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Spatio-Temporal Pattern of Carbon Emission and Optimization Strategy of Emission Reduction Path in Beijing from the Perspective of Green Finance

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Abstract: Beijing, as the capital of China and the pioneer of low-carbon transition, faces the dual challenges of deep emission reduction and economic development. From the perspective of green finance, this study combines spatio-temporal pattern analysis and coupled coordination model to systematically explore the characteristics of Beijing's carbon emissions and the optimization strategy of emission reduction path from 2000 to 2023. The study finds that: Beijing's carbon emissions show the spatial and temporal differentiation characteristics of "high concentration in the core area and low diffusion in the remote suburban areas", the carbon center is stable in Changping District for a long time, but the emerging urban areas, such as Chaoyang and Haidian Districts, have outstanding carbon emission intensity; the coupling and coordination degree of green finance and carbon emissions shows a leaping trend of "primary to intermediate to good coordination"; and the coupling and coordination degree of green finance and carbon emissions shows a leaping trend of "primary to intermediate to good coordination". The degree of coordination of green finance and carbon emission coupling shows a trend of "primary→inter mediate→good→coordinated", but there is a significant regional differentiation, with insufficient transformation momentum in the core urban areas and long-term lagging in the peri-urban industrial areas. By constructing a four-dimensional path framework of "scale effect - technology effect - structure effect - spatial effect", differentiated emission reduction strategies are proposed.

Keywords: Green Finance; Carbon Emission; Spatial And Temporal Pattern; Emission Reduction Strategy

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1.Introduction

Climate change crisis has swept across the world, and realizing the goal of "double carbon" has become a major national strategy in China. As the capital of China and the center of politics, economy and culture, Beijing shoulders the important responsibility of leading the country's low-carbon transformation. In recent years, with the unremitting efforts in industrial upgrading, energy restructuring, and pollution control, Beijing's environmental quality has improved significantly. However, in the face of the ambitious goal of carbon neutrality, the pressure to reduce emissions is still severe - the potential for deep emissions reduction is gradually being compressed, the cost of emissions reduction continues to rise, and it is necessary to explore more innovative, sustainable, and economically efficient emission reduction paths. In this context, it is of great practical significance and theoretical value to explore how to utilize green financial instruments to drive and support the deep reduction of Beijing's carbon emissions.

Traditional emission reduction strategies mostly focus on technical engineering means, and their limitations such as increasing marginal costs and huge financial pressure are becoming more and more prominent. Green finance, as a key bridge connecting the supply and demand of funds and optimizing the allocation of resources, injects new kinetic energy into the realization of carbon reduction goals. It covers a variety of market-based tools such as carbon trading market, green credit, green credit, green bonds, climate investment and financing, green insurance, etc., which provides a powerful support mechanism for guiding the flow of capital to low-carbon projects and incentivizing market players to reduce emissions spontaneously. However, there is still a lack of in-depth exploration on how green financial resources can accurately and efficiently flow to the emission reduction areas that are most in need of support in Beijing's spatial and temporal differences, and how to realize the "precise drip irrigation" of capital financing. Therefore, this study focuses on the spatio-temporal pattern of carbon emissions in Beijing, and explores the optimization strategy of emission reduction paths from the perspective of green finance.

2.Literature review

The combination of green finance and carbon emissions has become a popular research field, and many studies have shown that green finance has a significant inhibitory effect on carbon emissions. Wang Luanfeng[1]. concluded that green finance significantly reduces the carbon emissions of Chinese cities, especially in terms of the city's industrial transformation and green innovation capacity, through panel fixed-effects model and spatial Durbin model on the data of 286 prefecture-level cities, and that the green finance The carbon emission reduction effect of green finance in Chinese cities shows obvious regional differences, differences in natural resources endowment, differences in financial development level and differences in environmental protection enforcement; Li Qihan[2]. point out that green finance reform can effectively reduce carbon emissions in the experimental area and has the spillover effect of carbon reduction; Liu Wei[3]. prove that green finance and R&D inputs play a significant inhibitory effect on carbon emissions through the study of the panel data of 30 provinces. Moreover, Zhang Ying[4] pointed out in the study on the spatial spillover effect of green financial policies on carbon emissions that it is recommended to continuously optimize green financial policies, steadily promote the adjustment of energy structure, innovate and promote the upgrading of green technology, and reasonably plan the layout of policy pilots.

At the same time, the impact of green finance on carbon emissions has been specific to various industries, Jiang Pingfa[5] studied the coupling coordination between green finance and carbon emissions from tourism through the coupling coordination model of spatial and temporal characteristics; Ji Xinlong[6] pointed out that green finance has a significant inhibitory effect on the intensity of carbon emissions in agriculture, and there is a significant difference in the impact of different quartile levels; Li Ruijing[7] pointed out that green finance can effectively inhibit the household consumption of direct and indirect carbon emissions; Gu Gu and others pointed out that green finance can effectively inhibit household consumption of direct and indirect carbon emissions. Li Ruijing et al. pointed out that green finance can effectively curb direct and indirect carbon emissions from household consumption; Gu[8] proposed a study on the threshold and spatial effects of green finance on energy structure under the goal of "double carbon".

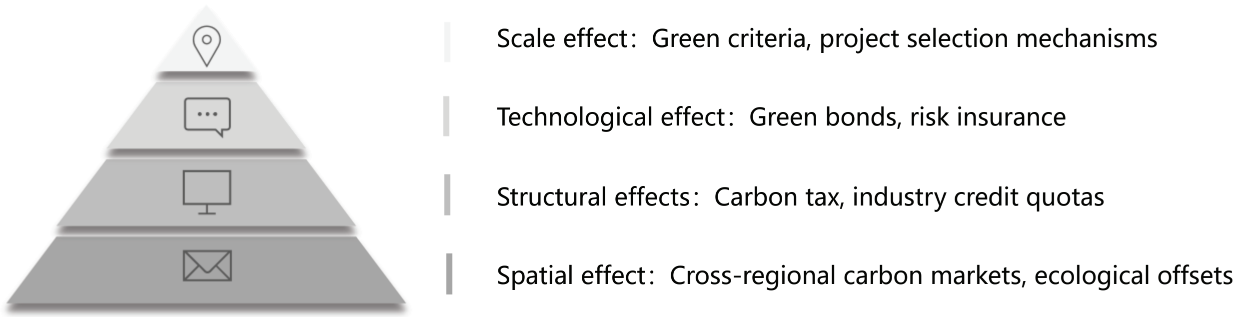
As the capital city and political and economic center of China, Beijing shoulders the mission of pioneering the low-carbon transition of the country, so the innovation of this paper mainly focuses on the spatial and temporal patterns of Beijing's regions, as well as the main industries affected by the region, and optimizes the regions and industries through the strategy of four-dimensional paths of finance and carbon emissions.

3.Theoretical Analysis

3.1 Finance-carbon emission four-dimensional path analysis

The impact of green finance on carbon emissions can be systematically analyzed through the "four-dimensional path", covering the scale effect, technology effect, structural effect and spatial effect. Scale effect mechanism, short-term increase in emissions, long-term optimization of transformation, green finance may be due to expanding the scale of investment to stimulate economic growth, resulting in the expansion of energy-intensive industries (such as infrastructure, heavy industry), short-term push up carbon emissions. However, as funds continue to be injected into the low-carbon field, the scale effect gradually shifts to optimize resource allocation and reduce the intensity of carbon emissions per unit of GDP; the technology effect mechanism, the core emission reduction driving force, green finance directly supports the research and development and application of clean technology by reducing the cost of financing; the structural effect mechanism, the driving force of the low-carbon transformation of industries, and guides the upgrading of the industrial structure by means of differentiated financial policies; the spatial effect mechanism, the regional synergy and the spillover effect, the cross-regional carbon market and the carbon market. spillover effect, cross-regional carbon market and green financial instruments to promote technology diffusion and resource complementarity.

Figure 1 Diagram of the core tools of the four-dimensional finance-carbon pathway.



3.2 Analysis of Carbon Emission Measurement Methods

The carbon emission characteristics of Beijing's urban management field are mainly characterized by a high concentration in certain areas and specific industries, such as construction and transportation. Among them, 90% of Beijing's carbon emissions are concentrated in less than 10% of the land area, mainly in the six districts of Dongcheng, Xicheng, Haidian, Chaoyang, Shijingshan and Fengtai. In order to better understand the carbon emission situation in Beijing, this paper adopts the "bottom-up" grid map from the perspective of spatial and temporal distribution as pointed out by Wang Yizhe[9].

The definition of carbon emissions in the metropolitan area is divided into three scopes: Scope 1 refers to all direct emissions within the jurisdiction of the metropolitan area, which generally include greenhouse gas emissions caused by transportation and construction, industrial production processes, agriculture, forestry and land use changes, and garbage disposal campaigns; and Scope 2 refers to energy-related indirect emissions outside the jurisdiction of the metropolitan area, which generally include purchased electricity, heating, and other energy-related emissions that are used to realize the consumption of metropolitan residents; and Scope 3 refers to the indirect emissions of the metropolitan area, which generally include purchased electricity, heating, and other energy related emissions. Scope 2 refers to indirect emissions related to energy consumption that are outside the jurisdiction of the municipality and generally include emissions from purchased electricity, heating and/or cooling to achieve consumption by municipal residents; Scope 3 refers to any intermediate emissions resulting from intra-municipal movements that occur outside the jurisdiction but are not included in Scope 2, and includes greenhouse gas emissions from the manufacture, transport, utilization and disposal of any goods purchased by municipal residents from outside the jurisdiction.

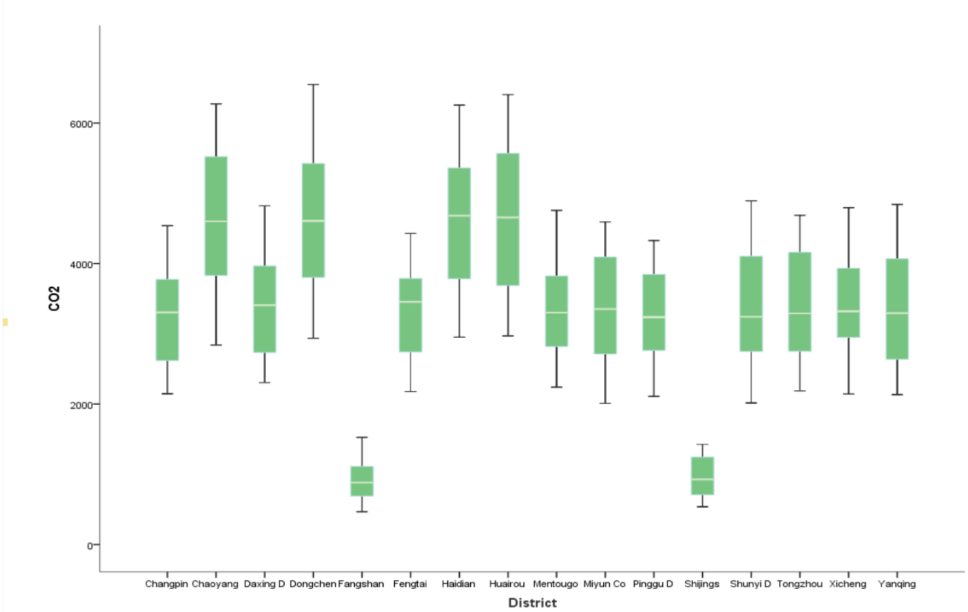
4.Spatial and temporal pattern of carbon emissions in Beijing

4.1 Regional CO2 Emission Data

The data in this paper mainly come from the websites of authoritative organizations such as the Bureau of Statistics, the Ministry of Science and Technology, and the People's Bank of China, as well as from various authoritative statistical yearbooks, including the national and provincial and municipal statistical yearbooks, the bulletin on the state of the environment, and a number of professional statistical yearbooks such as China Science and Technology Statistical Yearbook, China Energy Statistical Yearbook, China Financial Yearbook, China Agricultural Statistical Yearbook, China Industrial Statistical Yearbook, and so on. China Tertiary Industry Statistical Yearbook, etc.

Due to the different levels of economic development, population density, scale of industrial production, size of the area, and magnitude of population activities in different areas of Beijing, the level of CO2 emissions in each urban area varies considerably. As shown in the figure below Chaoyang District, Dongcheng District, Haidian District and Huairou District are much higher than the average carbon emission level of all total urban areas, Fangshan District and Shijingshan District are much lower than the average carbon emission level of all total urban areas, and the remaining urban areas are close to the average carbon emission level of all total urban areas. This provides basic data support for the following selection of areas for carbon emission in urban management in Beijing.

Figure 2 Carbon Emissions in Different Regions of Beijing.



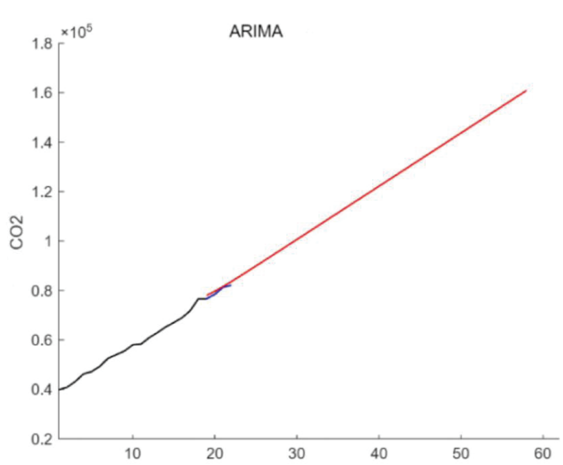
4.2 Model Establishment and Analysis

This study adopts the standard deviation ellipse method to characterize the spatial and temporal distribution of carbon emissions in Beijing from 2000 to 2023, to further study the shifting characteristics of the carbon center in Beijing, and to conduct further time-series forecasts of the regional industries through the ARIMA model to derive the areas with the greatest potential for emission reduction.

4.2.1 Temporal Characteristics of Carbon Emission in Beijing

In this study, under the modeling assumptions of no change in China's policies and carbon emissions from various industries not being influenced by other industries, the ARIMA model is used to make time series forecasts of CO2 in Beijing to conclude that the total CO2 emissions in Beijing show a trend of increasing year by year, and therefore relevant interventions should be carried out for carbon emissions from the industries in Beijing, as shown in Figure 3 below:

Figure 3 Carbon emission time series prediction of Beijing.



4.2.2 Standard deviation ellipse carbon center analysis

According to the carbon emission observation data of each urban area in Beijing from 2000 to 2023, the ellipse standard deviation analysis and carbon emission center calculation are carried out every 5 years using ArcGIS 10.8 software to analyze the differences in the distribution of the transfer paths and directions of the carbon centers of Beijing in the recent 20 years. The carbon center parameters are shown in Table 1:

Table 1 Carbon center parameters.

Year	Latitude	Longitude	Long axis	Short axis	Long/short axis	Affiliated locations
2000	E116°26’13	N40°5’26.08	0.506045	0.367578	1.376701	Changping
2005	E116°26’45	N40°5’31.21	0.506524	0.366277	1.382898	Changping
2010	E116°26’22	N40°4’58.41	0.496358	0.362741	1.368353	Changping
2015	E116°26’41	N40°5’18.67	0.501969	0.369904	1.357025	Changping
2020	E116°26’35	N40°5’14.08	0.504655	0.364499	1.384516	Changping

From the above table1, it can be seen that from 2000 to 2023, the carbon center area has become a northeast-southwest fluctuating and moving trend, with little change in longitude and latitude, and the carbon center of Beijing city has been relatively stable for many years. Moreover, the direction of the main axis of Beijing’s carbon emission shows a slight tendency of deflection to the west, and the overall magnitude of the deflection does not change much, which makes the carbon emission region of Beijing more stable. At the same time, the ratio of the long axis to the short axis of the standard deviation ellipse shows a decreasing trend, indicating that the distribution of Beijing’s emissions is gradually weakening, and the differences in carbon emissions among urban areas are gradually weakening.

From the above chart, it can be seen that from 2000 to 2023, the carbon center of Beijing is mainly concentrated in Changping District, and at the same time, according to the overview of the data in 4.1, it can be clearly seen that the carbon emission of Changping District has not reached the forefront of the carbon emission of the urban areas in Beijing, and at the same time, Chaoyang District is close to the carbon center point, and the annual average value of the carbon emission has reached the forefront of the urban area’s carbon emission, therefore, the analysis of the urban area’s carbon emission industry in the later stage will be based on the analysis of Chaoyang District, which is closer to the carbon center point.

4.2.3 Carbon Emission Forecast Analysis in Urban Management

Based on the spatial and temporal distribution characteristics of carbon emissions in each urban area of Beijing from 2000 to 2023, we use the ARIMA model to make time series forecasts for Chaoyang District, and the year 2000 is noted as time 0 in all the graphs below.Based on the small base of Scope 3 carbon emissions, although the growth index of Scope 3 carbon emissions is larger, the Scope 3 carbon emissions are much smaller than Scope 1 and Scope 2, so Scope 3 carbon emissions are not considered, and by comparing the carbon emission growth rates of Scope 1 and Scope 2 as shown in Table 2, we make a time series forecast for Scope 1. Starting from the year 2000, the growth rate of carbon emissions is calculated every five years.

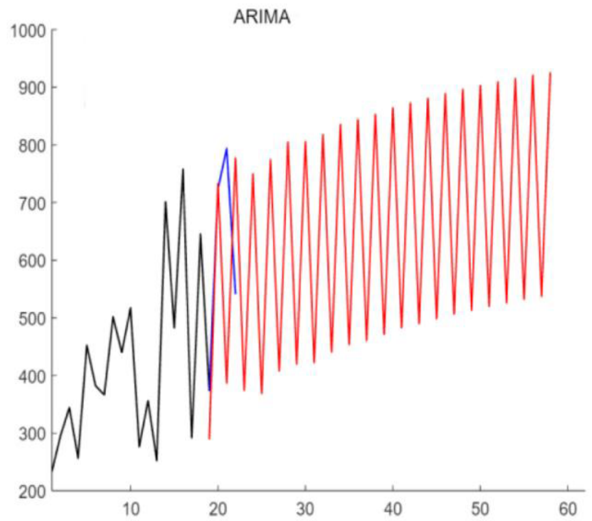
Table 2 Scope 1 and Scope 2 Growth Rates.

Year	Scope 1 Growth Rates	Scope 2 Growth Rates
2020-2025	0.14278176	0.019432
2025-2030	0.12599903	0.01232
2030-2035	0.11194233	0.007866
2035-2040	0.10067452	0.005044
2040-2045	0.09146627	0.003244
2045-2050	0.08380129	0.00209
2050-2055	0.07732163	0.001348

Scope 1 covers four areas: “Transportation and construction”, “Industrial processes”, “Agroforestry and land-use efficiency” and “Waste treatment”. Disposal”. The projected carbon emissions from these four areas are shown in Figures 4-7:

Figure 4: Transportation and Construction Time Series Forecasts.

Figure 5 Industrial Production Processes Time Series Forecasts.



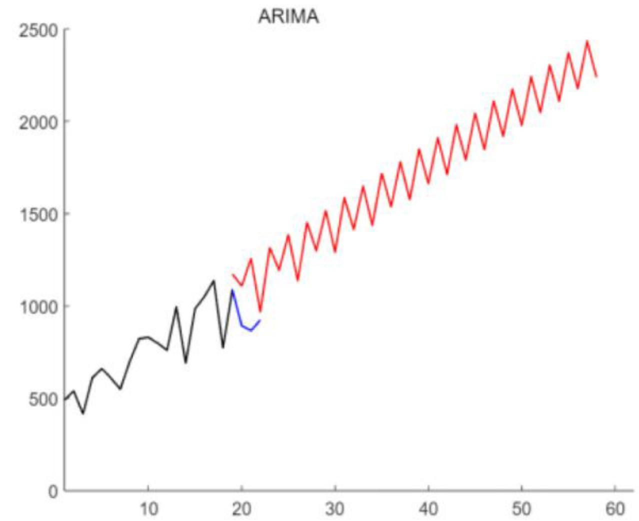
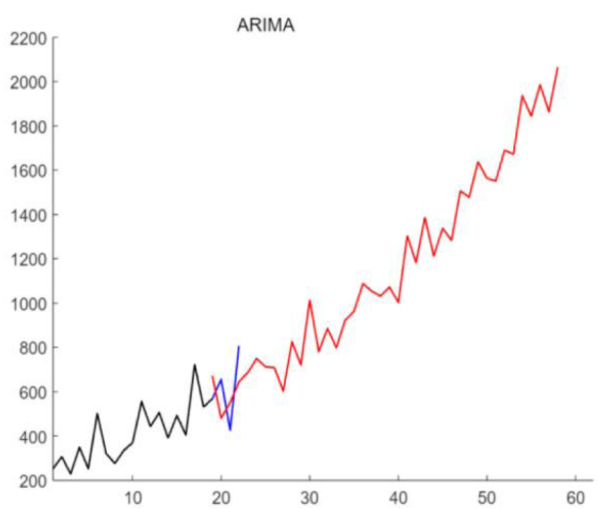


Figure 6 Agroforestry and land-use change time series.

Figure 7 Waste disposal time series projection.



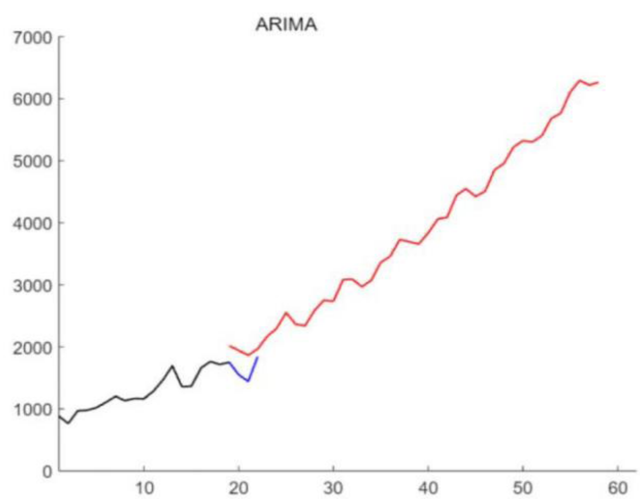


Table 3 Chart of growth rates by block, 2020-2055.

Year	Growth rate of transportation and construction	Growth rate of industrial processes	Growth rate of agroforestry and land-use change	Growth rate of waste disposal
2020-2025	-0.09565	0.267205	0.2866	1.003866
2025-2030	0.394485	0.30323	0.1012	-0.45398
2030-2035	-0.0307	0.123113	0.3927	0.994881
2035-2040	0.24378	0.172942	0.1981	-0.42791
2040-2045	-0.03417	0.11016	-0.0151	0.841535
2045-2050	0.213445	0.176818	0.2089	-0.41497
2050-2055	-0.0286	0.186609	0.2795	0.771236

Based on the projected growth rates of carbon emissions from each industry in Scope 1, we find that the growth rates of carbon emissions from "transportation and construction", "industrial production and agriculture/forestry" and "land use change" are significantly smaller than the growth rate of carbon emissions from waste disposal. The growth rate of carbon emissions from "transportation and construction", "industrial production and agriculture/forestry" and "land use change" is significantly smaller than the growth rate of carbon emissions from waste disposal. Therefore, green financial resources should emphasize the establishment of a better waste recycling system to prevent the rapid growth of carbon emissions from waste disposal.

5.Characteristics of green finance and regional carbon emission coupling and coordination

5.1 Indicator selection

In this study, the green finance index data of each region in Beijing is measured by entropy value method, and the comprehensive evaluation system is shown in Table 4:

Table 4 Comprehensive Green Finance Evaluation System.

Category	Specific Indicators	Calculation Formula
Green Credit	Share of credits for environmental projects	Total credit for environmental projects in the province/total credit in the province
Green Investment	Investment in environmental pollution control as % of GDP	Investment in environmental pollution control/GDP
Green Insurance	Extent of promotion of environmental pollution liability insurance	Environmental pollution liability insurance income/ total premium income
Green Bond	Extent of green bond development	Total green bond issues/total all bond issues
Green Support	Percentage of fiscal expenditure on environmental protection	Financial environmental protection expenditures/ financial general budget expenditures
Green Fund	Percentage of green funds	Total market capitalization of green funds/total market capitalization of all funds
Green Benefits	Green equity development depth	Carbon trading, energy rights trading, emissions trading/total equity market transactions

5.2 Model Establishment and Analysis

As a core tool to quantitatively analyze the synergistic effect of multi-systems, the coupled degree of coordination model has been widely used in the fields of regional economy, ecological and environmental governance, and social resource optimization. In order to guarantee the scientific nature of academic research, this paper draws on the modified coupling coordination degree model proposed by Wang Shujia[10] to analyze the coupling coordination degree of green finance index and carbon emission intensity in each region of Beijing. The results of spatio-temporal evolution are shown in Figures 8-11.

Figure 8 Degree of harmonization of regional coupling in Beijing, 2000.

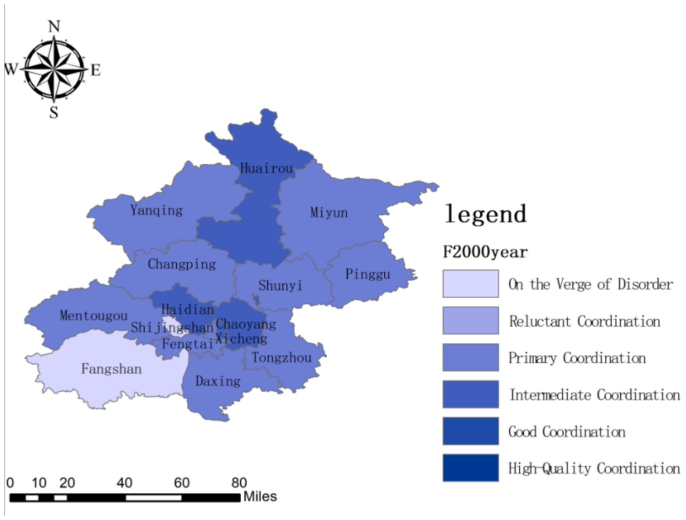


Figure 9 Degree of coordination of regional coupling in Beijing, 2010.

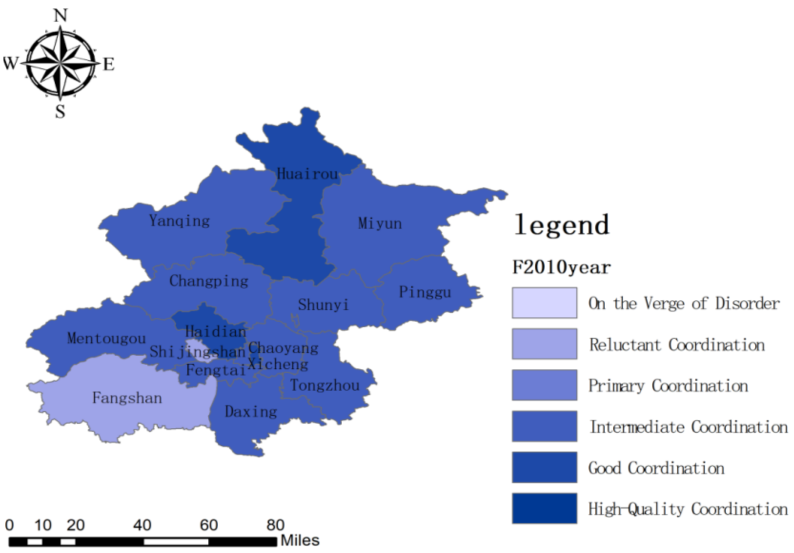


Figure 10 Degree of coordination of regional coupling in Beijing, 2020.

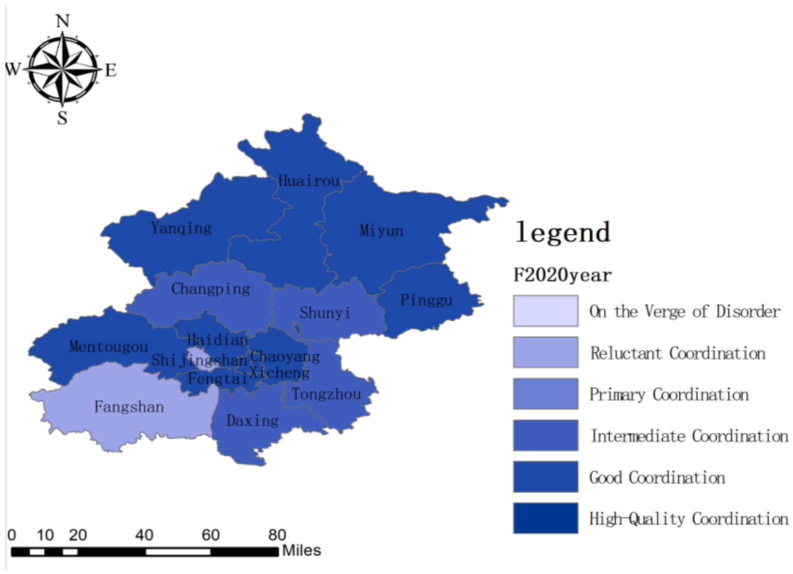
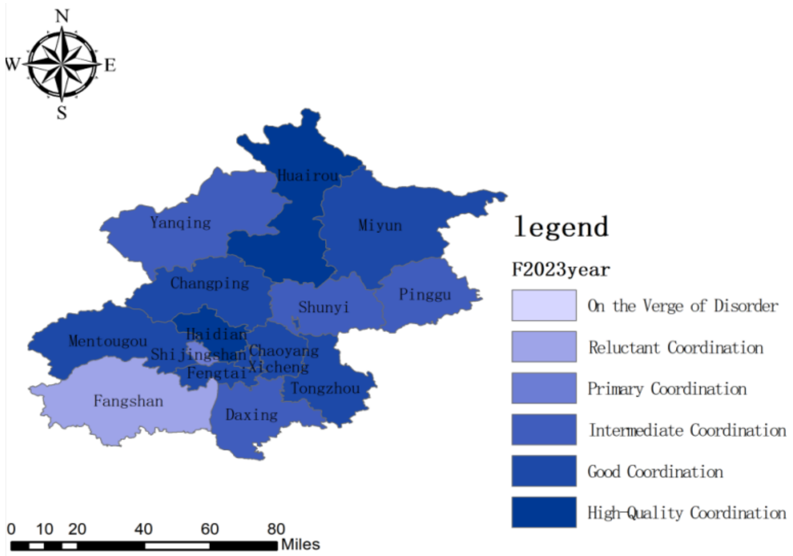


Figure 11 Degree of coordination of regional coupling in Beijing, 2023



From the perspective of time, according to the coupling coordination data, the coupling coordination degree of green finance and carbon emissions in each region of Beijing shows a gradual growth trend from 2000 to 2023, which indicates that the synergistic effect between the green financial system and the carbon emission control objectives has been continuously enhanced in the process of promoting the low-carbon transformation of the economy in the city. Through the three-dimensional framework of "policy guidance + market-driven + regional synergy", Beijing has effectively realized the synergy between green finance and carbon emission control, and most of the regions have gone through the evolution of primary coordination - intermediate coordination - good coordination, and the level of coordination has leapfrogged.

From a spatial perspective, although the overall trend has been gradually upgrading from "primary coordination" to "good/quality coordination", there is significant regional differentiation. Core urban areas (Dongcheng and Xicheng): Early on, they relied on policy advantages to take the lead in entering intermediate coordination, but later on, they are weak and will remain in intermediate coordination in 2023, reflecting the lack of transformation momentum in the old urban areas. Emerging urban areas (Chaoyang and Haidian): relying on industrial innovation (such as Zhongguancun and CBD), leading in the integration of green finance and low-carbon technology, and continuing to lead after 2010, becoming the benchmark for "double coordination". Remote Suburbs (Fangshan, Huairou, Miyun): Eco-cultivation zones (e.g. Miyun, Huairou) have steadily improved their degree of harmonization since 2010 due to the advantages of their environmental baseline, while industrial-dependent zones (Fangshan) have been in the low position for a long time due to lagging behind in the transformation process.

With the development of the region, the coupled coordination degree of Huairou, Haidian, and Chaoyang districts is much higher than that of the surrounding areas, and Huairou and Haidian districts even reach the stage of high-quality coordination in 2023. The high coupling and coordination degree of the three districts is essentially the result of the synergy of "policy guidance + industrial adaptation + financial empowerment + regional characteristics": Huairou District takes ecological nourishment and the construction of the Science City as the core, and strengthens the green infrastructure through the cooperation between the government and the bank; Chaoyang District relies on the advantages of the service industry to build a low-carbon model driven by the dual-wheel drive of consumption and industry; Haidian District gives full play to the advantages of science and innovation, and drives the low-carbon mode with technological breakthroughs. Haidian District plays to the advantages of science and innovation, and promotes the iteration of green financial products with technological breakthroughs. Fangshan District and Shijingshan District have long been in the low-value island, and Fangshan District is in the "long-term stagnation" warning, subject to the high proportion of traditional heavy industry (such as Yanshan Petrochemical), lagging behind in the application of green financial tools, ecological restoration pressure, and the need to systematically crack the "industry-environment" contradiction constraints, and in 2023, it will be necessary to solve the "industry-environment" problem. The constraints of the contradiction between "industry and environment" have never been broken through barely coordinated in 2023, which is the lowest and the most unstable area in the city; Shijingshan District, by taking advantage of the Beijing Winter Olympics (Shougang Park green renovation) and the construction of the new Shougang High-end Industrial Park, promotes the docking of low-carbon technology and financial capital, realizes the "ecological restoration + industrial upgrading" double-wheel drive, and breaks through primary coordination for the first time in 2021. In 2021, we will break through the primary coordination for the first time.

6.Financial Emission Reduction Path Optimization under Spatial Synergy

"Spatial Synergy + Structural Optimization" Strategy for Carbon Center Regions. Changping District is the spatial center of Beijing's carbon emissions, but its own carbon intensity is lower than that of core urban areas such as Chaoyang District and Haidian District. As the extension area of Zhongguancun Science City, Changping District possesses the scientific and technological innovation resources of "three cities and one district", but the synergy between green finance and industry is insufficient. The region is mainly strengthened through the spatial effect, cross-regional carbon market linkage, relying on the location advantage of Changping District near the central urban area, the establishment of "Changping - Haidian - Chaoyang" cross-regional carbon trading pilot, to promote the flow of carbon quotas across the region, the use of price signals to guide enterprises to reduce emissions. As well as the ecological compensation mechanism, the carbon sinks in Changping's ecological conservation areas (such as the Thirteen Tombs and Python Forest Park) will be incorporated into the green financial collateral system, attracting external funds to support ecological protection. Green credit targeted investment in green structural effect upgrading, targeting new energy industries (e.g. Zhongguancun Hydrogen Energy Industrial Park) and intelligent manufacturing enterprises in Changping District, providing low-interest loans and risk-sharing mechanisms (e.g. Green Credit Guarantee Fund), and promoting the orderly exit of high-carbon industries (e.g. traditional manufacturing industries).

Waste treatment (Scope 1): The whole chain "structure-technology-space" synergistic strategy, green funds to guide industrial transformation in the reconstruction of structural effects, the establishment of the "Beijing Municipal Waste Disposal Green Transformation Fund", with a focus on investment in waste incineration and power generation, The fund will focus on investing in waste incineration power generation and biodegradation technology R&D projects to gradually replace landfills. In terms of technological breakthroughs, green credit risk sharing has been carried out, with governmental financial guarantee institutions providing 80% risk coverage for CCUS (Carbon Capture, Utilization and Storage) technology for waste incineration, thus reducing banks' lending concerns. In terms of integration of spatial effects, cross-regional collaboration on waste treatment, establishment of the Beijing-Tianjin-Hebei Waste Treatment Green Finance Alliance, promotion of Zhangjiakou wind power to supply power to Beijing waste incineration plants, and realization of synergy between renewable energy and low-carbon treatment technologies, among others.

Optimization of regional differentiated emission reduction strategies, the core area (Dongcheng and Xicheng), the concentration of high-carbon business, mainly rigid emissions from domestic heating and transportation, the difficulty of spatial transformation (such as the density of old buildings in hutongs), the lack of financial penetration, the limited application of tools such as green credit and bonds, and the lack of new growth points. Through stock optimization, such as the implementation of "photovoltaic tiles + energy storage wall" transformation of hutong compounds, green credit subsidies according to the area (such as the first year of the subsidy rate of 3%), and policy innovations such as cross-district eco-settlement, signing an "ecological service agreement" with the Yanqing District, payment of carbon sinks Purchase costs to support the expansion of forest cover and activate low-carbon potential. Emerging regions (Chaoyang and Haidian), where market-based tools such as green bonds and funds are widely used, have high resistance to transforming high-carbon businesses. This can be achieved by strengthening technology-driven initiatives such as the establishment of a "Zero-Carbon Technology Venture Capital Fund" jointly with the Bank of Zhongguancun, supporting university laboratories in carbon capture and green hydrogen preparation technologies, and scale control such as green credit constraints, and the implementation of a "total volume control + incremental optimization" policy for logistics parks and data centers. ", new loans need to match the carbon emission reduction target, consolidate the leading edge. In remote urban areas, ecological conservation areas (Miyun and Huairou) can realize carbon sinks through the conversion of carbon sinks and cross-district cooperation; industrial zones (Fangshan) can realize industrial substitution and financial underwriting, and issue "Old Industrial Base Transformation Bonds" to support coking, chemical and industrialization industries. Bonds", supporting the transformation of coking plants into green hydrogen preparation bases, supporting hydrogen pipelines to Xiongan, and introducing "carbon asset price insurance" to hedge the risk of carbon price fluctuations, and setting up a "green credit risk reserve" to guard against transformation risks. The final result will be the formation of a "market internalization" in Beijing. Eventually, Beijing will form a sustainable development pattern of "endogenous market drive, policy synergy support, and city-wide low-carbon resonance".

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no

Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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