Prediction and Analysis of Carbon Emissions in China Based on ARIMA-BP Model

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Abstract. Based on the energy consumption data of 30 provinces in China from 2000 to 2021, this paper estimates and predicts the total carbon emissions of 30 provinces in China from 2000 to 2035 using ARIMA model and BP neural network model. ArcGIS and standard elliptic difference are used to visually analyze the spatio-temporal evolution characteristics, and LMDI model is further used to decompose the driving factors affecting carbon emissions. The results show that: (1) China's total carbon emissions increased year by year from 2000 to 2035, but the growth rate of carbon emissions decreased gradually; The carbon emission structure is "secondary industry > residents' livelihood > tertiary industry > primary industry". the growth rate of carbon in secondary industry and residents' livelihood is relatively fast, while the change trend of primary industry and tertiary industry is relatively small. (2) the spatial distribution of carbon emissions in China's provinces presents a typical "eastern > central > western" and "northern > southern" distribution pattern, with the carbon emission center moving to the northwest; (3) The regions with higher development level of digital economy, industrial structure and new quality productivity have relatively less carbon emissions, with significant group difference effect; (4) Energy consumption intensity effect is the main factor to drive the continuous growth of carbon emissions, per capital GDP and energy consumption structure effect are the main factors to curb carbon emissions, and the impact of industrial structure and population size effect is relatively small. Based on the research conclusions, policy suggestions are put forward from the aspects of energy structure, industrial structure, new quality productivity and digital economy.

Keywords: Carbon Emissions, ARIMA-BP Model, Temporal and Spatial Evolution, Standard Elliptic Difference.

1. Introduction

First of all, China has an important responsibility to reduce carbon emissions. China stressed "to actively and steadily promote carbon neutrality in peak carbon dioxide emissions". As can be seen from Figure 1, China's total carbon emissions have continued to rise rapidly since 2000. In 2023, China's total carbon emissions amounted to 12.6 billion tons, accounting for one-third of the global carbon emissions of 37.4 billion tons, making it the world's largest carbon emitter. Secondly, there are significant regional differences in carbon emissions. As can be seen from Figure 2, the province with the highest carbon emissions in 2023 is Shanxi, and the lowest carbon emissions in 2023 is Hainan, based on the above practical problems, this paper combines ARIMA time series analysis and BP neural network algorithm to estimate and forecast the carbon emissions of the whole country and each province, and analyzes the spatial evolution characteristics of China's carbon emissions, uses LMDI to decompose the driving factors, and the research conclusions provide decision-making reference for making scientific and reasonable emission reduction policies according to local conditions in different regions of China.

Data source: National Bureau of Statistics of China.China statistical yearbook. https://www.stats.gov.cn/sj/ndsj/.(2000-2020).

2. Construction of ARIMA-BP neural network model

Firstly, the ARIMA model is used to predict the data and obtain the prediction error sequence. Secondly, a two-level hidden layer BP neural network containing one neuron and three neurons is established. The error data are transmitted to the neural network in time sequence, with the input node set to 4 and the output node set to 1. By rolling the window, the error of the previous period is continuously transmitted to the neural network as part of the input, and the model is continuously modified and predicted. Finally, the combination model is used to predict the change of carbon emission intensity[1]. The combination of ARIMA model and BP neural network model is more suitable for the prediction and analysis of carbon emissions in this paper than the individual prediction and estimation:

(1) the ability to capture complex patterns. The traditional time series model is sensitive to the data quality and has high requirements for the data quality. If there are some problems such as missing values, outliers or large noise in the data, the fitting effect and prediction accuracy of the model will be affected. Neural network has a strong ability to capture nonlinear maps and can capture complex time series patterns and trends. BP neural network can approximate any nonlinear mapping relationship, and the learning algorithm is a global approximation algorithm, which has strong generalization ability, can well solve the shortcomings of ARIMA model, and can better deal with the nonlinear mapping relationship and long-term dependence.

(2) Multi-feature processing. Neural networks can process multiple features simultaneously as inputs, while traditional time series models usually only consider time series of single variable. Neural network can make better use of other characteristics related to time series to improve the prediction performance.

(3) long-term forecasting capability. The recurrent structure of neural network, such as long-term and short-term memory network or gating cycle unit, enables it to better deal with long-term prediction problems. Compared with the traditional time series model, the neural network may have better performance in long-term prediction.

3. Forecast and analysis of carbon emissions

3.1. analysis of the overall characteristics of carbon emissions in China

3.1.1 Forecast and analysis of national total carbon emissions

The change trend of total carbon emissions in China is shown in Figure 1. Total carbon emissions are the sum of carbon emissions from the three major industries and carbon emissions from residents' living consumption. From 2000 to 2035, China's total carbon emissions increased year by year, from 2,575 million tons to 21,351 million tons, an increase of 829%. The growth rate of carbon emissions gradually decreased, from 4.8% in 2000 to 1.7% in 2035. Before 2018, the growth rate of China's total carbon emissions was relatively slow, and the growth rate was relatively fast after 2018. The continuous increase in total carbon emissions involves various reasons such as economy, energy and lifestyle, especially the continuous increase in energy demand, which leads to the continuous growth of carbon emissions. At the same time, due to China's adherence to the concept of green development, promoting the synergy of pollution reduction and carbon reduction, the clean and low-carbon efficient use of coal, the rapid development of new energy sources such as wind and solar energy, and the vigorous research and development of green and low-carbon technologies, the growth rate of carbon emissions has gradually decreased.

3.1.2 Forecast and analysis of carbon emissions from various industries

As can be seen from Figure 1, from 2000 to 2035, the primary industry's carbon emissions increased from 44 million tons to 92 million tons, up 208%, the secondary industry's carbon emissions increased from 2,070 million tons to 14,278 million tons, up 690%, and the tertiary industry's carbon emissions increased from 73 million tons to 663 million tons, up 910%. It can be seen from this that the secondary industry has the highest carbon emissions, the primary industry has the lowest carbon emissions, the secondary industry's carbon emissions gradually increased, with a large change in trend. The primary industry and the tertiary industry's carbon emissions gradually increased, with a small change in trend. The economic development has entered a new era and turned to a high-quality development stage[2]. The industrial structure will be further transformed and upgraded. The proportion of the secondary industry will continue to decline steadily. China is making efforts to promote the upgrading of manufacturing industry and transition to high-end manufacturing industry. This will involve the research and development and application of advanced manufacturing technologies, such as artificial intelligence, big data, robotics, etc. With the continuous development of science and technology, agricultural modernization will become the main trend in the future. Agricultural modernization will greatly improve the efficiency of agricultural production and improve the quality and competitiveness of agricultural products. Under the background of the transformation and upgrading of the new generation of industries, the new type of urbanization and the upgrading of the quality of residents' consumption, the development of China's tertiary industry service industry has ushered in new opportunities, and the leading industry in economic development is further highlighted[3].

3.1.3 Forecast and analysis of carbon emissions from household consumption

As can be seen from Figure 1, from 2000 to 2035, China's domestic carbon emissions increased rapidly, from the lowest 388 million tons to the highest 6,317 million tons, an increase of 1642%. With the advancement of urbanization, the total carbon emissions of residents have shown a significant increase. Urbanization is characterized by the expansion of low population density, which promotes the continuous growth of carbon emissions. China is in the stage of rapid urbanization[4]496. People's demand for quality of life is gradually increasing. Consumption expenditures of various energy goods and services are correspondingly increasing, and the total carbon emissions are continuously increasing. The increase in carbon emissions from residents' lives indicates that low-carbon living should be promoted, public transportation should be promoted, walking and cycling should be encouraged, green buildings should be promoted, energy-saving and environment-friendly buildings should be constructed, energy consumption of buildings should be reduced, and upgrading of consumption should be promoted. At the same time, total carbon emissions from living consumption should be reduced to promote green development.

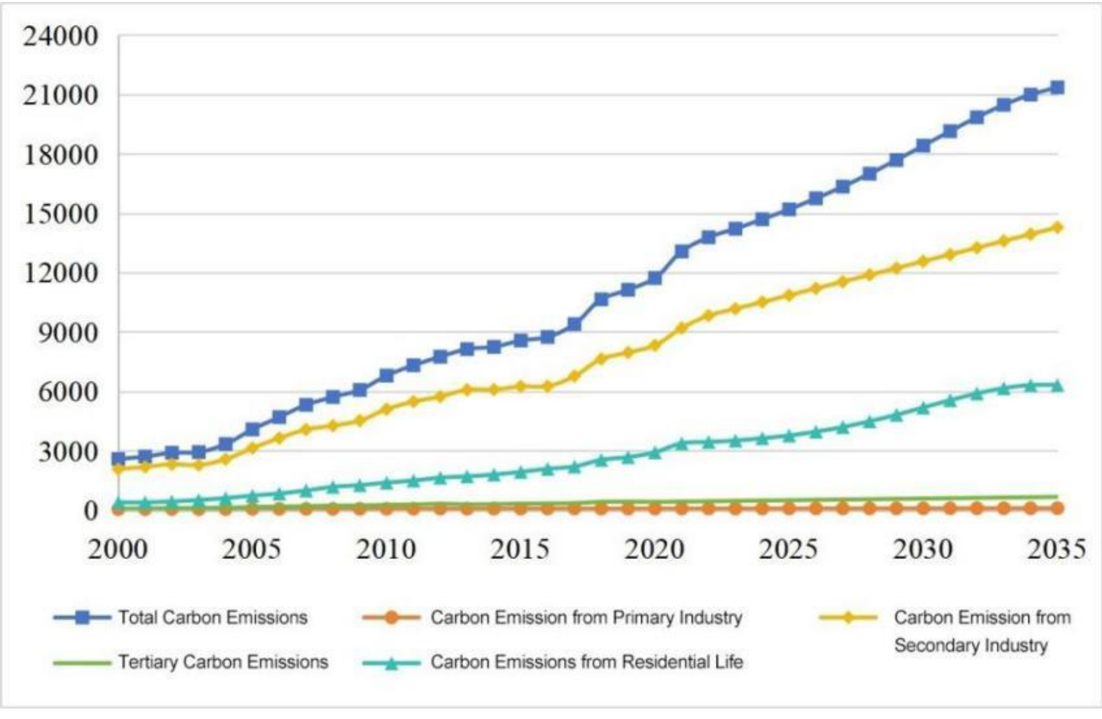

Figure 1. Forecast Trend of Total Carbon Emissions in China from 2000 to 2035

3.2. The spatial distribution of carbon emissions in China

As can be seen from fig. 2, the spatial distribution of carbon emissions in each province of our country presents a typical distribution pattern of "east > central > west" and "north > south", indicating that the regional differences of carbon emissions in our country are obvious. Specifically, from 2000 to 2035, China's provinces' carbon emissions continued to increase. The provinces with higher carbon emissions in 2000 were mainly concentrated in the eastern region (Figure 2.a), and the provinces with higher carbon emissions in 2021 were mainly the eastern and northern provinces (Figure 2.b). The development trend was more obvious in 2035 (Figure 2.c). According to the standard elliptic difference analysis, China's carbon emission center tends to move northwest. It shows that while China's power supply and heavy industry are moving to the northwest, the processing capacity of the terminal treatment facilities cannot keep up with it in time.

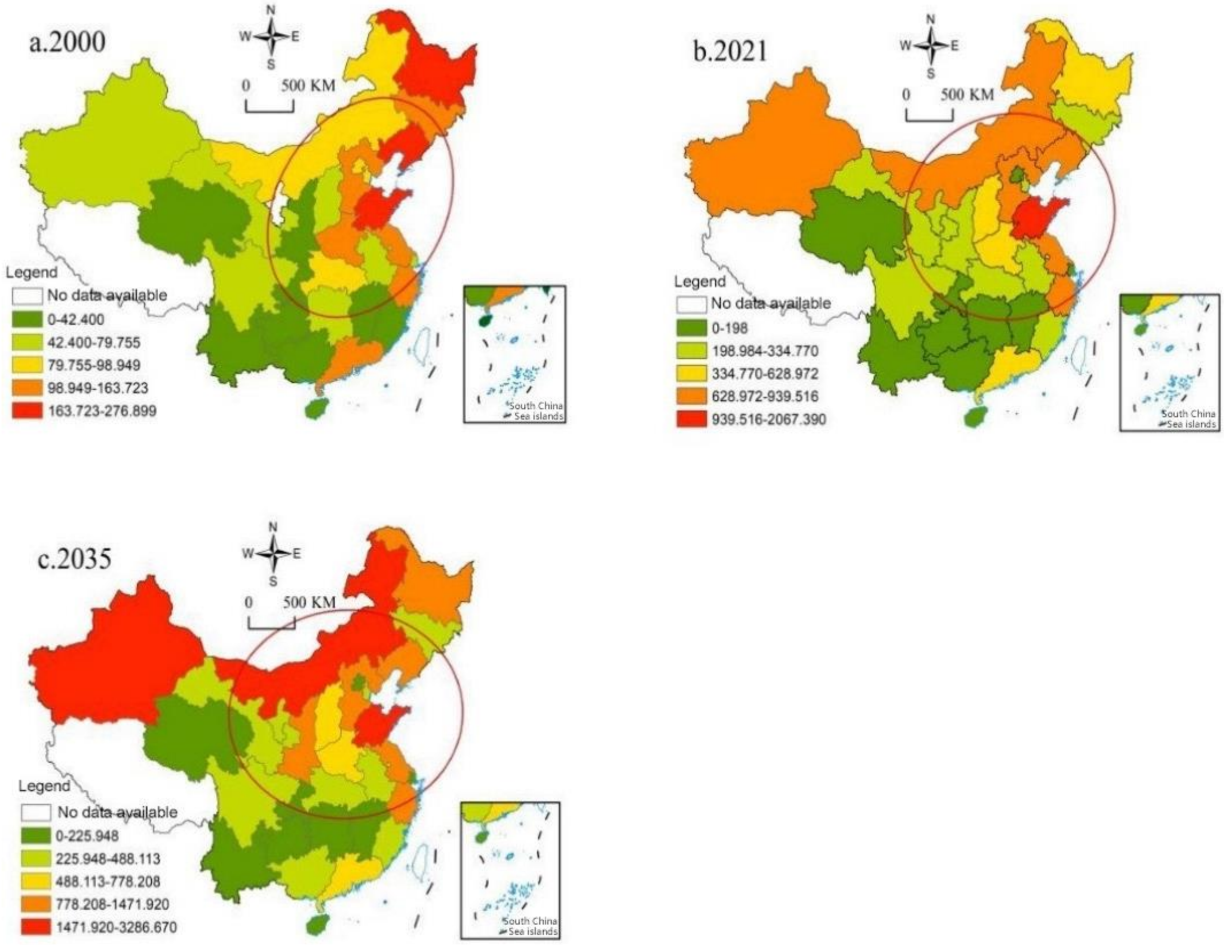

Figure 2. Spatial Distribution of Carbon Emissions of Each Province over the Years from 2000 to 2035

This paper further divides each province's carbon emissions into two time periods of 2000-2021 and 2022-2035, calculates the average value of each province's carbon emissions, and ranks them from high to low (Figure 3).

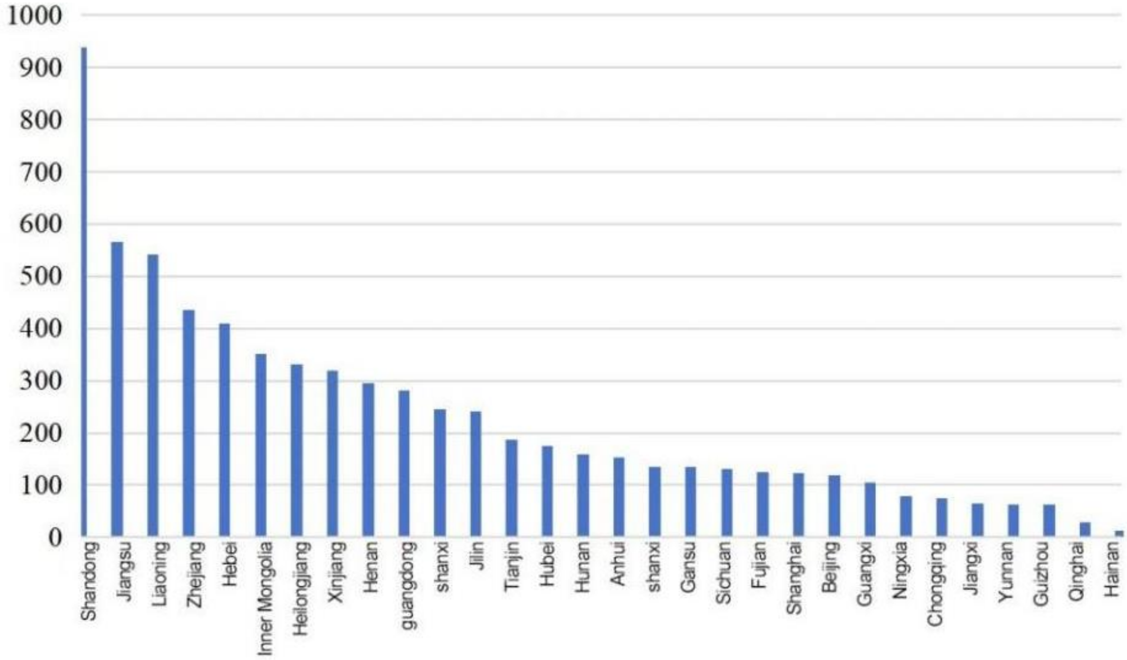

Figure 3. Average Carbon Emissions by Province (Million Tons) from 2000 to 2021

As can be seen from Figure 3, from 2000 to 2021, the average carbon emissions of all provinces in China were the highest in Zhongshan East Province, with an average carbon emissions of 940 million tons, and the lowest in Hainan Province, with an average carbon emissions of 12 million tons. The average carbon emissions of Shandong Province were 78.25 times that of Hainan Province. As the industrial structure of Shandong Province is mainly heavy industry, such as iron and steel, chemical industry, building materials, etc., these industries need a large amount of energy in the production process, and the energy use efficiency is low, resulting in high carbon dioxide emissions, and the energy consumption structure of Shandong Province is mainly coal. Although Shandong Province has gradually adjusted its energy structure in recent years to increase the use of clean energy such as natural gas and renewable energy, the dominant position of coal consumption is still difficult to change in a short period of time. Secondly, Shandong Province has a large number of high-energy consuming and high-emission ("two-high") industrial enterprises, such as thermal power, iron and steel, chemical industry, etc., which are the main sources of carbon dioxide emissions. Compared with other regions, Hainan Island's carbon emissions are relatively low. The main reason is that Hainan Island's economic structure is dominated by services and agriculture, with relatively few industries. Besides, the tourism industry is the mainstay of the economy. The Hainan Island government has adopted a series of environmental protection measures, such as encouraging the use of clean energy, limiting the entry of high-pollution industries, and carrying out environmental protection activities such as tree planting and afforestation. In addition, Hainan Island is also rich in marine resources, and the development of marine economy is also one of the ways to reduce carbon emissions. Nevertheless, Hainan Island, as an important participant in the common governance of global environmental issues, is still promoting green development, strengthening carbon emission control and mitigating the impact of climate change.

From Figure 4, it can be seen that from 2022 to 2035, the average carbon emissions of all provinces in China are the highest in Shandong Province, with an average carbon emissions of 2,721 million tons, and the lowest in Qinghai Province, with an average carbon emissions of 93 million tons, and the average emissions of other provinces have increased from 2000 to 2021, with a larger change trend. The reason is that China's industrialization and economic growth have led to an increase in energy consumption, especially the use of fossil fuels such as coal and oil, which will release a large amount of carbon dioxide. The population of our country keeps growing and the urbanization process is accelerating rapidly. This has led to an increase in buildings, roads and infrastructure, requiring more energy supplies. At the same time, urban traffic and industrial activities will also lead to an increase in carbon dioxide emissions. Among them, the ranking of Jiangsu and Zhejiang in the country has changed greatly, while that of Inner Mongolia and Xinjiang has changed greatly. The reason is that Jiangsu and Zhejiang, as developed regions, have high energy efficiency. High and new technologies such as photovoltaic power generation and biomass energy have greatly reduced carbon emissions. The rapid economic development in Xinjiang and Inner Mongolia in recent years has led to an increase in energy consumption, especially in the manufacturing industry and power and gas sectors, which consume a large amount of fossil energy. Low energy use efficiency and backward production processes have led to an increase in energy consumption intensity and increased carbon emissions. In the process of urbanization, urban population growth, per capita energy consumption increase and urban construction investment increase consume a large amount of energy, thus increasing carbon emissions[4]495.

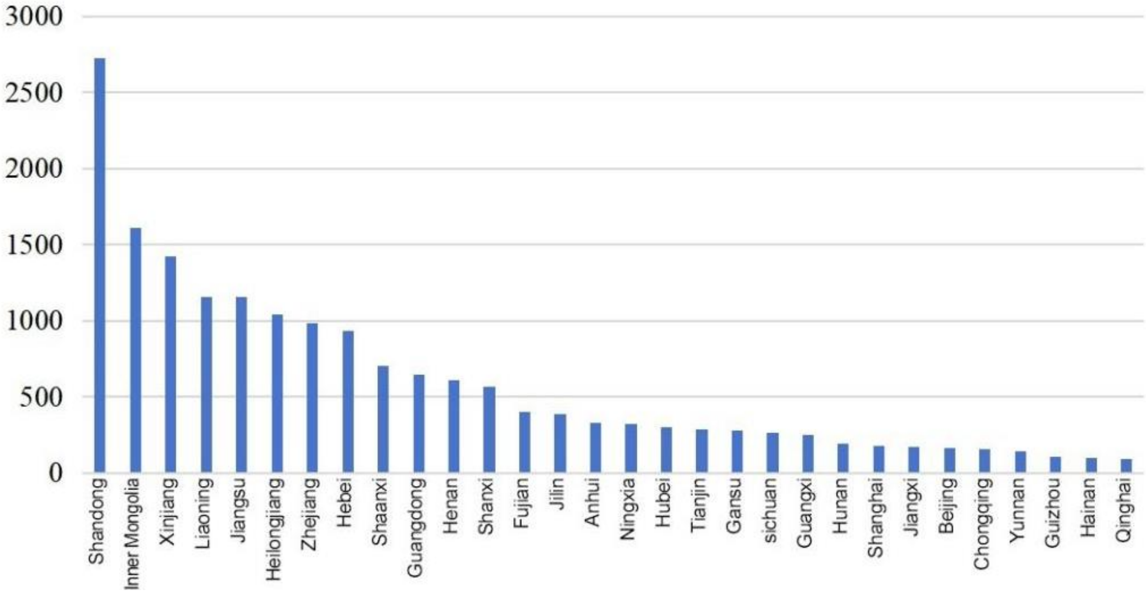

Figure 4. Average carbon emissions of each province from 2022 to 2035 (million tons)

4. Policy recommendations

4.1. Optimize the energy consumption structure

First, we will further improve the regulation of total energy consumption and intensity, focus on controlling fossil energy consumption, optimize the energy consumption structure, and gradually shift to a "dual control" system of total carbon emissions and intensity[5]. The second is to coordinate industrial restructuring, pollution control, ecological protection and response to climate change, vigorously develop clean energy by optimizing the energy system and promoting energy-saving technologies and equipment, promote clean energy represented by hydropower and nuclear power, reduce energy consumption, and jointly promote carbon reduction, pollution reduction, green expansion and growth[6]. The third is to effectively implement the policy of giving priority to energy conservation, to use energy resources in an economical and intensive manner throughout the whole process of economic and social development[7], in all fields and in all links, to foster a thrifty consumption concept and to accelerate the formation of an energy-saving society[8].

4.2. Promote the upgrading of industrial structure

First, promote agricultural modernization, promote green agricultural technology, encourage farmers to adopt conservation tillage, precision agricultural technology and biotechnology, etc., to improve the efficiency and quality of agricultural production and reduce carbon emissions. We will optimize the structure of the agricultural industry, rationally adjust the structure of planting and breeding industries, and promote the transformation and upgrading of the agricultural industry.

Secondly, we will promote the upgrading of the manufacturing industry, develop green manufacturing technologies, encourage enterprises to adopt advanced production technologies and equipment, improve production efficiency and product quality, and reduce energy consumption and carbon emissions. Optimize the industrial structure, accelerate the elimination of backward production capacity and high-pollution industries, develop new industries and green industries, and improve the green and low-carbon level of manufacturing industry[9]. Finally, vigorously develop the tertiary industry, develop green service industry and strengthen energy management in service industry.

4.3. Develop new productive forces

The regions with high development level of new quality productivity have low carbon emission intensity and realize green and low carbon development. New quality productivity is the key to reduce carbon emission. Reduce carbon emissions by promoting innovative technologies and sustainable development to achieve more efficient and cleaner production methods; Through scientific and technological innovation, improve production efficiency, such as actively cultivating new energy, new materials, advanced manufacturing, electronic information and other strategic emerging industries, reduce China's resource consumption and environmental pollution, and achieve sustainable development; Based on the regional imbalance of carbon emissions, establish and improve a carbon trading market to provide a platform for carbon emissions trading. The government should issue relevant policies to clarify the rules and standards of carbon trading, provide legal protection for carbon trading and strengthen the supervision of the carbon trading market.

4.4. Promote digital transformation

Regions with high levels of digital economy development have low carbon emission intensity. The development of digital economy is an important way to reduce carbon emissions错误!未找到引用源。[10]109. Digital transformation can reduce dependence on traditional industries and reduce energy consumption and carbon emissions. Optimize supply chain management, reduce energy consumption, build digital infrastructure, such as building a green data center, promote the use of energy-saving equipment and technology, and improve the energy efficiency of the data center. At the same time, renewable energy is used to power the data center and reduce carbon emissions. The 5G and Internet of Things technologies will be promoted to realize interconnection and intercommunication among equipment, improve energy utilization efficiency and reduce unnecessary energy consumption and carbon emissions[11].

5. Conclusion

(1) ARIMA-BP neural network model is used to predict the total carbon emissions of each province from 2000 to 2035. In general, China's total carbon emissions increased year by year, but with the continuous optimization of industrial structure, the growth rate of carbon emissions gradually decreased. Judging from the specific structural changes of carbon emissions, the order of total carbon emissions is "secondary industry > residents' livelihood > tertiary industry > primary industry", in which the growth rate of secondary industry and residents' livelihood carbon is faster, while the change trend of primary industry and tertiary industry is smaller.

(2) ArcGIS is used to characterize the spatial distribution of carbon emissions in China's provinces. The spatial distribution of carbon emissions in each province presents a typical "eastern > central > western" and "northern > southern" uneven distribution pattern, which reflects the characteristics of carbon emissions in different stages of economic development. According to the standard elliptic difference analysis, the carbon emission center will move to the northwest from 2000 to 2035[10]113.

(3) Based on the new development concept, each province's carbon emissions are divided into different groups, and the heterogeneity analysis of group effect is carried out. The regions with higher levels of development of digital economy, industrial structure and new quality productivity have

relatively less carbon emissions, with significant group difference effect, indicating the importance of industrial structure and new formats in emission reduction.

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