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Research on the Impact of Green Finance on Carbon Emission Intensity in Resource-Based Cities

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Abstract: Resource-based cities are important carriers of China's energy supply and economic development. However, their long-term reliance on resource development has led to a high-carbon development model, making them a key area for achieving the "dual carbon" goals. Therefore, green and low-carbon transformation inevitably requires strong financial support. Developing green finance is an important tool for implementing the "dual carbon" goals and promoting the green and low-carbon transformation of resource-based cities. Therefore, this paper uses resource-based cities in China from 2002 to 2024 as a research sample, constructs a panel data model, and analyzes the impact, mechanism, and nonlinear characteristics of green finance on the carbon emission intensity of resource-based cities. The main conclusions are: First, green finance has a significant inhibitory effect on the carbon emission intensity of resource-based cities, and this effect remains valid after endogeneity treatment and robustness tests. Further heterogeneity analysis reveals that green credit and green investment have a more prominent emission reduction effect. Mechanism testing shows that green innovation plays a transmission role in the process of green finance influencing carbon emission intensity, and green finance reduces the carbon emission intensity of resource-based cities by promoting green technology research and development and the transformation of innovative achievements. Finally, the threshold effect analysis shows that the impact of green finance and the level of green innovation development on carbon emission intensity both have threshold characteristics. Only when both exceed their respective threshold values can the carbon emission reduction efficiency of green finance be fully released. Therefore, the research conclusions of this paper have certain policy implications for resource-based cities to improve their green finance system and achieve green, low-carbon, and high-quality development.

Keywords: green finance; resource-based cities; carbon emission intensity; green innovation; threshold effect

1. Introduction

In September 2020, China formally put forward the solemn commitment of "reaching carbon peak before 2030 and carbon neutrality before 2060" at the 75th Session of the United Nations General Assembly, elevating green and low-carbon development to a national strategy. Promoting the comprehensive green transformation of economic and social development has become the core essence and inevitable path of high-quality development in the new era. As the world's largest developing country, China has long maintained a high total carbon emission level. Resource-based cities, as the core carriers of China's energy supply and important supports for industrial development, their carbon emission control effect is directly related to the timely realization of the "dual carbon" goals, and they are also the key areas for the implementation of China's ecological civilization construction and green development strategy.

Resource-based cities emerged and developed relying on natural resources such as minerals, forests, and oil and gas. In the long-term process of resource development and primary processing, they have formed a rigid "resource-dependent" development model, presenting in-depth development dilemmas such as a single industrial structure, prominent high energy consumption and high emission characteristics, declining ecological carrying capacity, and obvious "resource curse" effect. According to the "Report on the Development of Resource-Based Cities in China", there are 116 existing resource-based cities in China, covering 28 provinces, autonomous regions, and municipalities directly under the Central Government. Their total carbon emissions account for more than 40% of the total carbon emissions of cities in China, and the carbon emission intensity per unit of GDP is significantly higher than the national average level. Some resource-exhausted cities are even facing the dual pressures of "high carbon lock-in" and weak transformation capacity, making the low-carbon and green transformation imminent and arduous.

One of the core bottlenecks in achieving the "dual carbon" goals is the huge investment and financing gap in the green and low-carbon field. It is estimated that China's annual capital demand in the green and low-carbon field exceeds 5 trillion yuan. However, the traditional financial system is guided by profit as the core, and its support for green projects is insufficient, which is difficult to meet the capital needs of resource-based cities in energy conservation and emission reduction, technological innovation, and industrial upgrading during the transformation process. Against this background, green finance, as an innovative practice of practicing the concept of green development in the financial field, guides social capital to flow from high-carbon industries to low-carbon and environmental protection fields through differentiated financial tools such as credit, investment, and insurance, restrains the blind expansion of high-carbon industries, and becomes an important starting point for solving the green investment and financing gap and promoting the green and low-carbon transformation of resource-based cities.

In recent years, China's green financial system has been continuously improved, green financial products such as green credit, green bonds, and green insurance have been gradually enriched, and the scale of the green financial market has continued to expand. By the end of 2024, the balance of China's green credit exceeded 25 trillion yuan, and the cumulative issuance scale of green bonds exceeded 10 trillion yuan. Green finance has become an important force driving China's low-carbon development. However, it is worth noting that due to practical problems such as weak financial development foundation, high difficulty in industrial transformation, and low return rate of green projects in resource-based cities, the penetration and implementation effect of green finance are still obviously insufficient. How green finance can accurately empower the reduction of carbon emission intensity in resource-based cities and solve their high-carbon development dilemmas has become an important theoretical and practical issue that urgently needs to be solved.

From a theoretical perspective, existing studies have initially confirmed that there is a close correlation between green finance and carbon emissions. However, most studies take the provincial and prefecture-level city levels as the research objects, lacking targeted analysis on the special group of resource-based cities, and failing to fully combine the typical characteristics of resource-based cities such as high carbon dependence, rigid industrial structure, and fragile ecological environment to explore the impact mechanism and nonlinear characteristics of green finance on their carbon emission intensity. From a practical perspective, the transformation path of resource-based cities is special. The reduction of their carbon emission intensity not only requires the capital support of green finance but also relies on the synergistic effect of multiple factors such as green innovation and industrial upgrading. Existing studies have not deeply explored the synergistic impact of green finance and green innovation on carbon emission intensity, making it difficult to provide sufficient empirical support for resource-based cities to formulate accurate and effective green financial policies.

Based on this, this paper, based on the theory of sustainable development and the theory of externality, takes 116 typical resource-based cities in China from 2002 to 2024 as the research sample, constructs a panel data model, a mediating effect model, and a threshold regression model to systematically explore the impact effect, action mechanism, and nonlinear characteristics of green finance on the carbon emission intensity of resource-based cities, focusing on verifying the mediating transmission effect and threshold effect of green innovation. It aims to make up for the deficiencies of existing studies, provide theoretical reference and policy enlightenment for resource-based cities to improve the green financial system, strengthen green innovation drive, and realize green, low-carbon, and high-quality development, and help China achieve the "dual carbon" goals as scheduled.

2. Literature Review

Existing literature on the relationship between green finance and carbon emissions can be summarized into the following two categories:

The first category is research on the relationship between green finance and carbon emissions, and the conclusions are divided into two categories: inhibitory effect and promotion effect. Most studies have confirmed that green finance has a significant inhibitory effect on carbon emissions. Zhang W et al. [1] verified the effect of green finance on improving carbon emission efficiency through relevant channels from the perspective of green finance development. Ran C and Zhang Y [2] explored the driving factors of carbon emission reduction in China and pointed out that insufficient green supply in the traditional financial structure may affect the carbon emission reduction process. On this basis, Chen X and Chen Z [3] used 30 provinces in China as research samples to confirm that the development of green finance has a significant carbon emission reduction effect. Sun C [4] further found that there is a significant correlation between green finance and carbon emissions based on the improved neural network method, and its impact has complex characteristics. Xu W et al. [5] confirmed from the perspective of energy consumption optimization that the impact of green finance on carbon emissions in China has obvious regional differences. However, some studies hold the opposite view. Early Dasgupta et al. [6] found that the improvement of the level of financial development will promote the expansion of production scale, which in turn leads to an increase in carbon emissions, that is, financial development has a carbon emission promotion effect. Dogan and Seker [7] further pointed out that the impact of financial development on carbon emissions is not linear, but rather exhibits an inverted U-shaped relationship, with carbon emissions potentially increasing due to scale expansion in the early stages of development. Kant [8] 's research on green bonds showed that green bonds are unlikely to play a role in carbon emission reduction.

The second category is research on the mechanism and heterogeneity of green finance's impact on carbon emissions. In terms of mechanism, Li H *et al.* [9] first demonstrated the impact of green finance on regional carbon emission reduction and its mechanism, while Meo MS and Abd Karim MZ [10] then pointed out that green finance plays an important role in reducing carbon dioxide emissions. Some studies have also identified chain transmission and moderating effects: Umar M and Safi A [11] clarified the logic of the impact of green finance and innovation on environmental protection, and Akomea -Frimpong I *et al.* [12] proved that related factors can strengthen the emission reduction effect of green finance in the field of green building. From the perspective of heterogeneity and policy effect, Fu C *et al.* [13] found that the carbon reduction effect of green finance in promoting the process of sustainable development is more obvious in specific regions. Al Mamun M *et al.* [14] and Afzal A *et al.* [15] have given strong evidence that the emission reduction effect of green finance varies in different regions and scenarios. More notably, Ren X *et al.* [16] examined the relationship and spatial correlation between green finance and carbon intensity, while Sharif A *et al.* [17] demonstrated that the synergy between green finance and related policies can greatly enhance the emission reduction effect.

Overall, while existing research has reached certain conclusions, there is still room for expansion in the following aspects. First, the research subjects are not specific enough. Existing literature mostly focuses on provincial, prefecture-level city, or city-level studies, with insufficient discussion of resource-based cities as the main force in carbon emission reduction. It has not conducted systematic empirical analysis considering their high carbon dependence and rigid industrial structure. Second, the depth of the research perspective needs to be explored. Although existing research has confirmed the emission reduction effect of green finance, it has not sufficiently explored the nonlinear characteristics of emission reduction under the synergistic effect of green finance and green innovation, and has failed to clearly reveal the dynamic impact mechanism of their development on carbon emission intensity.

Therefore, the marginal contributions of this paper are mainly reflected in the following two aspects: First, by focusing on resource-based cities as the research object, it makes up for the lack of systematic analysis in this field in existing research. Combining the typical characteristics of high-carbon development in resource-based cities, it empirically examines the impact of green finance on their carbon emission intensity, providing empirical evidence for the financial support path for the low-carbon transformation of resource-based cities. Second, it expands the research perspective on the emission reduction effect of green finance. This paper not only verifies the transmission role of green innovation, but also further reveals the threshold characteristics under the synergistic effect of the two, enriching the nonlinear research results on the relationship between green finance and carbon emissions.

3. Theoretical Analysis and Research Hypotheses

3.1 The effect of green finance development on inhibiting carbon emission intensity in resource-based cities

Against the backdrop of China's push for "dual carbon" goals, resource-based cities face severe pressure to transform. Their long-standing industrial model, dominated by resource extraction and primary processing, has not only led to resource depletion but also severe environmental pollution and high carbon emissions. Furthermore, the production activities of energy-intensive enterprises in resource-based cities generate substantial negative externalities, which market mechanisms cannot effectively address. Based on externality theory, green finance can internalize environmental externalities. Green credit policies, by raising the financing threshold for highly polluting enterprises, force them to adopt energy-saving and emission-reduction measures, internalizing previously unborne environmental costs. For green and low-carbon enterprises, green finance provides low-cost funding to compensate for the additional costs incurred in creating environmental benefits, incentivizing them to expand green production. From the perspective of sustainable development theory, green finance guides social capital towards energy-efficient and environmentally friendly green industries, promoting the transformation of resource-based cities' industrial structure from high-carbon to low-carbon. Based on the above theoretical analysis, Hypothesis H1 is proposed:

H1: The development of green finance can significantly reduce the carbon emission intensity of resource-based cities.

3.2 The Indirect Impact of Green Finance on Carbon Emission Intensity in Resource-Based Cities through Green Innovation

Green innovation is the core driving force for achieving low-carbon transformation in resource-based cities, and green finance is closely linked to green innovation, thus affecting carbon emission intensity. According to sustainable development theory, innovation is a key element in promoting sustainable economic development. Green innovation can apply low-carbon technologies to improve resource utilization efficiency, thereby reducing carbon emissions in economic activities. However, green innovation is characterized by large investments and long cycles; enterprises cannot meet their innovation needs solely through their own funds and require external financial support. Therefore, green finance provides important financial security for green innovation. From the perspective of externality theory, green finance has a positive externality compensation function for green innovation activities. For example, enterprises can use green finance funds to develop new energy-saving technologies and apply them to the production process, improving energy utilization efficiency and reducing carbon emissions per unit of product; or they can develop new energy products to replace traditional high-carbon products, reducing market demand for high-carbon products and thus reducing the carbon emission intensity of the entire industry. Therefore, green innovation plays a bridging role between green finance and carbon emission intensity. Based on this, hypothesis H2 is proposed:

H2: Green finance indirectly reduces the carbon emission intensity of resource-based cities by promoting green innovation.

3.3 The threshold effect of green finance on carbon emission intensity in resource-based cities

The impact of green finance on the carbon emission intensity of resource-based cities is not linear and may exhibit a threshold effect. From the perspectives of sustainable development theory and externality theory, the level of green finance development and green innovation development are crucial factors influencing its carbon emission reduction effectiveness, and their mechanisms and effects differ at different stages. In the early stages of green finance development, the green finance system is still imperfect, the types of green financial products and services are limited, the scale of funds is small, and financial institutions lack the capacity to identify and assess green projects, resulting in a negligible impact of green finance on carbon emission intensity. At this time, although green finance begins to guide funds towards green sectors, due to limitations in scale and capacity, it is difficult to have a substantial impact on the industrial structure and corporate behavior of resource-based cities, and thus cannot effectively reduce carbon emission intensity.

As the level of green finance development continues to improve, once a certain threshold is reached, the green finance system gradually becomes more robust, and the scale of funds continues to expand. At this stage, green finance can more accurately identify green projects and provide them with financial support, significantly enhancing its ability to suppress carbon emission intensity. Similarly, a similar threshold effect exists in the development level of green innovation. In the early stages of green innovation development, technological R&D capabilities are limited, and the efficiency of innovation results transformation is low, making it difficult to have a significant impact on carbon emission intensity. Once the level of green innovation development crosses a certain threshold, a large number of green innovation results emerge and are applied to actual production, significantly improving energy efficiency and reducing carbon emission intensity. Based on the stage-specific characteristics of green finance and green innovation development, Hypothesis H3 is proposed:

H3: The impact of green finance on the carbon emission intensity of resource-based cities has a threshold effect.

4. Research Design

4.1 Sample Selection and Data Sources

The data of the dependent variables are from the statistical yearbooks of resource-based cities, the China Energy Statistical Yearbook and the Industrial Economic Statistical Yearbook. The main energy consumption of coal, oil and natural gas, GDP and industrial added value are selected as core economic indicators. At the same time, pollutant emission indicators such as industrial sulfur dioxide and smoke dust emission are included as auxiliary indicators. The data of the explanatory variables are from the National Bureau of Statistics, the CSMAR database and the statistical yearbooks of resource-based cities. This paper selects 116 typical resource-based cities in China from 2002 to 2024 as the research sample. The selection criteria for resource-based cities refer to the research results of Yu J *et al.* [18] and Ruan F *et al.* [19]. Finally, 2668 valid panel data were obtained. Some missing data were supplemented by linear interpolation. The data selection of this paper is shown in Table 1:

Table 1 Variable Selection

Classification	variable	symbol	Measurement

Explained variable	carbon emission intensity	Carbon	Calculation based on IPCC method
Explanatory variables	Green finance	GFI	Synthesis based on entropy weight method
	population size	lnpop	Logarithm of the regional population
	Government intervention	lngov	Logarithm of regional government expenditure
control variables	Industrial structure	IS	Logarithm of the added value of the secondary industry
	Industrial level	INS	Number of industrial enterprises above designated size
Mechanism variables	Green Innovation	GI	Logarithm of green patents

4.2 Indicator Selection

4.2.1 Explained Variable

This paper adopts the recommended method of the National Greenhouse Gas Inventory Guidelines issued by the IPCC (Intergovernmental Panel on Climate Change) in 2019 [20] to calculate the carbon emission intensity of resource-based cities. The carbon emission sources are divided into five categories: energy activities, industrial production processes, agriculture, land use change and forestry, and waste treatment. In this study, we focus on the two core emission sources of energy activities and industrial production processes, and use the emission factor method to calculate carbon emissions, and then obtain the carbon emission intensity per unit of GDP.

When calculating carbon emission intensity, the consumption of major energy sources such as coal, oil, and natural gas, as well as economic indicators such as industrial added value and GDP, are selected. Pollutant emission indicators such as industrial sulfur dioxide emissions and industrial particulate matter emissions are also included as auxiliary variables. Specifically, energy consumption data is used to calculate carbon emissions, using the following formula:

$$CE_i = \sum_{j=1}^{n} E_{ij} \times EF_{ij} \times O_j$$

Where is $CE_i$the carbon emissions of city i, $E_{ij}$is the energy consumption of city i in the j- th energy source, $EF_{ij}$is the carbon emission factor of energy source j, $O_j$is the oxidation rate of energy source j, $Carbon_i$and carbon emission intensity is calculated as the ratio of carbon emissions to GDP.

$$Carbon_i = CE_i/GDP_i$$

4.2.2 Explanatory Variables

This study is based on the "Guiding Opinions on Building a Green Financial System" and also references Zhou G *et al.* The study [21] selected indicators from seven dimensions, determined the weights of each indicator using the entropy weight method, and then analyzed the green finance level of each city. See Table 2 for details:

Table 2 Construction of Green Finance Indicator System

Secondary indicators	variable	Calculation method	symbol
Green credit	Credit ratio for environmental protection projects	Total credit for environmental protection projects in the province / Total credit in the province	X1
Green Investment	Investment in environmental pollution control as a percentage of GDP	Investment in environmental pollution control / GDP	X2
Green Insurance	Promotion of environmental pollution liability insurance	Environmental pollution liability insurance revenue / Total premium revenue	X3
Green bonds	Development of green bonds	Total issuance of green bonds / Total issuance of all bonds	X4
Green support	The proportion of fiscal expenditure on environmental protection	Fiscal expenditure on environmental protection / Fiscal expenditure on general budget	X5
Green Fund	Green Fund Proportion	Total market capitalization of green funds / Total market capitalization of all funds	X6
Green rights	Depth of Green Rights Development	in carbon trading, energy consumption rights trading, and pollution rights trading/equity markets	X7

4.2.3 Control Variables

To control for the interference of other factors on carbon emission intensity, the control variables selected in this paper include: urbanization rate, measured by the ratio of urban population to resident population; science and technology expenditure, measured by the ratio of science and technology expenditure to general public budget expenditure; level of openness to the outside world, measured by the ratio of total import and export volume to GDP; level of fiscal revenue, measured by the ratio of general public budget revenue to GDP; and human capital, measured by the ratio of the number of students enrolled in regular colleges and universities to the number of registered residents.

4.2.4 Mechanism Variables

This paper uses green innovation (GI) as a mechanism variable and measures it with the logarithm of green patents. This not only reflects the actual achievements of regional green technology R&D but also effectively measures green innovation capacity. It contributes to the study of the mechanism by which green innovation plays a role in the relationship between green finance and carbon emissions.

4.3 Model Design

This paper constructs the following two-way fixed-effects panel data model to examine the impact of green finance on carbon emission intensity:

$$Carbon_{it} = \alpha_0 + \alpha_1 GFI_{it} + \sum \beta_j \, controls_{j,it} + \lambda_i + \mu_t + \varepsilon_t$$

Where: $Carbon_{it}$represents the carbon emission intensity of city i in year t; GFI_{it}represents the level of green finance development; $\alpha_1$represents $GFI_{it}$the regression coefficient before t, and its positive/negative and significance are used to verify the impact of green finance on carbon emission intensity; $controls_{j,it}$ represents the set of control variables; $\lambda_i$and μ_t represent the individual and time fixed effects, respectively. $\varepsilon_t$is the random error term.

Regarding the mediating role of green innovation, this paper constructs the following mediation effect model:

$$Carbon_{it} = \alpha_0 + \alpha_1 GFI_{it} + \sum \beta_j \, controls_{j,it} + \lambda_i + \mu_t + \varepsilon_t$$

$$GI_{it} = \alpha_0 + \sigma_1 GFI_{it} + \sum \beta_j \, controls_{j,it} + \lambda_i + \mu_t + \varepsilon_t$$

$$Carbon_{it} = \alpha_0 + \gamma_1 GFI_{it} + \gamma_2 GI_{it} + \sum \beta_j \, controls_{j,it} + \lambda_i + \mu_t + \varepsilon_t$$

Where: GI_{it}represents the level of green innovation. If $\sigma_1$it is significant, and both $\gamma_1$and $\gamma_2$are significant, and $\gamma_1$the coefficients become relatively $\alpha_1$smaller, it indicates that green innovation plays a mediating role between green finance and carbon emissions.

Furthermore, the Hansen threshold regression model is used to examine the threshold effect of green finance and green innovation:

$$Carbon_{it} = \theta_0 + \theta_1 I(q_{it} \le \gamma_1) GFI_{it} + \theta_2 I(q_{it} > \gamma_1) GFI_{it} + \sum \beta_j \, controls_{j,it} + \lambda_i + \mu_t + \varepsilon_t$$

$$Carbon_{it} = \theta_0 + \theta_1 I(q_{it} \le \gamma_1) GI_{it} + \theta_2 I(q_{it} > \gamma_1) GI_{it} + \sum \beta_j \, controls_{j,it} + \lambda_i + \mu_t + \varepsilon_t$$

Where: $q_{it}$is the threshold variable, $\gamma_1$is the threshold value, $I(\cdot)$and is the indicator function.

5. Empirical Analysis

5.1 Benchmark Regression Analysis of Green Finance on Carbon Emission Intensity

Table 3 shows the regression results. In model (1), when only the green finance variable is introduced, the coefficient of GFI is -0.370, which is significant at the 5% significance level, indicating that green finance has a clear inhibitory effect on carbon emission intensity. In model (2), after adding control variables, the coefficient of GFI is -0.295, which is still significant, indicating that after controlling for relevant factors, the inhibitory effect of green finance on carbon emission intensity remains robust, verifying hypothesis 1.

Table 3 Benchmark Regression

	(1)	(2)
	Carbon	Carbon
GFI	-0.370**	-0.295**
	(-2.506)	(-2.024)
lnpop		0.446***
		(4.519)
lngov		0.113***
		(5.266)
IS		0.001***
		(4.558)
INS		-2.888*
		(-1.786)
_cons	16.599***	12.590***
	(421.417)	(21.665)
N	2668	2668
F	6.281	19.545
Adj. R^2	0.989	0.989

Note: The values in parentheses are t-statistics, and **, **, ** represent significance at the 1%, 5%, and 10% significance levels, respectively.

5.2 Endogeneity Analysis

Considering the potential endogeneity issues such as omitted variables and reverse causality between green finance and carbon emission intensity, this paper selects the year-end loan balance of urban financial institutions lagged by two periods as the instrumental variable (IV) of GFI, and uses the two-stage least squares (2SLS) method to test for endogeneity. The basis for selecting this instrumental variable is that the loan balance lagged by two periods reflects the historical foundation of urban financial development and is highly correlated with the current level of green finance; and the lagged variable is not affected by the reverse influence of the current carbon emission intensity. The results in Table 4 show that the coefficient of the instrumental variable in column (1) is significantly positive, indicating that the instrumental variable is highly correlated with GFI; the value of the Cragg-Donald F statistic is higher than the Stock-Yogo critical value, excluding the problem of weak instrumental variables. The coefficient of GFI in column (2) is -9.955 and is significantly negative, indicating that after controlling for endogeneity issues, the inhibitory effect of green finance on carbon emission intensity is still significant.

Table 4 Endogeneity Analysis

	(1)	(2)
	GFI	Carbon
IV	0.002***	
	(4.75)	
GFI		-9.955*
		(-2.340)
control variables	Yes	Yes
Fixed effects	Yes	Yes
Insufficient identification test (Anderson LM statistic)	22.40***	
Weak instrumental variable test (Cragg-Donald F statistic)	22.54	
Stock-Yogo weak instrumental variable threshold	16.38	

Note: The values in parentheses are t-statistics, and **, **, ** represent significance at the 1%, 5%, and 10% significance levels, respectively.

5.3 Robustness Test

(1) Considering the lagged effects of green finance. This paper introduces the first-order lagged term of green finance (L.GFI) for regression. The results show that the coefficients of L.GFI are -0.299 and -0.250, respectively, which are significantly negative. This indicates that the development of green finance in the early stage has a suppressive effect on the current carbon emission intensity, and the conclusion is robust.

Table 5 Robustness Tests – Considering the Lagging Effects of Green Finance

	(1)	(2)
	Carbon	Carbon
L.GFI	-0.299**	-0.250*
	(-2.006)	(-1.698)
lnpop		0.432***
		(4.333)
lngov		0.120***
		(5.435)
IS		0.001***
		(4.341)
INS		-3.200**
		(-1.976)
_cons	16.614***	12.585***

	(424.984)	(21.425)
Individual fixed effects	Yes	Yes
Year fixed effect	Yes	Yes
N	2552	2552
F	4.025	18.513
Adj. R^2	0.990	0.990

Note: The values in parentheses are t-statistics, and **, **, ** represent significance at the 1%, 5%, and 10% significance levels, respectively.

(2) Eliminating the impact of major events. To eliminate the interference of the COVID-19 pandemic on the results, this paper excluded the samples from 2020, 2020-2021, and 2020-2022 for regression analysis. The results show that the coefficients of GFI remained negatively significant in all three regression groups. This indicates that after excluding the abnormal impact of special periods, the inhibitory effect of green finance on carbon emission intensity remains stable, and the conclusion is reliable.

Table 6 Robustness checks - removing the impact of major events

	(1) Excluding 2020	(2) Excluding 2020 and 2021	(3) Excluding 2020 to 2022
	Carbon	Carbon	Carbon
GFI	−0.308**	−0.336**	−0.272*
	(−2.017)	(−2.088)	(−1.981)
lnpop	0.445***	0.444***	0.453***
	(4.435)	(4.362)	(4.412)
lngov	0.114***	0.112***	0.106***
	(5.188)	(4.968)	(4.553)
IS	0.001***	0.001***	0.000**
	(4.323)	(3.680)	(2.420)
INS	−2.697	−2.437	−2.258
	(−1.628)	(−1.432)	(−1.277)
_cons	12.577***	12.605***	12.624***
	(21.217)	(20.838)	(20.561)
N	2552	2436	2320
F	18.462	16.067	12.135
Adj. R^2	0.989	0.989	0.990

Note: The values in parentheses are t-statistics, and **, **, ** represent significance at the 1%, 5%, and 10% significance levels, respectively.

5.4 Heterogeneity Analysis

Regression analysis was conducted across seven green finance dimensions, including green credit and green investment. The results show significant differences in carbon reduction effects across these dimensions. The coefficient for green credit was negative at the 10% significance level, and the coefficient for green investment was negative at the 5% significance level , both demonstrating a significant inhibitory effect on carbon emission intensity in resource-based cities. The coefficients for green insurance, green bonds, green support, green funds, and green equity were all negative but not significant, while the coefficient for green funds was negative and close to the 10% significance level. This indicates that current carbon reduction in resource-based cities primarily relies on green credit and green investment, while the emission reduction effects of green insurance and green bonds have not been effectively realized due to factors such as immature market development and limited promotion. Green funds, however, possess certain emission reduction potential.

Table 7 Heterogeneity Analysis - Different Dimensions of Green Finance

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Carbon	Carbon	Carbon	Carbon	Carbon	Carbon	Carbon
Green credit	-0.753*						
	(-1.766)						
Green Investment		-3.091**					
		(-2.051)					
Green Insurance			-1.483				
			(-1.634)				
Green bonds				-3.459			
				(-1.611)			
Green support					-0.554		
					(-0.355)		
Green Fund						-0.605	
						(-1.404)	
Green rights							-0.584
							(-1.018)
lnpop	0.613***	0.613***	0.615***	0.618***	0.624***	0.618***	0.622***
	(5.828)	(5.828)	(5.843)	(5.882)	(5.929)	(5.876)	(5.921)
lngov	0.310***	0.310***	0.310***	0.308***	0.305***	0.309***	0.307***
	(47.858)	(49.131)	(48.206)	(50.647)	(51.716)	(47.407)	(50.879)
IS	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**	0.000**
	(2.454)	(2.422)	(2.453)	(2.447)	(2.394)	(2.408)	(2.392)
INS	-1.173	-1.152	-1.161	-1.125	-1.108	-1.098	-1.109
	(-0.701)	(-0.689)	(-0.694)	(-0.673)	(-0.662)	(-0.656)	(-0.663)
_cons	8.928***	8.928***	8.925***	8.918***	8.916***	8.912***	8.910***
	(16.454)	(16.458)	(16.447)	(16.436)	(16.421)	(16.422)	(16.415)
Individual fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	2668	2668	2668	2668	2668	2668	2668
F	1618.862	1619.770	1618.489	1618.426	1616.365	1617.904	1617.124
Adj. R^2	0.988	0.988	0.988	0.988	0.988	0.988	0.988

Note: The values in parentheses are t-statistics, and **, **, ** represent significance at the 1%, 5%, and 10% significance levels, respectively.

5.5 Analysis of the Impact Mechanism of Green Innovation

Column (1) shows that the regression coefficient of green finance on carbon emission intensity is significantly negative. In column (2), the regression coefficient of green finance on green innovation is significantly positive at the 1% level, indicating that green finance can significantly promote the development of green innovation. This shows that green innovation plays an intermediary role in the process of green finance affecting the carbon emission intensity of resource-based cities. That is, green finance reduces carbon emission intensity by promoting green innovation, thus verifying hypothesis 2.

Table 8 Mechanism Analysis

	(1)	(2)
	Carbon	GI
GFI	-0.295**	0.155***
	(-2.024)	(24.617)
lnpop	0.446***	0.000
	(4.519)	(0.016)
lngov	0.113***	0.000
	(5.266)	(0.200)
IS	0.001***	-0.000
	(4.558)	(-0.450)
INS	-2.888*	-0.029
	(-1.786)	(-0.410)
_cons	12.590***	-0.004
	(21.665)	(-0.161)
Individual fixed effects	Yes	Yes
Year fixed effect	Yes	Yes
N	2668	2668
F	19.545	122.190
Adj. R^2	0.989	0.788

Note: The values in parentheses are t-statistics, and **, **, ** represent significance at the 1%, 5%, and 10% significance levels, respectively.

5.6 Threshold Effect Analysis

This paper uses the Hansen threshold regression model, with the level of green finance development and the level of green innovation development as threshold variables, to examine the nonlinear impact of the two on carbon emission intensity and explore the threshold characteristics of the carbon emission reduction effect of green finance.

(1) Threshold effect analysis of the impact of green finance development level on carbon emissions. The regression results with green finance development level as the threshold variable show that there is a single threshold effect between the two. When the green finance development level is below the threshold value, its impact coefficient on carbon emission intensity is positive but not significant, indicating that in the early stage of green finance development, it has not yet played a role in carbon emission reduction due to factors such as small scale and imperfect system. When the green finance development level crosses the threshold value, its impact coefficient on carbon emission intensity is significantly negative at the 5% level, indicating that after the green finance development level is improved, the resource allocation capacity is significantly enhanced, which can effectively guide funds to green industries, and the inhibitory effect on carbon emission intensity begins to appear and strengthen.

Table 9. Threshold Regression Results – GFI as the Threshold Variable

	(1) Carbon
lnpop	0.546***
	(5.177)
lngov	0.329***
	(37.584)
IS	0.000**
	(2.367)
INS	−0.496
	(−0.298)
GFI< λ	0.160
	(1.049)
GFI≥ λ	−0.268**
	(−2.073)
_cons	9.054***
	(16.783)
N	2668
F	1372.712
Adj. R^2	0.753

Note: The values in parentheses are t-statistics, and **, **, and ** represent significance at the 1%, 5%, and 10% significance levels, respectively; λ represents the threshold values for the level of green finance development.

(2) Threshold effect analysis of the impact of green innovation development level on carbon emissions. Regression results using green innovation development level as the threshold variable show a double threshold effect. When the green innovation development level is below the first threshold, the impact coefficient of green finance on carbon emission intensity is significantly negative at the 1% level, and the absolute value of the coefficient is large. At this time, the carbon emission reduction inhibition effect of green finance is strong. When the green innovation development level crosses the first threshold but does not reach the second threshold, the impact coefficient of green finance on carbon emission intensity is still significantly negative at the 5% level, but the absolute value of the coefficient decreases, and the carbon emission reduction inhibition effect weakens. This indicates that the green innovation development level has a moderating effect on the carbon emission reduction effect of green finance, and the carbon emission reduction effect of green finance varies significantly under different stages of green innovation development.

Table 10 Threshold Results – GI is the threshold variable

	(1)
	Carbon
lnpop	0.587***
	(5.551)
lngov	0.316***
	(36.239)
IS	0.000***
	(2.660)
INS	-1.119
	(-0.671)
$GI \leq \lambda$	-0.836***
	(-3.744)
$\lambda < GI \leq \lambda$	-0.282**
	(-2.169)
_cons	9.036***
	(16.654)
N	2668
F	1356.133
Adj. R^2	0.750

Note: The values in parentheses are t-statistics, and **, **, ** represent significance at the 1%, 5% and 10% significance levels, respectively; λ_1 and λ_2 are the two threshold values for the level of green innovation development ($\lambda_1<\lambda_2$).

6. Conclusions and Policy Recommendations

This paper uses 116 resource-based cities in China from 2002 to 2024 as a sample to empirically test the impact of green finance on carbon emission intensity. The conclusions are as follows: First, green finance has a significant inhibitory effect on carbon emission intensity in resource-based cities. Second, the carbon emission reduction effect of green finance is heterogeneous, that is, green credit and green investment have a more prominent emission reduction effect, while the emission reduction effect of other dimensions of green finance is not yet obvious. Third, green innovation plays a significant transmission role between green finance and carbon emission intensity. Green finance is conducive to promoting green technology innovation, thereby reducing carbon emission intensity. Fourth, both have a threshold effect on carbon emission intensity: the carbon emission reduction inhibitory effect of green finance increases significantly after the development level of green finance exceeds a single threshold, while the development level of green innovation has a double threshold characteristic.

Based on the above conclusions, the following policy recommendations are proposed:

First, we need to improve the green finance system. We must first improve the green finance policy framework for resource-based cities, give preferential policies to green credit and green investment, and reduce the financing costs of green projects through tax breaks, thereby guiding financial institutions and social capital to increase their allocation in the low-carbon field.

Secondly, to strengthen the transmission role of green innovation, we must first establish differentiated financial incentive mechanisms, substantially increase financial support for green technology research and development and patent transformation, and enable green innovation and green finance to interact virtuously, thereby giving full play to the role of green finance in promoting carbon emission reduction.

Third, we should clarify the threshold characteristics of green finance and green innovation in theory, and promote the development of green finance and green innovation in stages: initially improve the system and expand the scale, and after exceeding the threshold, improve the efficiency of resource allocation, actively and effectively promote the deep integration of the two, and give full play to the nonlinear effect of synergistic emission reduction.

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