

Energy Carbon Emission Measurement and Influencing Factor Analysis - A Case Study of Ningxia Abstract

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Abstract. This study takes five prefecture-level cities in Ningxia—Yinchuan, Shizuishan, Wuzhong, Guyuan, and Zhongwei—as research subjects, using the emission factor method to calculate urban carbon emissions from 2011 to 2023. It analyzes the impacts of population size, economic development level, industrial structure, and other factors on carbon emissions, and explores key driving forces by integrating data on green finance, innovation indices, and urbanization. The findings indicate that carbon emissions in Ningxia exhibit significant spatial disparities, with high-emission areas concentrated in northern industrial cities, showing a "high north, low south" distribution pattern. Total carbon emissions have shown an upward trend, while emission intensity has continuously declined, indicating a gradual decoupling between economic growth and carbon emissions. Economic level, industrial structure, and energy consumption are the core drivers, while green finance and technological innovation demonstrate significant emission reduction effects. Urbanization shows an inverted "U"-shaped relationship with carbon emissions. Finally, the study proposes differentiated policy measures, region-specific controls for northern and southern areas, core-led initiatives, and ecological prioritization as pathways for emission reduction, offering strategic recommendations for pollution control and carbon mitigation in Ningxia Hui Autonomous Region to achieve its dual carbon goals.

Keywords: Carbon Emission, Spatiotemporal Evolution, Green Finance, Technological Innovation, Urbanization, Ningxia.

1. Introduction

The "China Climate Change Blue Book (2025)" points out that the warming trend of the climate system continues; since the 1990s, global ocean warming, sea-level rise, and glacial melting have accelerated significantly. China is a sensitive and significantly affected area of global climate change, with a warming rate higher than the global average during the same period, and extreme weather and climate events becoming more frequent and intense. In 2024, China's annual average temperature, the melting loss of the No. 1 glacier at the source of the Tianshan Urumqi River, and the sea level along China's coast all reached new highs. Against this backdrop, the "15th Five-Year Plan" proposed to "accelerate the comprehensive green transformation of economic and social development and build a beautiful China." The Central Economic Work Conference deployed the key task of "adhering to 'dual carbon' leadership and promoting comprehensive green transformation." To implement the spirit of the Central Economic Work Conference, all regions and departments are firmly committed to the path of ecological priority, conservation and intensive use of resources, and green, low-carbon, and high-quality development, and are working together to promote carbon reduction, pollution reduction, greening, and growth, achieving a virtuous cycle and mutual reinforcement of high-level protection, high-quality environment, and high-quality development. Therefore, it is essential to calculate carbon emissions and explore their driving factors.

Ningxia Hui Autonomous Region, located in Northwest China, is a major national energy and chemical industry base and a crucial node in the "West-to-East Power Transmission" strategy. The region is rich in coal resources, with a significant coal-dependent energy structure, and its carbon emission intensity has long been among the highest in the country. Under the constraints of "dual carbon" targets, Ningxia faces the dual pressures of energy transition and economic development.

However, current research on carbon emission accounting and driving factors at the prefecture-level city level in Ningxia remains relatively weak, lacking systematic regional comparative analysis.

Based on the above background, this paper takes five prefecture-level cities in Ningxia Hui Autonomous Region (Yinchuan, Shizuishan, Wuzhong, Guyuan, and Zhongwei) as the research object, calculates the total carbon emissions of each city from 2011 to 2023, and uses the emission coefficient method to empirically analyze the impact of factors such as population size, economic development level, and industrial structure on carbon emissions.

2. Literature Review

2.1. Carbon Emission Measurement Methods and Industry Research

Many scholars have conducted research on carbon emission accounting, and the mainstream research methods include emission factor method, data envelopment analysis, and spatial remote sensing inversion. Zhang et al. (2026) [1] used the emission coefficient method to study and calculate the spatiotemporal evolution of carbon emissions from planting industry in the Songhua River Basin from 2002 to 2022; Yuan et al. (2026) [9] used a bottom-up method to calculate the carbon emissions of tourism industry in Liaoning Province from 2004 to 2022; Xue et al. (2025) [11] used a combination of the top-down energy consumption method and the bottom-up driving mileage method to calculate the carbon emissions of transportation in Xi'an City; Feng et al. (2026) [12] used the IPCC carbon emission coefficient method to calculate the carbon emissions of cultivated land use in counties in the Southwest Karst region; Hu et al. (2026) [4] used the indirect extrapolation method based on the material balance principle to calculate the carbon emissions of Caijia Smart New City in Chongqing; Li et al. (2026) [8] used the unit GDP energy consumption method to calculate carbon emissions and explore the spatiotemporal evolution characteristics of carbon balance in three counties in the karst region; Zhe Yang and Chao Hu (2026)[14] used Data Envelopment Analysis (DEA) and Epsilon-Based Measure (EBM) models to calculate carbon emissions from 26 cities in the Yangtze River Delta urban agglomeration.

In their research on carbon emissions, scholars have shown a significant diversity in the types of research subjects and spatial scales they have selected. At the industry level, Zhang Yuan et al. (2026) [1] focused on carbon emissions from the planting industry in the Songhua River Basin; Yuan Man et al. (2026)[9] calculated the scale of carbon emissions from the tourism industry in Liaoning Province; Ju Jindan et al. (2025)[6] conducted a systematic analysis of carbon emissions from the textile and apparel industry; Xue Shuqi et al. (2025)[11] explored the characteristics of carbon emissions from the transportation industry; and Xinbao Chen et al. (2025)[13] focused on carbon emissions from the heavy industry sector. In terms of spatial scale, the research scope covers multiple levels, including macro, meso and micro: Du Qiang et al. (2024)[15] used the whole country as the research scale; Zuo Ximei et al. (2025)[10] selected cities along the Silk Road Economic Belt; Yu Shaoqiang et al. (2026)[3] focused on the Bohai Rim region; Xinbao Chen et al. (2025)[13] took the Yangtze River Midstream City Cluster as the research object; Wang Qi et al. (2025)[2], Li Zhenzhen et al. (2026)[8], and Xie Yunjie et al. (2026)[5] have conducted relevant studies with Heilongjiang Province, karst counties, and Jiangxi Province as their respective research units; Hu Miaofen et al. (2026)[4] and Ju Jindan et al. (2025)[6] selected the urban area of Chongqing and Hangzhou as typical regions for analysis, respectively.

2.2. Research Methods for Carbon Emission Influencing Factors

When identifying the influencing factors of carbon emission efficiency, scholars mainly rely on econometric models for analysis. Among them, the Tobit model is widely used and has significant advantages, as it can handle situations with limited data well. For example, scholars such as Yu Shaoqiang et al. (2026)[3] and Zhe Yang and Chao Hu (2026)[14] have used this model for analysis. In addition, studies often use STIRPAT models, such as Ju Jindan et al. (2025)[6] and Song Xiaowei et al. (2026)[7], or spatial econometric models, such as Li Zhenzhen et al. (2026)[8], as a basis to

construct corresponding analytical frameworks, thereby revealing the mechanism of action of each factor more accurately.

2.3. Scenario Prediction Methods

Currently, the scenario analysis method is mainly used to predict the peak path of carbon emissions. Researchers will set up multiple possible future scenarios for comparison based on different economic and social development trends, the speed of technological progress, and the intensity of policy intervention.

In specific analyses, simulations are often conducted using tools such as the LEAP model and system dynamics models. Du Qiang et al. (2024)[15] used a system dynamics model to conduct a simulation study on the dynamic integration of carbon emission reduction potential in China's construction sector; Tang Wei et al. (2025)[16] integrated a system dynamics model with a multi-agent simulation model to evaluate decarbonization strategies for highways; Lin Jinyao et al. (2025)[17] combined the LEAP model with the FLUS model to predict the carbon neutrality scenario in Shenzhen; and Wang Zhiwei et al. (2024)[18] coupled the LEAP model with the LMDI model to simulate the carbon peaking and carbon neutrality pathway in Gansu Province.

3. Research Methods and Data Sources

3.1. Research Methods

Based on authority and feasibility, and drawing on the carbon emission factor method given in the "2006 IPCC National Greenhouse Gas Inventory Guidelines," the carbon emissions from energy consumption in various prefecture-level cities in Ningxia were calculated. The specific calculation formula is as follows:

$$C = \sum_{i=1}^n C_i = \sum_{i=1}^n e_i \times \theta_i \times \mu_i$$

Where: C represents the total carbon emissions from energy consumption; i represents the energy type, including coal, coke, crude oil, gasoline, diesel, kerosene, fuel oil, and natural gas; e_i represents the physical quantity of end-use energy in category i ; θ_i represents the physical quantity of end-use energy in category i ; μ_i represents the standard coal conversion factor for category i ; μ_i represents the physical quantity of end-use energy in category i ; μ_i represents the carbon emission factor for category i .

Due to the different original units of various energy sources, unit conversion was performed before calculation, uniformly converting them to 10,000 tons of standard coal equivalent. According to the "2006 IPCC National Greenhouse Gas Inventory Guidelines" and commonly used domestic research results, the carbon emission factors for various energy sources are as follows: coal 0.756, coke 0.855, crude oil 0.586, gasoline 0.571, kerosene 0.571, diesel 0.592, fuel oil 0.619, and natural gas 0.448.

3.2. Data Sources

Energy consumption data are obtained from the "Ningxia Statistical Yearbook" (2011-2023) and statistical bulletins of various prefecture-level cities. For missing data for individual years, linear interpolation was used to supplement the missing data. The study area is the five prefecture-level cities under the jurisdiction of Ningxia Hui Autonomous Region, including Yinchuan, Shizuishan, Wuzhong, Guyuan, and Zhongwei.

4. Empirical Results Analysis

4.1. Analysis of Economic and Social Development in Ningxia Hui Autonomous Region

Based on the GDP data from the "Ningxia Statistical Yearbook," Figure 1 was drawn to observe the changes in GDP of various cities in Ningxia.

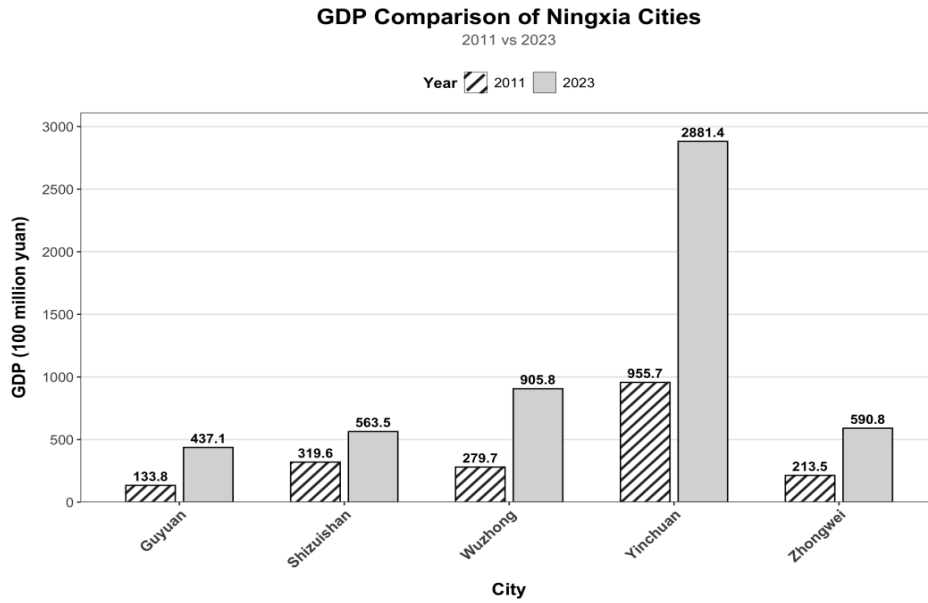


Figure 1. GDP of cities in Ningxia Hui Autonomous Region

As shown in Figure 1, from 2011 to 2023, cities in Ningxia achieved significant growth in gross regional product. The economic output of Yinchuan, the provincial capital, increased from 95.57 billion yuan in 2011 to 288.14 billion yuan in 2023—a more than twofold increase—maintaining its absolute leading position within the region and highlighting its role as a core engine of regional economic development. Other cities also experienced varying degrees of economic growth over the past 12 years, with Wuzhong's GDP rising from 27.97 billion yuan to 90.58 billion yuan—an increase of over 2.2 times—closely linked to the development of local characteristic industries and support from national policies. From an absolute difference perspective, the gap in GDP among Ningxia's cities has widened. However, despite growing disparities in economic scale, the overall improvement in economic levels indicates that regional development is moving toward greater balance, laying a solid foundation for Ningxia's sustainable development.

Based on the permanent population data from the "Ningxia Statistical Yearbook", Figure 2 was drawn to observe the changes in the total population of each city in Ningxia.

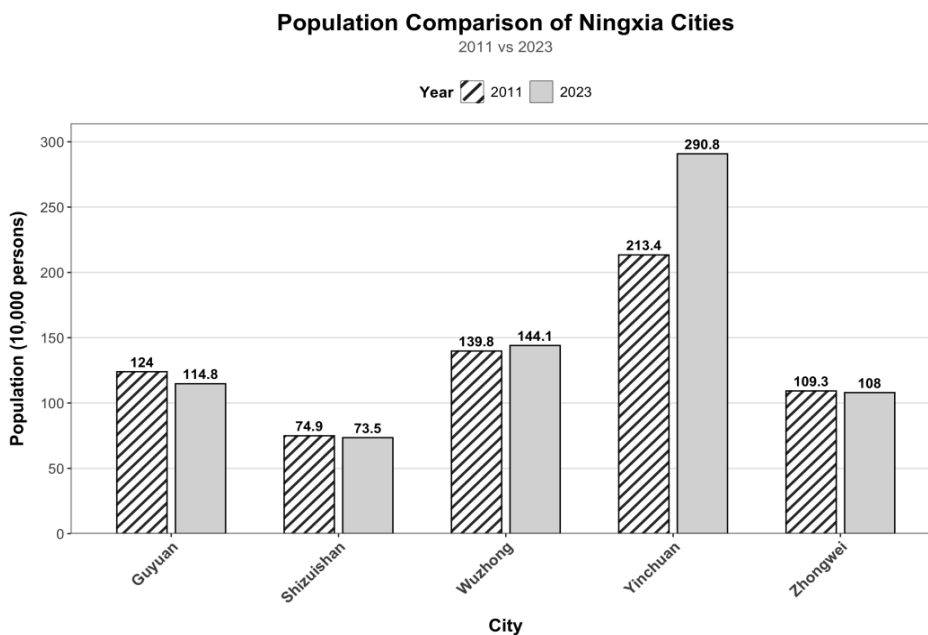


Figure 2. Population of Cities in Ningxia Hui Autonomous Region

As shown in Figure 2, Yinchuan City experienced significant growth in its permanent population from 2011 to 2023, increasing from 2.134 million to 2.908 million—a cumulative increase of 774,000 people, representing a growth rate of 36.3%. As the political, economic, and cultural center of the entire region, Yinchuan has achieved a relatively high level of economic development, creating numerous employment opportunities. Meanwhile, substantial progress has been made in infrastructure construction and public service facilities, collectively enhancing residents' quality of life and attracting large-scale population inflow. Apart from Yinchuan, Wuzhong City also saw modest population growth, rising from 1.398 million to 1.441 million, an increase of 3.1%. In contrast, Guyuan, Shizuishan, and Zhongwei cities all experienced varying degrees of population decline: Guyuan decreased from 1.24 million to 1.148 million, a drop of 7.4%; Shizuishan declined from 749,000 to 735,000, a decrease of 1.9%; and Zhongwei fell from 1.093 million to 1.08 million, a reduction of 1.2%. Overall, across Ningxia, the pattern of permanent population distribution shows a clear trend of "central concentration and peripheral contraction," with a marked tendency for population to concentrate in the capital city.

4.2. Analysis of Total Carbon Emissions and Intensity in Ningxia Hui Autonomous Region

Ningxia, as an important energy and industrial base in the northwest region, witnessed a typical decoupling trend in its total carbon emissions and carbon emission intensity from 2011 to 2023, with "continuous increase in total emissions and overall decline in intensity". This reflects the gradual separation of regional economic growth from carbon emissions and the remarkable achievements in green and low-carbon development.

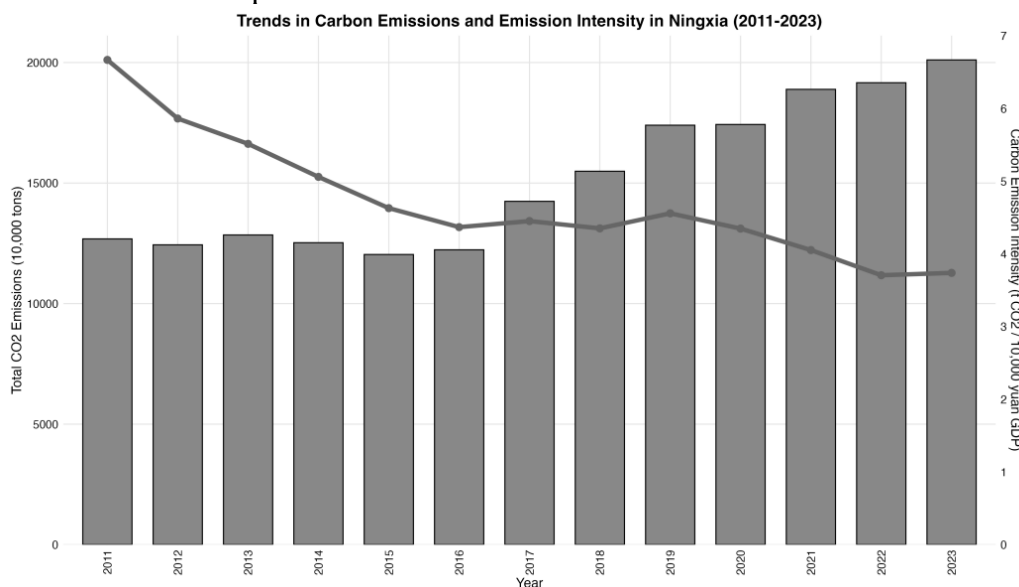


Figure 3. The trend of carbon emission volume and carbon emission intensity in Ningxia Hui Autonomous Region from 2011 to 2023

From the perspective of total carbon emissions, the total carbon emissions in Ningxia showed a fluctuating upward trend from 2011 to 2023, as shown in Figure 3. In 2011, the total carbon emissions across the region were at a relatively low level. Among them, Yinchuan City, as the core city, had the highest carbon emission proportion, followed by Shizuishan City and Wuzhong City. Guoyuan City had the smallest carbon emission scale. After 2016, with industrial expansion, increased energy consumption, and accelerated urban construction, the total carbon emissions in the region entered a period of rapid growth. Yinchuan City had the most significant increase in carbon emissions. Zhongwei City saw a significant jump from 2022 to 2023, while Shizuishan City and Wuzhong City maintained steady growth. Guoyuan City, due to its relatively light industrial structure, had carbon emissions that remained at a low level and with a small increase. By 2023, the total carbon emissions of the entire Ningxia region had significantly increased compared to 2011. Yinchuan City remained

the city with the largest carbon emissions, forming a spatial pattern of "core cities with high emissions and ecological cities with low emissions".

From the perspective of carbon emission intensity (carbon dioxide emissions per unit of GDP), Ningxia's carbon emission intensity showed a continuous downward trend from 2011 to 2023, forming a significant contrast with the total carbon emissions. In 2011, the overall carbon emission intensity of the region was relatively high, indicating that economic growth was heavily reliant on high-energy-consuming and high-emission pathways. With the optimization of industrial structure, the improvement of energy efficiency, the promotion of energy-saving technologies, and the advancement of green transformation, the carbon emission intensity of various cities has decreased year by year, and the carbon emission cost of economic growth has continued to decline. Among them, the carbon emission intensity of traditional industrial cities such as Shizuishan and Wuzhong has decreased more significantly, while the carbon emission intensity of Guyuan and Zhongwei has always been at a low level. Yinchuan has maintained a steady decline in carbon emission intensity while its economic scale has expanded rapidly, achieving the high-quality development characteristics of "total growth and intensity decline".

Overall, the increase in total carbon emissions and the decrease in carbon emission intensity in Ningxia from 2011 to 2023 coexist, reflecting both the objective needs of rapid regional economic and social development, as well as the positive progress made by Ningxia in energy transformation, industrial upgrading, and ecological protection, laying a solid foundation for achieving carbon peak and carbon neutrality goals.

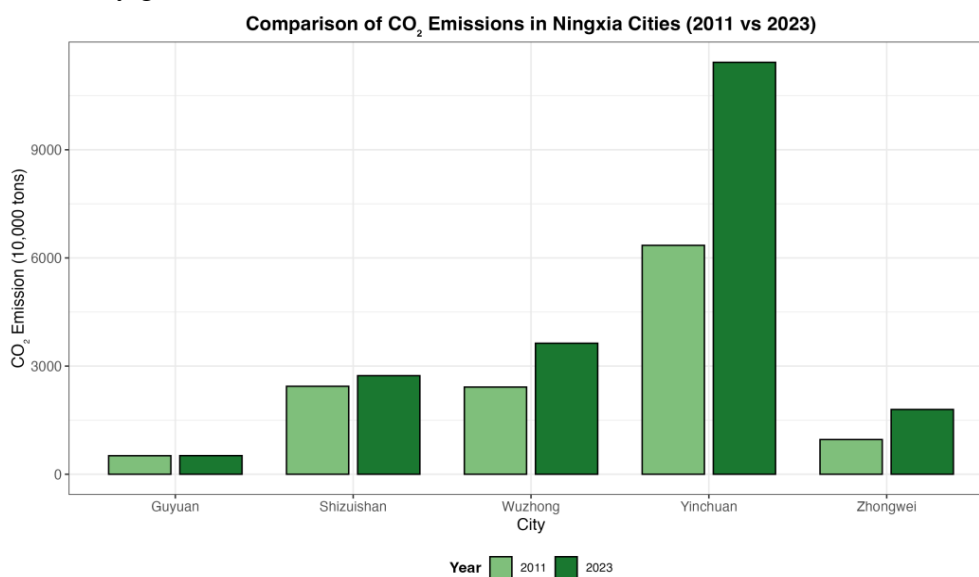


Figure 4. Comparison of Carbon Emissions between 2011 and 2023 in Ningxia Hui Autonomous Region

From 2011 to 2023, as shown in Figure 4, Yinchuan City saw the most significant increase in total carbon emissions in Ningxia, with its carbon emission growth rate far exceeding that of other cities in the region. The reasons for this are threefold: First, the concentrated presence of energy-intensive industries. As the industrial core of the region, Yinchuan is dominated by energy-intensive industries such as coal mining, power generation, and chemicals. Its total energy consumption has long ranked first in the region, with thermal power and coal chemical industries making particularly significant contributions to carbon emissions, serving as the core driving force behind the continuous rise in total carbon emissions. Second, the rapid advancement of industrialization and urbanization. With the expansion of urban built-up areas and the growth of manufacturing and construction industries, energy demand has increased significantly, especially with increased traffic flow and building energy consumption, further pushing up carbon emission levels. Third, the high concentration of economic activity and population. As the capital of Ningxia, Yinchuan City has a highly concentrated

population and economic activity, with strong demand for housing, commerce, and transportation, indirectly driving rigid growth in energy consumption.

From 2011 to 2023, the cities in Ningxia with relatively small growth rates in carbon emissions, and even showing a downward trend, are Guyuan City and Zhongwei City. The carbon emissions have always been at a low level in the entire region, and the growth trend is flat. One possible reason is the green transformation and optimization of the industrial structure. Guyuan City focuses on ecological agriculture and tourism as its core industries, with a very low proportion of high energy consuming industries. Its energy consumption structure is dominated by renewable and clean energy, and its carbon emission intensity has remained at a relatively low level for a long time; Zhongwei City has effectively controlled industrial carbon emissions by transforming and upgrading traditional industries, eliminating outdated production capacity, and actively developing low-carbon industries such as cloud computing and new energy. The second is the large-scale substitution and utilization of clean energy. The two cities rely on the abundant wind and solar resources in Ningxia to vigorously develop renewable energy such as wind power and photovoltaics, promote distributed photovoltaics and centralized heating projects, reduce coal combustion and fossil energy consumption, optimize energy consumption structure, and reduce carbon emission intensity. The third is the promotion of ecological protection and green development strategies. Guyuan City and Zhongwei City are important components of the ecological barrier in southern Ningxia, with strong efforts in ecological protection and restoration, strict control over industrial development, and effective constraints on carbon emissions growth.

The temporal and spatial variation characteristics of carbon emissions in various cities within Ningxia demonstrate significant differences among different regions in terms of economic structure, industrialization process, and energy consumption patterns. Specifically, the rapid growth of total carbon emissions is mainly concentrated in Yinchuan City, which is dominated by industry and has a higher level of economic development. While Guoyuan City and Zhongwei City, which are dominated by ecological agriculture and tourism, have achieved effective control of carbon emissions through industrial structure optimization and the substitution of clean energy. This regional disparity essentially reflects the imbalance in economic development level, industrial structure type, and energy utilization efficiency among different regions in Ningxia, providing an important basis for subsequent regional collaborative emission reduction and the formulation of differentiated low-carbon development policies.

4.3. Factors Affecting Carbon Emissions

Existing research typically summarizes the key factors affecting carbon emission efficiency into the following four aspects:

First, there are economic factors. Generally speaking, as the level of economic development increases, carbon emission efficiency will also improve significantly. In contrast, the impact of industrial structure is more complex, and different studies have yielded different conclusions, sometimes even insignificant ones. This indicates that simply adjusting the industrial ratio may have limited effect, and future emission reduction policies should perhaps focus more on promoting technological upgrading and energy efficiency improvement within various industries.

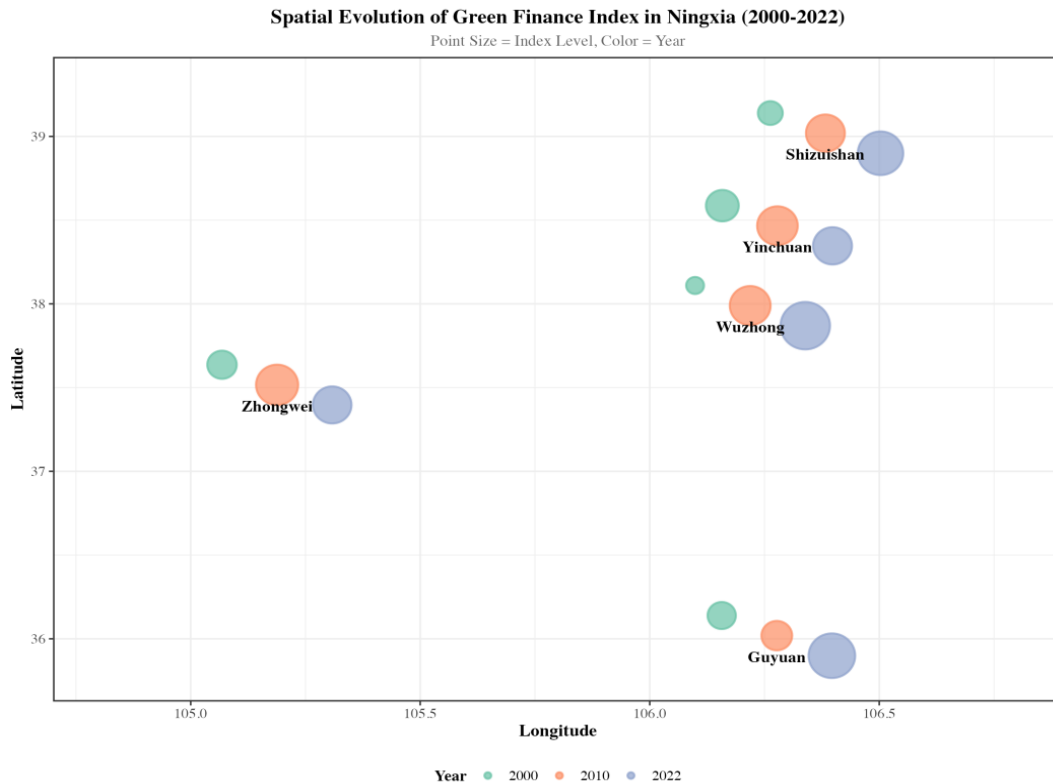


Figure 5. Spatial Evolution of Green Finance Index in Cities of Ningxia Hui Autonomous Region

As shown in Figure 5, green finance plays a significant supporting role in carbon emission control in Ningxia. During the sample period, the development level of green finance in all prefecture-level cities of Ningxia continued to improve, showing a steady upward trend overall. Among them, Yinchuan City, with a relatively complete financial system and policy support, has maintained a leading position in the green finance index in the region for a long time; Shizuishan City, relying on the green transformation of traditional industries, effectively enhanced the support of green finance for low-carbon development; Wujiang City, Zhongwei City and Guoyuan City, relying on the development of clean energy and ecological agriculture construction, promoted the steady development of green finance. Through the guiding role of credit, the optimization of capital allocation and the mitigation of risks, green finance effectively suppressed the growth of regional carbon emissions and significantly reduced the carbon emission intensity, becoming an important driving force for promoting the low-carbon transformation of Ningxia and achieving the "dual carbon" goals.

Secondly, there are social and demographic factors. The spatial agglomeration of population can often improve resource utilization efficiency through economies of scale, thereby helping to improve carbon emission efficiency. The impact of urbanization is more subtle, and its effectiveness largely depends on the "quality" of urbanization, such as the completeness of infrastructure, the level of public services, and whether it incorporates the concept of green development. The urbanization process exhibits an inverted U-shaped effect on carbon emissions, initially increasing and then decreasing. Rapid urbanization from 2000 to 2015 led to an expansion in energy consumption, resulting in a simultaneous rise in carbon emissions; after 2016, with the popularization of new urbanization, green buildings, and public transportation, the growth of carbon emissions slowed down. In Ningxia, the relationship between urbanization and carbon emissions has entered a decoupling phase, providing favorable conditions for peak carbon emissions.

The third is the factor of technology and openness. Technological innovation is widely regarded as the core driving force for improving carbon emission efficiency. At the same time, opening up to the outside world can also indirectly promote efficiency improvement by introducing advanced foreign technologies and management experience and enhancing market competition.

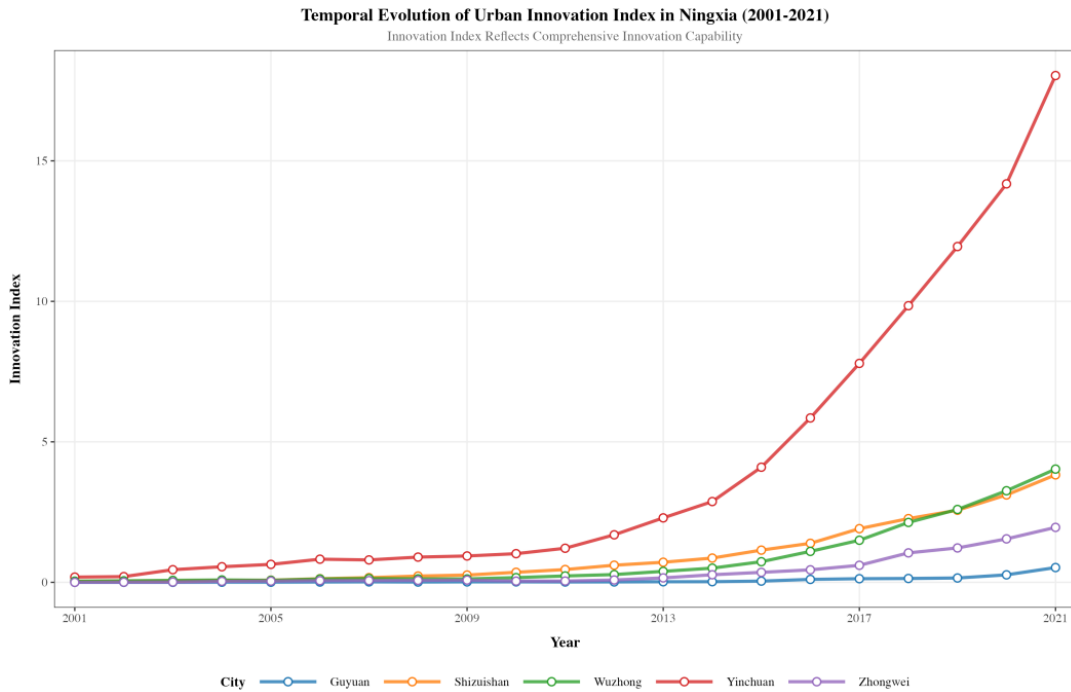


Figure 6. Evolution of Innovation Index in Cities of Ningxia Hui Autonomous Region from 2021 to 2023

From the perspective of time evolution, the Ningxia Urban Innovation Index maintained high-speed growth from 2001 to 2021, showing a stepped upward trend, as shown in Figure 6. The continuous improvement of innovation capability provided strong impetus for the reduction of regional carbon emissions and low-carbon transformation. The innovation index of Yinchuan City increased from 0.186 in 2001 to 18.036 in 2021, a growth of 96.8 times. With outstanding innovation advantages, it has become the core engine for low-carbon technology research and development and exploration of carbon reduction models in the entire region; The innovation level of Shizuishan and Wuzhong cities has rapidly improved synchronously, with growth rates of 94.5 times and 96.5 times respectively. By relying on technological upgrades to promote energy efficiency improvement in high energy consuming industries, the pressure of carbon emission growth has been effectively alleviated; Guyuan City and Zhongwei City have steadily improved their innovation capabilities from a low starting point, achieving low-carbon development through the application of green technology and the development of ecological industries. Overall, the innovative development of Ningxia presents a spatial and temporal pattern of "one core leading, multi-point improvement", and innovation driven development has become a key path to reduce carbon emission intensity and promote green and low-carbon development.

Finally, there are policy factors. The impact of environmental regulations on carbon emission efficiency is not a simple linear relationship, and its effectiveness depends crucially on the strength and implementation of policies, as well as the coordination between different regions. This also highlights the importance of promoting regional collaborative governance and policy integration in achieving efficient emission reduction.

5. Summary

This paper, through the calculation of carbon emissions in Ningxia Hui Autonomous Region and the analysis of influencing factors, found that the spatial differentiation characteristics of carbon emissions in Ningxia are basically consistent with the overall pattern in the country. High carbon emission areas are mainly concentrated in northern industrial cities, and the overall spatial distribution pattern is "high in the north and low in the south". This is consistent with the spatial agglomeration

and regional differentiation characteristics of carbon emissions in most parts of the country [1,2,12]. The improvement of the level of green finance development has a significant driving effect on the low-carbon transformation of Ningxia and can effectively suppress the growth of carbon emissions. This conclusion is highly consistent with the views of existing research [10]. At the innovation-driven level, Ningxia's urban innovation presents a pattern of "one core leading and multiple points supporting". Yinchuan City's innovation level is significantly higher than that of other cities, becoming the core carrier of regional low-carbon technology breakthroughs. Innovation promotes emission reduction through technological progress and efficiency improvement, further verifying the theoretical logic of innovation-driven emission reduction [10,14]. At the same time, Ningxia's urbanization process has entered the middle and late stages of development. Urbanization and carbon emissions are gradually showing a decoupling trend, and the growth rate of carbon emissions has slowed down significantly, which is consistent with the inverted "U"-shaped evolution law revealed by the Environmental Kuznets Curve [4]. From the perspective of driving mechanisms, the level of economic development, industrial structure characteristics and energy consumption structure remain the core factors affecting carbon emissions in Ningxia, consistent with the classic research conclusions of the STIRPAT model [6,7].

Overall, the carbon emissions in Ningxia exhibit the characteristics of significant spatial concentration, obvious regional differentiation, and a gradually slowing growth trend. The high-emission areas continue to be concentrated in the northern industrial cities. Green finance, urban innovation, and urbanization all have a significant impact on carbon emissions, and the intensity of this impact is constantly increasing. Based on these characteristics, Ningxia should implement differentiated policies, implement differentiated control measures between the north and south, lead with core cities, and adopt an eco-friendly development-oriented approach for differentiated emission reduction. Future research can further combine methods such as multi-scenario prediction, system dynamics models, and coupled coordination analysis to conduct in-depth research on carbon peak path simulation and emission reduction policy optimization.

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