right)X_t=a_t$$

3.4. White noise test

After conducting a stationarity test, we also need to conduct a white noise test on the time series after eliminating trend and seasonal terms. We use the built A model for fitting and output the fitting results using R language. We find that p<0.034, rejecting the null hypothesis, indicating good fitting.

There are two main types of tests for the model, one is the normality test of the residuals and the other is the autocorrelation test of the residuals. The residuals need to meet the normality, mainly to make the residuals concentrated in a certain value, if this value is very close to 0, it actually obeys the normal distribution with mean 0, that is, it is a white noise series. When the residual is a white noise sequence, it means that the useful information in the time series has been extracted, and the rest are random perturbations that cannot be predicted and used.

3.5. Forecast results and evaluation

With the help of the model, we obtained the predicted time series of carbon emissions from the whole life cycle of residential buildings in Anhui Province from 2016 to 2023. Subsequently, we compare the original time series as well as the predicted series, as shown in the table below, we find that the overall overlap between the two is high, and the fitting effect is good, while the gray area is the predicted part of the annual carbon emissions of the whole life cycle of residential buildings in Anhui Province in 2024, which shows a downward trend at the tail end, and the annual carbon emissions of 1,187,323,830 tons are obtained by calculating the data, and the data requested are for reference only.

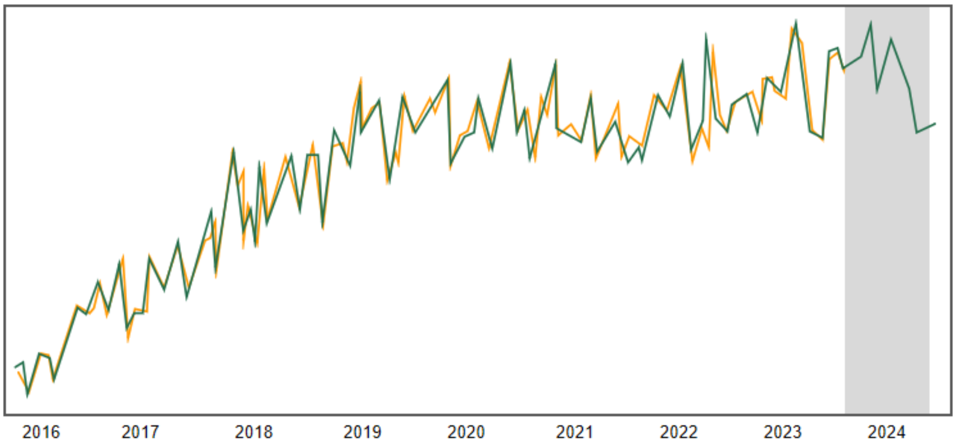

Figure 5. Time series and forecast of whole life cycle carbon emissions from residential buildings in Anhui Province, 2016-2024

4. Conclusions and suggestions

Based on the above research and analysis, we have a more comprehensive understanding of the whole life cycle of the carbon emissions of residential buildings in Anhui Province, and through the construction of relevant mathematical models to carry out in-depth investigation, which found that although the growth trend of the carbon emissions of residential buildings in recent years has gradually slowed down, but the overall base is large, the green transformation of the construction industry can not be slowed down, and the carbon emission reduction policy of residential buildings in Anhui Province[8]. Here we put forward objective suggestions on the carbon emission reduction policy for residential buildings in Anhui Province.

4.1. Promote green building materials and technologies

Traditional building materials often produce large amounts of carbon emissions and environmental pollution during production, transportation and use. Green building materials, such as bamboo, recycled plastics, and eco-concrete, not only reduce energy consumption and pollution emissions during production, but also provide better energy efficiency and environmental performance during building use. In addition, green technologies such as solar photovoltaic panels, rainwater harvesting systems, and natural ventilation and lighting designs can effectively reduce the energy consumption and operating costs of buildings.

From the current point of view, the use of traditional building materials for housing construction materials is relatively large in Anhui Province, and traditional building materials tend to produce a large amount of carbon emissions and environmental pollution during

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production, transportation and use, whereas green building materials, such as bamboo, recycled plastics, and eco-concrete, not only reduce energy consumption and pollution emissions during production, but also provide better energy efficiency and environmental performance during the use of buildings. and environmental performance during building use. In addition, green technologies such as solar photovoltaic panels, rainwater harvesting systems, natural ventilation and lighting design can effectively reduce the energy consumption and operating costs of buildings. It can be seen that from the supply chain perspective, the use of green building materials to replace traditional building materials in the upper reaches of the industry can effectively reduce the carbon emissions of residential buildings, thereby eliminating carbon dioxide production from the source.

4.2. Introduce and improve carbon trading policies

In the long run, we should further implement the general tone of realizing the goal of "double carbon", and introduce relevant policies to carry out the carbon reduction measures mentioned above for the whole life cycle of residential buildings from construction, operation to dismantling.

In the short term, some cities need to develop economically, while others are not strong enough to support carbon reduction measures, which will inevitably result in larger carbon emissions. For this reason, the policy of carbon trading has to be mentioned. The so-called carbon trading is a new type of transaction in which the right to emit carbon dioxide is treated as a commodity and circulated through buyers and sellers. At present, carbon trading in China started late, relative to international, its policy documents and legal system is not perfect, only carbon trading trial regulations, and local carbon trading regulations and market is not yet exist, the future in anhui province if you can try to carry out the carbon trading between cities, can effectively narrow the gap between the level of carbon emissions between the city of residential buildings.

4.3. Strengthen green building education and training

The development of green building requires the support of professional talents. By strengthening education and training related to green building, the professional quality and technical level of construction industry practitioners can be improved so that they can better understand and apply green building concepts and technologies. At the same time, education and training can also enhance public awareness and acceptance of green building, laying a solid social foundation for the development of green building.

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