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*Original Research*

# Carbon Emission Growth Mechanism and Trend Forecast in Baotou Based on Production-Living-Ecological Space

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## Abstract

Taking Baotou city as an example, we calculate carbon emissions and carbon sinks in the "Production-living-ecological space" from 2005 to 2021, and use the STIRPAT model and GM(1,1) model to analyse and forecast the factors influencing carbon emissions and carbon emissions in the next ten years. The results show that (1) the carbon emission reduction strategies for the production, living and ecological spaces of Baotou City were implemented from 2005 to 2011. The results show that: (1) from 2005 to 2021, the total carbon emissions in Baotou City increased by 103,643,100t, with a 3.2-fold increase in total carbon emissions and an average annual growth rate of 7.92%. Production space has the highest contribution to the total carbon emission, and the amount of carbon sink in ecological space is small compared to the total carbon emission. (2) According to the results of the STIRPAT model, the total population, GDP per capita, energy intensity, urbanization rate, the proportion of secondary industry and total carbon emissions in Baotou are synergistic, while the proportion of tertiary industry and total carbon emissions are antagonistic. (3) According to the prediction results of the GM(1,1) model, the total carbon emissions in Baotou will increase from 145,102,300 t to 207,230,500 t in the period of 2022-2031, which shows that the overall carbon emissions in Baotou are still on a growing trend, but the trend is gradually slowing down. Finally, on the basis of the previous study, carbon emission reduction suggestions such as optimising industrial structure and improving the efficiency of agricultural production inputs are put forward.

**Keywords**: Baotou, production-living-ecological space, carbon emissions, STIRPAT model, trend forecast

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## Introduction

As a country with a large population, China's biggest challenge at present is to cope with the effects of climate warming. Based on the national emphasis on spatial planning, the concept of green development and the goal of sustainable development, the concept of "production-living-ecological space" has emerged. The rational planning of the 'production-living-ecological space' to achieve carbon reduction targets is one of the most important research topics for scientists at present [1].

Among the studies on the factors influencing carbon emissions, Liu Maohui, Yue Yayun, Liu Shengnan et al. [2] used the STIRPAT model to conduct a multi-faceted study on carbon emission reduction in Tianjin, showing that carbon emissions are mainly generated by industry, and that total population, urbanisation rate, regional GDP, energy intensity and carbon emission intensity are important factors affecting the synergistic effect of air pollution and carbon emission reduction in the region; Zhao Ci, Song Xiaochong et al. [3] used the STIRPAT model to predict the peak carbon emissions in Zhejiang Province, and the results showed that the baseline scenario, low-carbon scenario and enhanced low-carbon scenario could all achieve the carbon peak target in Zhejiang Province by 2030, and the analysis of the model coefficients revealed that population, energy structure and GDP per capita were the main factors affecting carbon emission reduction in Zhejiang Province. Regarding research on carbon emission trend prediction, Ma Niansheng et al. [4] used the GM(1,1) model to predict the ecological security of Tibetan farmland from 2016 to 2025, concluding that effective measures should be taken as soon as possible to control the development of ecological disadvantage in Tibetan farmland; Lai Kongqing et al. [5] used the GM(1,1) model to predict the 2016 to 2020 and the 2020 Hunan agricultural soil input of carbon emission evolution trend, estimated the carbon dioxide emission from farmland in 2020 as 4.343 million t, and put forward policy recommendations to reduce carbon dioxide emission from farmland.

There are also many relevant studies on carbon emissions and sustainable development. Wang Mengjie and Wang Yanjun et al. [6] combined remote sensing data of ChangZhuTan cities in 2013-2017 to estimate and monitor carbon emissions and concluded that carbon emissions in ChangZhuTan city cluster from 2013-2017 were mainly distributed in the northern central region of the city cluster with a negative growth trend, providing scientific Kanwal Iqbal Khan et al. [7] used structural modelling (ISM) to analyse the barrier factors in the use of the green financial system and analysed the relationship between each barrier factor, which is an important aspect of a green low carbon economy, and the results showed that all the barrier factors are linked and their changes not only affect each of the other barrier factors, but also have a feedback effect on themselves. Using a qualitative research approach, Wahab Musa et al. [8] analysed extensive data from relevant studies to argue for the need for renewable energy, the importance and technical advantages of sustainable power systems, and how to maximise the use of renewable energy, and the results showed that the use of renewable energy can be maximised by determining the optimal configuration of generation and the timing, scale of production, location and type of various generation facilities. Jan Fuka et al. [9] used a mixed research approach to analyse the impact of studying complex phenomena such as emergencies on the economy, society and the environment, showing that emergencies raise public budget expenditures and induce $CO_2$ emissions, while also causing residents to feel less personally secure and trusting of public institutions.

In recent years, with the continuous development of Baotou's economy, the city has formed pillar industries with the iron and steel industry, coal and chemical industry, rare earth industry, aluminium industry, equipment manufacturing industry, new energy industry, as the core industries. In order to further study the influencing factors of carbon emission in Baotou and control the trend of carbon emission increase, this paper integrates various indicators of carbon emission influencing factors, and selects six indicators of carbon emission influencing factors, such as total population at the end of the year, urbanization rate, GDP per capita and energy intensity, according to the current situation of Baotou in the context of "production-living-ecological space". Finally, the GM(1,1) model was used to analyse the carbon emission trends in Baotou from 2005 to 2021 and to forecast the total carbon emissions in Baotou from 2022 to 2031, providing a theoretical basis for the formulation of energy saving and emission reduction measures in Baotou.

## Data and Methods

### Overview of the Study Area

According to the Baotou Statistical Yearbook (2021), Baotou's GDP per capita is RMB 102,949, with a total population of 2,710,300. Baotou is a prefecture-level city under the jurisdiction of the Inner Mongolia Autonomous Region and is the largest rare earth exporting region in China, playing an important role in all aspects of China's economic and social development, which has led to an annual increase in total carbon emissions in Baotou. Based on this, it is of typical significance to select Baotou as a study area for land use change and carbon emissions.

### Data Sources and Processing

Based on the land use data of Baotou City in 2020 as an example, this is used as the basis for the analysis of land use changes and carbon emissions in Baotou City. The data shows that arable land, forest land, construction land, grassland, water area and unused land account for 23.5%, 14.15%, 2.13%, 50.36%, 1.75% and 8.06% of the total area of Baotou City respectively. At the same time, regarding the six land use types and the division of the "production-living-ecological space", the specific land types within the "production-living-ecological space" were determined by taking into account the functions of each land use type and the accuracy of data acquisition. The land use data were obtained from the Data Centre for Resource and Environmental Sciences of the Chinese Academy of Sciences [10, 11], and the carbon emission coefficients of each carbon source for industrial and mining land were selected from the "Methodology and Reporting Guidelines for Corporate Greenhouse Gas Emissions" for power generation facilities and the "Guidelines for the Preparation of Provincial Greenhouse Gas Inventories (for Trial Implementation)". The indicators of total population, regional GDP, GDP per capita, total energy consumption, energy intensity and other related indicators in the application of the model were selected from the Baotou Statistical Yearbook (2005-2021), the energy intensity indicator was obtained from the ratio of total energy consumption to GDP per capita in the Statistical Yearbook, the urbanisation rate was derived from the Statistical Bulletin of National Economic and Social Development (2005-2021), and transport data from the China Transport Statistical Yearbook (2005-2021).

## Classification of "Production-Living-Ecological Space" and Calculation of Carbon Absorption/Emissions

Land use types are classified according to the "production-living-ecological space Classification and Evaluation System", with forest land, grassland, water and unused land classified as ecological space, arable land, industrial and mining land, and transportation land classified as production space, and urban land and rural residential land [12, 13] classified as living space, with three primary categories and nine secondary categories. . The main function of "ecological space" and part of "production space" is "carbon sink", and the main function of "living space" and "production space" is "carbon sink". "The main function of the 'production space' is to be a 'carbon source'.

### *Ecological Space*

Ecological space plays an important role as a 'carbon sink', including woodland, grassland, water and unused land. The carbon sink coefficients for forest land, grassland, water and unused land are 0.0578, 0.0021, 0.0252 and 0.0005 kg/($hm^2$-a) respectively [14].

### *Production Space*

The production space is divided into arable land and industrial and mining land. With regard to cultivated land, most scholars believe that carbon emissions generated directly or indirectly by human production activities are responsible for the large amount of greenhouse gases produced on cultivated land [15]. In this study, carbon emissions from cultivated land are divided into four main components: firstly, carbon emissions from the consumption of fertilisers, pesticides and agricultural films used in cultivation and production; secondly, carbon emissions from agricultural machinery used in the production process; thirdly, carbon loss from soil through tillage; and fourthly, carbon emissions from the extraction of groundwater by agricultural irrigation systems. The parameters involved in the calculation of carbon emissions from arable land in the production space are taken as values (Table 1). The calculation equation is as follows:

$$E_A = C \bullet k_C + M \bullet K_M + W \bullet k_W + G \bullet k_G + F \bullet k_F \quad (1)$$

$$M = S \bullet D \quad (2)$$

In the formula, $E_A$ is the total carbon emission from agricultural land; C is the discounted fertiliser application; M is the sown area of agricultural land; W is the total power of agricultural machinery; G is the actual area of tilling; F is the irrigated area; K is the carbon emission coefficient of different agricultural activities.

Most of the carbon emissions from industrial land come from industrial energy handling activities and industrial production processes. Five indicators of the main energy products in Baotou, namely raw coal, coke, gasoline, diesel and natural gas, were selected and the carbon emission estimation method used in this study is the carbon emission factor method.

Table 1. Carbon emission conversion factors for each production activity on arable land.

| Carbon source factors | Carbon emission factor | Reference sources |
|---|---|---|
| Fertilizer | 0.8956 kgC/kg | Oak Ridge National Laboratory, USA |
| Agricultural machinery | 0.18 kgC/kW | West [16] |
| Ploughing | 312.60 kgC/$hm^2$ | School of Biotechnology, China Agricultural University |
| Irrigation | 266.48 kgC/$hm^2$ | Dubey [17] |
| Agricultural cultivation | 16.47 kgC/$hm^2$ | Wang Ge et al. [18] |

Table 2. Carbon emission parameters for each carbon source on industrial and mining land.

| Main energy products Energy Products | Energy low level heat generation | Unit calorific value Carbon content | Carbon oxidation rate | Carbon dioxide emission factor |
|---|---|---|---|---|
| Raw Coal | 20908 KJ/kg | 26.37 TC/TJ | 0.94 | 1.9003 kg/kg |
| Coke | 28435 KJ/kg | 29.5 TC/TJ | 0.93 | 2.8604 kg/kg |
| Petrol | 43070 KJ/kg | 18.9 TC/TJ | 0.98 | 2.9251 kg/kg |
| Diesel | 42653 KJ/kg | 20.2 TC/TJ | 0.98 | 3.0959 kg/kg |
| Natural gas | 38931 KJ/kg | 15.3 TC/TJ | 0.99 | 2.1621 kg/m$^3$ |

The calculation formula is as follows:

$$C = \sum_i E_i \times EF_i \tag{3}$$

In the formula, C is the carbon emissions from industrial energy, t; $E_i$ is the consumption of the i-th energy source, t; $EF_i$ is the $CO_2$ emission factor of the ith energy source. The five energy sources in the table below were selected to calculate carbon emissions [19] and the parameters were calculated.

*In Table 2, $CO_2$ emission factor = carbon emission factor * energy low level heating value * 0.000001 * (44/12) * carbon oxidation rate [20].

*Living Space*

The living space is divided into urban land, rural residential land and road transport land. The main sources of carbon for urban land and rural residential land are carbon emissions from the respiration of urban residents and carbon emissions from the domestic energy consumption of rural residents, respectively. Among them, the carbon emission factor of human respiration is 79 kgC/person/a [21] and domestic energy consumption includes coal, straw burning and respiration (Table 3). According to the relevant literature, 100% of straw resources can be collected by modern technology [22], and the carbon emission CS from straw combustion is calculated as follows:

$$C_S = \sum_{i=1}^{n} P_i \times S_C \times Q_i \times c \times d \tag{4}$$

In the formula, n for crop type; $P_i$ is the yield of the ith crop, kg; $S_C$ is the cereal to grass ratio of crop *i*; $Q_i$ is the carbon emission factor for the burning of straw of crop *i*; *c* is the straw open burning ratio, the value is 0.165; *d* is the straw burning efficiency and the value is taken as 0.8 [23].

In order to estimate $CO_2$ emissions from road transport land, this study adopted a bottom-up inventory accounting method and selected different urban transport modes as $CO_2$ accounting vehicles [24], such as: private cars, taxis, buses, road passenger transport, road freight transport, etc. Due to the lack of data on annual mileage travelled and energy consumption in the data collection of Baotou City. Therefore, according to the relevant literature, the annual mileage of private cars is around 15,000 km [25]; the annual mileage of taxis is around 120,000 km, which is the national average; the average value of fuel consumption of petrol cars is taken as 8.8 L/100 km [26]; the gas consumption of natural gas cars is taken as 9 m²/100 km [27]. The principle of the calculation method is to prioritise the use of turnover data for calculation, and use car ownership for calculation if there is insufficient data (Table 4). The formula for calculating carbon emissions E from road transport land is as follows:

Calculation of emissions using turnover and related parameters:

$$E = \sum_{i=1}^{n} T \times et \times C \tag{5}$$

In the formula, *i* is the ith mode of transport; *T* is the volume of turnover; *et* is the energy consumption per unit of turnover; *C* is the carbon emission per unit of energy consumption.

Table 3. Cereal to grass ratio and straw burning carbon emission factors for various crops.

| Crop type | Cereal Grass Ratio | Carbon emission factors for straw burning/(t·t$^{-1}$) |
|---|---|---|
| Paddy | 1 | 0.058 |
| Wheat | 1.1 | 0.089 |
| Maize | 2 | 0.041 |
| Beans | 1.7 | 0.061 |
| Potatoes | 1 | 0.019 |

Table 4. Carbon emission calculation methods for different transport types.

| Type of transport | Calculation using turnover | Calculated using holdings |
|---|---|---|
| Roads | √ | |
| Bus | | √ |
| Taxis | | √ |
| Private Car | | √ |

Calculation of emissions using holdings and relevant parameters:

$$E = \sum_{i=1}^{n} Q \times M \times he \times C \quad (6)$$

In the formula, $i$ is the ith mode of transport; $Q$ is car ownership; $M$ is annual mileage; *he* is energy consumption; $C$ is carbon emissions per unit of energy consumption.

### Calculation of Total Carbon Emissions

The carbon emissions from the "living space" and "production space" of the "production-living-ecological space" in Baotou are subtracted from the carbon emissions from the "ecological space The net carbon emissions are obtained by subtracting the carbon sinks of "ecological space" and part of "living space" from the carbon emissions of "living space" and "production space" in Baotou.

### Model Selection

#### *STIRPAT Model*

In this study, the STIRPAT model was used to analyse the influence of each influencing factor on carbon emissions, and six influencing factors, such as population, urbanisation rate and energy intensity, were selected in conjunction with the Statistical Bulletin of National Economic and Social Development of Baotou City (2005-2021) and the leading industries. york et al. break through the limitations of the Kaya constant equation and the traditional IPAT model in terms of hypothesis testing, and further improve the accuracy of the non-equal proportional impact of the influencing factors on the environment. Eq. (7) is the standard form of the STIRPAT model, and taking the logarithm of each side of the equation yields Eq. (8):

$$I = aP^{b}A^{c}T^{d}e \quad (7)$$

$$lnI=lna+blnP+clnA+dlnT+lne \quad (8)$$

In the formula, $I$, $P$, $A$ and $T$ are the environmental impact, demographic factor, wealth factor and technological factor respectively; $a$ is the model coefficient; $b$, $c$ and $d$ are the coefficients of the demographic factor, wealth factor and technological factor respectively; and $e$ is the random error term. $i$ According to the concept of elasticity coefficient, every 1% change in $P$, $A$ and $T$ will cause a b%, c% and d% change in $I$ respectively [28].

Combined with the actual situation of the "production-living-ecological spaces" in Baotou, a number of influencing factors of carbon emissions were selected, and after deformation, Equation (9) was obtained:

$$lnI=lna+blnP+clnA+dlnT+flnK+jlnS+klnL+lne \quad (9)$$

In the formula, $K$ is the urbanisation rate; $S$ is the share of secondary industry in GDP; $L$ is the share of tertiary industry in GDP; $f$, $j$ and $k$ are the urbanisation rate, the share of secondary industry and the share of tertiary industry respectively. i is the total carbon emission, million $t$; $P$ is the total population of Baotou city at the end of each year, million people; $A$ is the GDP per capita, Yuan/person; $T$ is the energy intensity, $t$ (standard coal)/million yuan; $K$ takes the value of urbanisation rate; $S$ and $L$ are the shares of the secondary and tertiary industries in GDP respectively.

#### *GM(1,1) Models*

Grey prediction model is a long-term prediction model, which is now widely used in research in industry, agriculture, environment and other fields [29]. The grey prediction model is able to obtain valuable information and analyse its intrinsic patterns on the basis of partially known and unknown information, extract regular information from irregular series for model building, and finally make predictions based on the results. Compared with other models, grey forecasting models have higher forecasting accuracy, require less data and do not require consideration of subjective coefficients. In this paper, the grey prediction GM(1,1) model is used to model and calculate the total carbon emission data of Baotou City from 2005 to 2021, and the results are analysed and studied.

## Results and Analysis

### Analysis of Carbon Emissions in Baotou

Based on the net carbon emissions of the "production-living-ecological space", the total carbon emissions of Baotou from 2005 to 2021 were calculated (Fig. 1). The total carbon emissions in Baotou increased from 47.759 million t in 2005 to 151.402 million t in 2021, showing a gradual decrease and stabilisation in stages before increasing again, with an overall increase of 3.17 times. Carbon emissions from living space increased from 543,000 t in 2005 to 2,596,000 t in 2021, an increase of 4.8 times; carbon emissions from production space increased from 47,230,000 t in 2005 to 148,821,000 t in 2021, an increase of 3.2 times; carbon sinks in ecological space increased from 14,200,000 t in 2005 to 14,500,000 t in 2021. The carbon emissions from the production space far exceed the carbon emissions from the living space, and the carbon sink value of the ecological space is extremely low compared to the other two spaces.

The estimation of carbon emissions in Baotou can be divided into three periods: Phase 1 (2005-2012) is the stage of rapid growth of total carbon emissions in Baotou. In terms of production space, industrial land

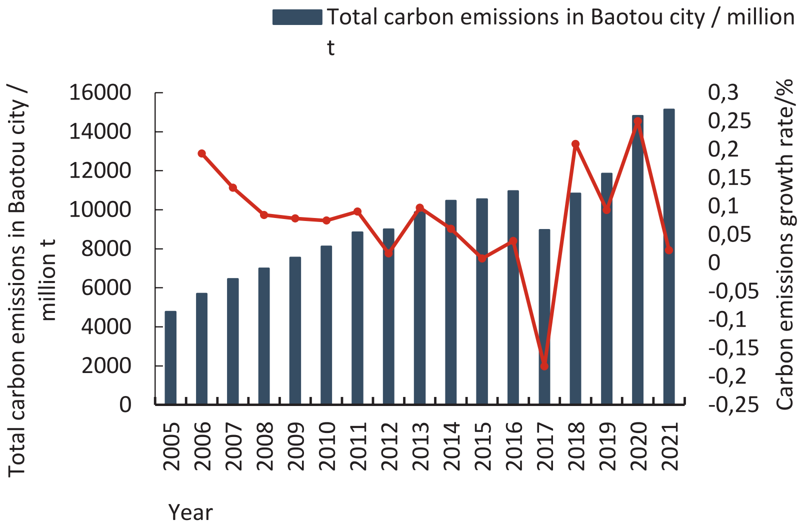


Fig. 1. Total carbon emissions and growth rate in Baotou, 2005-2021.

had the largest increase in carbon emissions during this period, with its carbon emissions increasing by 87.8%. The main sources of carbon emissions from agricultural land were fertilizer, agricultural machinery, tillage, irrigation and agricultural cultivation, which accounted for 29.53%, 0.13%, 2.54%, 19.51% and 48.29% of carbon emissions respectively, with fertilizer and agricultural machinery showing higher growth rates. The rate of carbon emissions generated by irrigation decreased by 0.9%, the fundamental reason coming from the reduction in the area of agricultural land; in terms of living space, the greatest increase in carbon emissions was seen in rural settlements and road traffic land during this period. The urban population in Baotou grew by 215,800 between 2005 and 2012, and the total carbon emissions from urban land increased by 8.8%. This type of phenomenon occurs due to the increasing level of urbanisation in Baotou city, which is currently supported by the state, and the migration of a large number of farmers to the city. In terms of road transport land, as people's living standards improve, some households are changing from "one car per household" to "multiple cars per household", and the carbon emissions from road transport land are growing at a high rate of 247.9%.

Phase 2 (2013-2016) is a phase of steady growth in total carbon emissions. The total carbon emissions of Baotou City in this phase grew from 98.696 million t in 2013 to 109.546 million t in 2016, with an average annual growth rate of 5.1%. Overall, Baotou City had the highest contribution of production space to carbon emissions from 2013 to 2016. In terms of industrial and mining land, its carbon emission contribution rate was as high as 98.2%, with a growth rate of 10.8%. In terms of agricultural land, the overall trend of carbon emissions from agricultural land in Baotou from 2013-2016 was on the rise, with a growth rate of 3.31%. The growth rates of carbon emissions from fertilizer, agricultural machinery, tillage, irrigation to and agricultural cultivation were 1.6%, 4.5%, 5.2%, 0.9% and 5.2% respectively, which were decreasing compared to Phase 1. In terms of living space, the growth rate of carbon emissions from urban land was 0.6%. During this period, the urban population grew from 2,669,200 in 2013 to 2,689,400 in 2016, showing a slight upward trend. In terms of road transport land, the growth rate of carbon emissions generated by fuel vehicles is also gradually decreasing with the widespread use of clean energy in China, and the growth rate of carbon emissions from road transport land was 28% during this period. Overall, the total carbon emissions in Baotou City showed a steady growth trend from 2013 to 2016, with a 4.48% decrease compared to the average growth rate from 2005 to 2012.

Phase 3 (2017-2021) is the phase of small growth in total carbon emissions. Since 2017, in order to make the advanced manufacturing industry in Baotou City advance towards high-quality development and vigorously develop the industrial level, the production of pig iron, crude steel and steel in Baotou City has increased substantially, with the production of pig iron increasing from 13.864 million t to 20.253 million t, the production of crude steel increasing from 15.1359 million t to 19.997 million t and the production of steel increasing from 15.352 million t to 18.422 million t. The growth rates were 46.1%, 31.9% and 19.9% respectively. The growth rate of total carbon emissions in Baotou from 2017-2021 is 70.1%. In terms of production space, carbon emissions from industrial and mining land increased from 87,293,000t in 2017 to 148,625,000t in 2021, with a growth rate of 70.3%. In contrast, carbon emissions from agricultural land decreased from 20.2% in 2017 to 19.6% in 2021, with carbon emission growth rates of -0.9%, 3%, -5.3%, -0.2% and -5.3% for fertiliser, agricultural machinery, tilling, irrigation and agricultural cultivation, respectively. In terms of living space, the growth rate of total carbon emissions is 22.4%, with road traffic land accounting for 90.5% of total emissions, while rural settlements and urban land account for 0.5% and 9% of total emissions respectively. the growth rate of total carbon emissions in baotou city from 2020 to 2021 moderates slightly, with the growth rate decreasing from 24.9% in 2020 to 2.24% in 2021, due to the reform policy The implementation of the implementation in place, the vigorous adjustment of the industrial investment structure in Baotou, and the vigorous development of new materials, high-end equipment and strategic emerging industries such as energy conservation and environmental protection, have laid the foundation for the implementation of the carbon peaking and carbon neutral targets.

## Analysis of Factors Influencing Carbon Emissions

The variance inflation factor (VIF) of carbon emissions in Baotou was 4.30, 11.65, 21.26, 32.25, 84.94 and 99.11 for total population, urbanisation rate, GDP per capita, energy intensity, proportion of secondary industry and proportion of tertiary industry respectively. The VIFs of urbanisation rate, GDP per capita, energy intensity, share of secondary industry and share of tertiary industry were 4.30, 11.65, 21.26, 32.25, 84.94 and 99.11 respectively, and all the factors were greater than 10 except for the VIF of total population at the end of the year, which was less than 10, indicating serious multicollinearity among these factors. Therefore, the data were regressed using the ridge regression method to eliminate the effect of multicollinearity on the final results (Table 5). Through the fitting results, it was found that all independent variables passed the 5% significance level test and the F-statistics passed the 1% significance level test, indicating that the six selected influencing factors are highly sensitive to carbon emissions in Baotou City. In summary, the following equation was obtained from the analysis:

$$lnI = lna + 0.415lnP + 0.378lnA + 0.055lnT + 0.577lnK + 0.596lnS - 1.270lnL + lne \quad (10)$$

The model analysis shows that the fitted coefficients for the total population, GDP per capita, energy intensity, urbanisation rate and the proportion of secondary industry in Baotou are all positive, when these independent variables have a catalytic effect on carbon emissions, while the fitted coefficient for the proportion of tertiary industry is negative, indicating that it has a suppressive effect on carbon emissions. The specific analysis shows that for every 1% increase in the total population, GDP per capita, energy intensity, urbanisation rate and share of secondary industry in Baotou, carbon emissions will increase by 0.415%, 0.378%, 0.055%, 0.577% and 0.596% respectively, while for every 1% increase in the share of tertiary industry, carbon emissions will decrease by 1.27%. The urbanisation rate and the proportion of the secondary industry have the greatest contribution to carbon emissions, while the proportion of the tertiary industry has the greatest inhibiting effect on carbon emissions. The reason for this is that the secondary and tertiary industries are the most important pillar enterprises in Baotou. Over the years, the proportion of the primary industry has fluctuated less up and down, and the carbon emission density of the secondary industry is much higher than that of the tertiary industry, so a decrease in the proportion of the tertiary industry will inevitably lead to an increase in the proportion of the secondary industry, so the tertiary industry plays a suppressive role in carbon emissions.

## Carbon Emission Projection Analysis

According to the carbon emission data of Baotou City from 2005-2021, the GM(1,1) prediction model of carbon emission of Baotou City from 2005-2021 was established by using SPASS software, and the carbon emission prediction results of Baotou City from 2022-2031 were obtained after two residual analyses of the carbon emission data from 2005-2021 (Table 6). The prediction accuracy of the model was tested to reach 1% in all cases, indicating that the prediction results are accurate and credible.

The predicted values of carbon emissions in Baotou from 2005 to 2021 were obtained by the GM (1,1) prediction model. After fitting and analysis, it was found that the deviation of the predicted values from the true values was small, and only a few years had a large deviation. According to the prediction results, the total carbon emissions in Baotou City increased from 145.102 million t in 2022 to 207.231 million t in 2031, with an overall increasing trend and an annual growth rate of 4.08%, indicating that the growth rate of carbon emissions in Baotou City is gradually slowing down while rising (Fig. 2). This paper predicts the carbon emissions of Baotou in the next ten years based on the total carbon emissions of the city in the past 17 years, and based on the validity of the predicted data, we conclude that there is great pressure on Baotou to reduce carbon emissions in the future. Firstly, as an old industrial city, Baotou has a heavy energy consumption structure and difficulties in transformation, and the pillar enterprises it relies on are mostly high carbon emission enterprises. Secondly, new urbanisation is an inevitable choice for Chinese-style modernisation. A significant increase in population will inevitably lead to a large increase in carbon emissions arising from the breathing and living of the population.

# Discussion

This paper uses data on energy consumption, road traffic and crop production in Baotou to calculate carbon emissions and carbon sinks in the “Production-living-ecological space” from 2005 to 2021, and uses the STIRPAT model and GM (1,1) model to analyse

Table 5. STIRPAT model ridge regression results.

| Independent variable | Numerical values | Standard error | Standard factor | T-statistic | Significance |
|---|---|---|---|---|---|
| lnP | 0.415 | 0.036 | 0.415 | 11.550 | <0.001 |
| lnA | 0.378 | 0.072 | 0.378 | 5.270 | <0.001 |
| lnT | 0.045 | 0.106 | 0.045 | 0.420 | <0.005 |
| lnK | 0.577 | 0.232 | 0.577 | 2.490 | <0.005 |
| lnS | 0.596 | 0.542 | 0.596 | 1.100 | <0.005 |
| lnL | -1.270 | 1.020 | -1.270 | -1.250 | <0.005 |

Table 6. Projected carbon emissions results for 2022-2031.

| Year | Total carbon emissions (million t) |
|---|---|
| 2022 | 14510.229 |
| 2023 | 15143.632 |
| 2024 | 15790.566 |
| 2025 | 16451.32 |
| 2026 | 17126.19 |
| 2027 | 17815.476 |
| 2028 | 18519.488 |
| 2029 | 19238.538 |
| 2030 | 19972.95 |
| 2031 | 20723.05 |

and forecast the factors influencing carbon emissions and carbon emissions in the next ten years. From 2005 to 2021, the total carbon emissions of Baotou City have been increasing, but the growth rate has been gradually decreasing, with an average annual growth rate of 7.92%, which is also related to the development of low-carbon energy and industrial restructuring in the study area in recent years. The study found that the share of the tertiary sector had a dampening effect on the increase in carbon emissions, while the urbanisation rate and the share of the secondary sector played a major contributing role. In recent years, in addition to the six influencing factors selected in this paper, influencing factors such as agricultural land input, forest expenditure and industrial intensification also affect the change of carbon emissions to some extent. Research on carbon emissions in resource-based cities in western Inner Mongolia needs to be further deepened. In future studies, scholars can also conduct in-depth research through further data collection and methodological improvement.

## Suggested Measures

By analysing the factors influencing the total carbon emissions of Baotou from 2005 to 2021 and the future projection results, it is concluded that the total carbon emissions of Baotou will continue to grow in

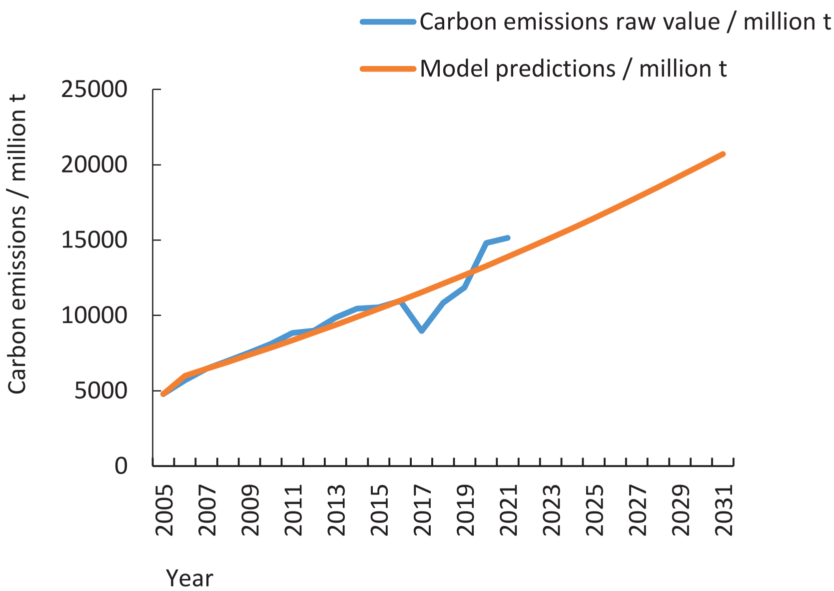


Fig. 2. Fitted line between true and predicted values for the GM (1,1) model 2005-2031.

the coming years. In order to promote the low-carbon development of Baotou, the proposed measures based on the "production-living-ecological space" are proposed in order to achieve carbon emission reduction.

### Carbon Emission Reduction in Production Space

The actual industrial structure and economic development of Baotou show that the share of secondary industry and agriculture are important factors in carbon emissions and growth rates. Baotou is not only a key economic and trade centre in the Inner Mongolia Autonomous Region, but also the largest industrial production base. In recent years, Baotou has introduced "low carbon" policies and policies to optimise its energy and industrial structure, but the results have not been significant. To date, Baotou's core pillar industries are single, and new leading industries have not been retained, leaving only the secondary industry, with its high emissions intensity, as the focus of economic development. With regard to measures to reduce carbon emissions in the production space of Baotou, improvements can be made with reference to the following two aspects.

Optimise the industrial structure and develop pillar industries. Baotou City is dominated by the secondary industry, of which the energy sector, the iron and steel sector and the machinery sector are all heavy carbon emitting industries. On the basis of resolving and eliminating excess and backward production capacity, the industrial structure and pattern will be optimised, and new industrial support policies will be proposed to foster the development of new industries. The development of the tertiary sector, with a focus on tourism, information and technology, the development of primary industries such as handicrafts and textiles in tandem with tourism, the development of high technology industries with low energy consumption and high added value, increased support for the tertiary sector at the policy, talent and technology levels, and increased government investment in energy conservation and environmental protection in the secondary sector.

Improve the efficiency of agricultural production inputs and reduce energy consumption on farmland. The State Council is deeply promoting the reduction of chemical fertilisers and increasing their efficiency, and increasing the policy of promoting organic fertilisers instead of chemical fertilisers in 2022. The future development of agriculture in Baotou should continue to develop and promote new fertilisers, improve the efficiency of fertiliser application, save irrigation resources as well as application resources, and keep carbon emissions below the predicted value.

### Carbon Reduction from Living Space

The total population, the urbanisation rate and the turnover of transport land are all key factors in carbon emissions. Under the current trend of economic development, an increase in urbanisation rate is inevitable, and the growth of population will at the same time bring the burden of carbon emissions to the city. Baotou should synergise its green economy with energy saving and emission reduction policies and carry out territorial spatial planning under the concept of low carbon development. More attention needs to be paid to the linkages between different social facilities, services and transport facilities. Large service distances between facilities can lead to higher road turnover and higher travel costs for residents, making it difficult to achieve low-carbon goals, while smaller service distances can lead to unnecessary waste of resources. Therefore, Baotou should take the road of "dense + sparse" to improve the utilisation rate of urban public facilities, while at the same time, to achieve the welfare of the people and the purpose of "carbon emission reduction".

### Increase Carbon Sinks in Ecological Space

According to the National Desertification and Sandy Land Inspection Report, by the end of 2020, more than 2 million hm² of desertification and sandy land in Baotou had not been effectively treated, and most of the land was in a "low carbon sink" condition. The city has a good opportunity to promote the simultaneous control measures of wind and sand control and development [30]. At the same time, Baotou is blessed with natural scenery and humanistic landscapes, which should be scientifically planned to develop grassland ecotourism products suitable for the region in order to promote its tertiary industry. The government should improve the regulation of industrial energy production and consumption, and accelerate the pace of "low-carbon development".

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## Conflicts of Interest

The authors declare no conflict of interest.

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