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Impact of Green Finance on Carbon Emission Performance

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Abstract: This paper examines the impact of green finance on urban carbon emission performance by utilizing panel data from 280 prefecture-level cities in China from 2012 to 2022. The results indicate that the development of green finance can improve carbon emission performance. Mechanism analysis reveals that green finance enhances carbon emission performance by promoting industrial structure upgrades and green technological innovation, and this conclusion is confirmed through a series of robustness tests. Heterogeneity analysis shows that the impact of green finance on carbon emission performance is more significant in non-resource-based cities and in eastern regions. Based on these findings, this paper offers relevant policy recommendations, providing useful insights for improving urban carbon emission performance in China.

Keywords: Green finance; Carbon emission performance; Green technological innovation; Industrial structure

1 Introduction

With the rapid development of the global economy, the ecological environment has been subjected to unprecedented impacts. In recent years, phenomena such as intensified global warming, glacier melting, rising sea levels, and frequent smog have all warned us that climate change is severely threatening human survival. The climate crisis has become a common challenge faced by all of humanity, and no country can remain unaffected. In response to this crisis, the international community is cooperating, with countries such as France, the UK, and Germany having already achieved their carbon peak targets and entered the reduction phase; the US, Japan, and other countries have also committed to achieving carbon neutrality by around 2050 [1]. As the world's second-largest economy, China, despite ranking high in GDP, is still in the stage of rapid industrialization and urbanization, with energy demand continuing to grow. Carbon emissions have not yet reached their peak and are still rising. By 2023, China's total carbon emissions had reached 3.74 billion tons, ranking first in the world. In the face of this severe situation, the Chinese government has placed great emphasis on the issue of carbon emissions. President Xi Jinping solemnly promised at the United Nations General Assembly that China would make every effort to achieve the carbon peak by 2030 and carbon neutrality by 2060 [2]. Subsequently, the *Opinions of the Central Committee of the Communist Party of China and the State Council on Fully, Accurately, and Comprehensively Implementing the New Development Philosophy to Achieve Carbon Peak and Carbon Neutrality* further clarified the specific timetable and roadmap for achieving carbon peak and carbon neutrality in China, demonstrating China's great responsibility and commitment in the field of environmental protection. Green finance, as an important part of China's financial supply-side structural reform, is a powerful tool to promote energy conservation, emission reduction, and the green transformation of the economy and society. It innovates and optimizes the traditional financial model by incorporating environmental protection and ecological resources into investment and financing decisions. It helps diversify the risks of green development, promotes the innovation and application of green technologies, and improves energy efficiency, thus achieving energy conservation and emission reduction goals. In recent years, relying on the existing financial system, China has gradually built a relatively complete green finance system. In 2016, under the leadership of the central bank, a joint effort was made with the Ministry of Finance and other departments to release the *Guiding Opinions on Building a Green Financial System*, aiming to promote the improvement of China's green finance standard system through top-level design and institutionalized, standardized principles. In 2017, Zhejiang, Jiangxi, and five other provinces were selected as pilot areas for green finance reform and innovation. At the same time, a series of standards, such as the *Green Bond Support Project Catalog (2021 version), Environmental Information Disclosure Guidelines for Financial Institutions, and Environmental Rights Financing Tools*, were introduced. By 2021, the national carbon market officially started trading, marking China's efforts and determination in the field of green finance, aiming to promote sustainable and high-quality economic development. Against this background, this paper will combine theoretical and empirical analysis to study the development of green finance in China and its impact on carbon emission performance.

Early research mainly focused on the relationship between financial development and carbon emissions, resulting in two divergent views. Some scholars emphasized that the financial system positively impacts carbon emission reduction by guiding resources towards clean technologies and improving energy efficiency [3]. On the other hand, some argued that in the absence of effective environmental regulation, financial development could accelerate the expansion of high-carbon industries, thus increasing carbon emissions [4]. With the acceleration of global green transformation, the research focus has gradually extended from traditional finance to green finance, examining whether it can effectively promote carbon emission reduction as a policy and market tool to guide low-carbon economic development. On the empirical level, existing studies mostly focus on green bonds [5], clean stock indices [6], green investments [7], and other single dimensions. Although these findings provide preliminary evidence, due to the limited scope and local nature of the indicators, they are unable to systematically depict the overall development level of green finance and fully reveal the complex relationship between green finance and carbon emissions. To address these deficiencies, some scholars have attempted to construct a comprehensive green finance index to examine the relationship between green finance and carbon emissions from a systematic perspective, thus advancing research from a localized perspective to an overall assessment. Nevertheless, there is still no consensus in the academic community regarding the carbon emission reduction effect of green finance. Some studies confirm its positive role and offer explanations from a mechanism perspective, such as improving energy efficiency [8] and expanding environmental protection expenditure [9]. However, other studies have drawn different conclusions, such as green investment contributing to optimizing the energy structure but having no significant direct impact on carbon emissions [10]. Other scholars have pointed out that the relationship between green finance and carbon intensity may follow an inverted U-shaped nonlinear pattern [11], suggesting that its effectiveness may be constrained by factors such as the development stage and policy support. Overall, although significant progress has been made in identifying the relationship between green finance and carbon emissions, there are still noticeable shortcomings in the following areas: first, most literature focuses on the "scale" of carbon emissions while neglecting the "efficiency" dimension, with a lack of systematic research on carbon emission performance; second, the assessment of green finance still relies heavily on single or partial indicators, with the need for improvement in comprehensiveness and theoretical rationality; third, the analysis of its impact mechanisms has yet to form a systematic framework, particularly the mediating roles of green technological innovation and industrial structure upgrading that require empirical testing. Based on the above research gaps, this paper advances existing work by constructing a multi-dimensional green finance development index and a comprehensive carbon emission performance evaluation system using panel data from 280 Chinese cities from 2012 to 2022. It empirically tests the direct impact of green finance on carbon emission performance and further reveals its mechanism through the dimensions of green technological innovation and industrial structure upgrading, with the aim of providing theoretical and empirical support for optimizing the green finance system and formulating emission reduction policies.

2 Theoretical Analysis and Research Hypotheses

2.1 Benchmark Theoretical Analysis

As an emerging form of finance, the core goal of green finance is to address climate change, optimize environmental quality, and improve resource utilization efficiency. Through policy tools such as green bonds and special-purpose loans, green finance guides capital flows into the environmental protection sector, significantly enhancing the effectiveness of low-carbon actions [12]. Specifically, the role of green finance in carbon reduction is mainly reflected in two aspects: first, green finance provides a solid financial backing for carbon reduction, compensating for the shortcomings of traditional finance. When enterprises engage in environmental governance, they often face long cycles, high investment costs, prominent risks, and uncertain results, leading to a lack of willingness from conventional financial institutions to get involved and limited support. Green finance, through the design of flexible terms and controllable costs for special financing tools, precisely matches the risk-return characteristics of low-carbon projects, providing differentiated support to entities with different emission reduction needs, thus broadening the coverage of financial services and deepening the capital penetration for low-carbon transformation [13]. In addition, the government stimulates traditional financial institutions' endogenous motivation to participate in low-carbon projects through incentive measures such as dynamic interest rate adjustments, credit policy preferences, and optimization of access thresholds, further expanding the scale effect of green finance and injecting sustained momentum into achieving the "dual carbon" targets. Second, green finance optimizes the allocation efficiency of green resources. It integrates low-carbon and environmental protection concepts into financial decisions, guides institutions to actively participate in environmental governance, and through diversified financing models, focuses on supporting smart grid upgrades, renewable energy projects, and circular economy industries, accelerating the formation of a green industry ecosystem [14]. Especially crucial is that green finance has a significant value guidance function, leveraging the effect of leverage and credit endorsement to mobilize social capital towards low-carbon sectors, while simultaneously forming an investment constraint mechanism for high-carbon industries. Specifically, this is manifested in the reduction of financing space for energy-intensive industries, the restriction of pollution enterprises' debt expansion, and the limitation of new production capacity investment, ultimately achieving a structural tilt of financial resources toward green sectors [15] and systematically reducing regional carbon emission intensity. Based on the above analysis, this paper proposes the following hypothesis:

Hypothesis 1: The development of green finance can improve carbon emission performance.

2.2 Analysis of the Impact Mechanism of Green Finance on Carbon Emission Performance

2.2.1 Industrial structure effect

Green finance policies focus on providing credit support and preferential policies for green environmental protection and energy conservation and emission reduction sectors, aiming to promote the vigorous development of green industries, high-tech industries, and the service sector. At the same time, by strengthening long-term financing restrictions on "high-emission" industries and projects, these industries are encouraged to undergo green transformation, thereby accelerating the optimization and upgrading of the industrial structure [16]. As the pace of industrial upgrading accelerates, the proportion of green economy sectors such as energy-saving environmental protection industries and high-tech industries in the national economy increases, while high-energy consumption and high-pollution traditional industries gradually exit the market or undergo resource reallocation. This adjustment in the industrial structure realizes the gradual decline of high-pollution industries in exchange for the rise of green economy sectors, effectively reducing carbon emissions in economic activities. Based on the above analysis, this paper proposes the following hypothesis:

Hypothesis 2a: The development of green finance can improve carbon emission performance by promoting industrial structure upgrading.

2.2.2 Green technological innovation effect

When enterprises advance clean technology and green product development, relying solely on their own funds is often insufficient to meet actual needs. Moreover, due to the long cycle, high risk, and significant uncertainty inherent in green technological innovation, enterprises often face difficulties in obtaining adequate support from traditional financial channels. Given the long cycle, high risk, and significant uncertainty inherent in green technological innovation, enterprises often struggle to obtain sufficient financial support from traditional financial channels. However, emerging financial sectors, due to their preference for high-risk projects, are more willing to provide financial support for the research and development of green technologies and products. As a representative of emerging financial sectors, green finance effectively alleviates the financial tension faced by enterprises in green technological innovation through diversified financing channels such as loans and funds. The low-interest, long-term stable financial support it provides not only greatly stimulates the innovative vitality of enterprises but also encourages enterprises to increase investment in research and development. These positive effects jointly drive the continuous progress and development of green technological innovation [17]. As the level of green technological innovation continues to improve, energy utilization efficiency is continually enhanced, and the efficiency of production factors such as labor and capital is also significantly improved, effectively reducing carbon emissions in economic activities. Based on the above analysis, this paper proposes the following hypothesis:

Hypothesis 2b: The development of green finance can improve carbon emission performance by promoting green technological innovation.

3 Research Design

3.1 Variable Selection

3.1.1 Dependent variable: Carbon emission performance

Following the method of Wang et al. [18], the carbon emission performance indicator is calculated by considering both input and output indicators. In terms of input, the fixed capital stock, the number of employed persons at the end of the year, and the total electricity consumption are selected as proxies for capital, labor, and energy input factors to assess carbon emission performance. For output, regional GDP is selected as the expected output, and carbon dioxide emissions as the undesirable output. A comprehensive evaluation index system is established as shown in Table 1, and the Super Efficiency SBM model is used to calculate urban carbon emission performance.

Table 1. Comprehensive evaluation index system of carbon emission performance

First-Level Indicator		Second-Leve Indicator	Third-Level Indicator	Unit
Carbon Emission Performance	Input	Labor	Number of employed persons at the end of the year	Ten thousand persons
		Capital	Capital stock	Ten thousand RMB
		Electricity Consumption	Total electricity consumption	Ten thousand kWh
	Expected Output	Economic Growth	GDP	Ten thousand RMB
	Undesirable Output	Air Emissions	Sulfur dioxide emissions	Ten thousand tons

3.1.2 Independent variable: Green finance

The core function of green finance is to support green and low-carbon development through the directed allocation of financial resources, risk diversification, and price discovery. Its system construction needs to closely align with the three core dimensions: "fund supply — risk prevention — market trading." Based on the functional attributes and theoretical framework of green finance, and drawing on the indicator design logic of Zhong et al. [19], combined with data availability at the prefecture level, six core indicators are selected from the three dimensions of green capital supply, green risk prevention, and carbon market trading to construct a green finance comprehensive evaluation system (Table 2). The entropy method is then applied to measure the development of green finance at the prefecture level. The theoretical basis for the selection of indicators is as follows.

Table 2. Comprehensive evaluation index system of green finance

	First-Level Indicator	Second-Level Indicator	Unit
Green Finance	Green Credit	Total energy-saving and environmental protection project loans / Total national loans	Positive
	Green Bonds	Total green bond issuance / Total national bond issuance	Positive
	Green Funds	Total market value of green funds / Total market value of funds	Positive
	Green Insurance	Environmental pollution liability insurance revenue / Total insurance premium revenue	Positive
	Green Investment	Environmental pollution governance investment / GDP Energy-saving and environmental protection fiscal expenditure / Total fiscal expenditure	Positive
	Carbon Finance	Carbon emission trading volume / Total national carbon emission trading volume	Positive

Green Capital Supply Dimension: This dimension focuses on the resource allocation function of green finance, with the core being the provision of stable financial support for low-carbon projects through diversified financial instruments, covering four core tools:

Green Credit: The ratio of "total green project loans / total national loans" is used as a proxy indicator. Green credit is the core tool for the banking system to support green development. Through preferential credit limits and differentiated interest rates, it reduces the financing costs of low-carbon projects while restricting funds from flowing into high-energy-consuming projects. The proportion of green credit directly reflects the green orientation of the credit market.

Green Bonds: The ratio of "total green bond issuance / total national bond issuance" is used as a measure. Green bonds, which have long financing terms and low costs, are an important direct financing tool for enterprises to carry out green projects (such as renewable energy development and pollution control). The issuance scale of green bonds reflects the support of the bond market for green projects.

Green Funds: The ratio of "total market value of green funds / total market value of funds" is used as an indicator. Green funds gather social capital for green industries, with advantages in both capital aggregation and professional investment. The market value ratio reflects the capital market's long-term investment confidence and allocation efficiency for green industries.

Green Investment: Two sub-indicators are selected from both government and market perspectives: "environmental pollution investment / GDP" and "energy-saving and environmental protection fiscal expenditure / total fiscal expenditure." The former reflects the investment strength of market entities in environmental governance, and the latter reflects the government's determination to guide green development through fiscal policies. These two together form the complete dimension of green investment, in line with the "market-driven, government-guided" green finance development logic.

Green Risk Prevention Dimension: The ratio of "environmental pollution liability insurance revenue / total insurance premium revenue" is used as a proxy indicator (i.e., green insurance). Green insurance internalizes environmental risks into enterprise production costs through risk pricing and loss compensation mechanisms. It not only provides insurance for environmental pollution accidents but also incentivizes enterprises to strengthen environmental management through differentiated insurance premiums. Green insurance is a core component of the green finance risk prevention system and fills the gap in risk control functions left by the capital supply dimension.

Carbon Market Trading Dimension: The ratio of "carbon emission trading volume / total national carbon emission trading volume" is used to measure the level of carbon finance development. Carbon finance, with carbon emission rights as the trading subject, guides enterprises to reduce emissions through market pricing mechanisms, and is a key financial tool to achieve the carbon peak and carbon neutrality goals. This indicator directly reflects the participation degree and emission reduction enthusiasm of the prefecture-level city in the national carbon market and represents the synergistic effect between green finance and the carbon pricing mechanism.

These six indicators correspond to the core functional system of green finance: "fund supply (credit, bonds, funds, investment) — risk prevention (insurance) — carbon market trading (carbon finance)." They cover both indirect and direct financing tools, consider the participation of both government and market entities, and cover the entire chain from pre-funding allocation, in-process risk prevention, to post-market incentives, comprehensively and systematically reflecting the overall level of green finance development at the prefecture level.

3.1.3 Mediating variables

Green Technological Innovation (GTP): In this paper, the number of green patents as a proportion of total patent applications is used as a proxy variable for green technological innovation. This is based on the categorization of green patents in the *China Green Patent Statistical Report (2014-2017)* with keywords such as "pollution control, pollution treatment, environmental materials, alternative energy, energy saving and emission reduction, green agriculture, green forestry, recycling, new energy, green buildings, green management," and patent data is obtained from the National Intellectual Property Office's patent search and service platform.

Industrial Structure Upgrading is measured using two indicators: rationalization of industrial structure (RIS) and advancement of industrial structure (AIS). For the rationalization of industrial structure, the method of Wang et al. [20] is referenced, using the Theil index for measurement. The specific calculation formula is shown in Eq. (1). The greater the deviation from 0, the more unreasonable the industrial structure, so this index is a negative indicator. The advancement of industrial structure is measured by the ratio of tertiary industry value-added to secondary industry value-added.

$$\text{RIS} = \sum_{i=1}^{n} \left(\frac{Y_i}{Y}\right) \ln \left(\frac{Y_i}{L_i} / \frac{Y}{L}\right) \tag{1}$$

where, Y represents output value, L represents employment, i represents industries, and n represents the number of industry sectors.

3.1.4 Control variables

This paper draws on existing literatures [21, 22] and selects the following variables as control variables: (1) Regional Population Density (PD): The population per square kilometer plus 1 is taken as the logarithm for measurement. (2) Regional Openness (FDI): The ratio of actual foreign investment to regional GDP, expressed in logarithmic form. (3) Human Capital (HNC): The number of university students per 10,000 people plus 1 is taken as the logarithm for measurement. (4) Government Intervention Intensity (GOV): The ratio of local government general budget expenditure to GDP. (5) Industrialization Level (INL): The ratio of industrial sector value-added to regional GDP. (6) Market Potential (MTP): The ratio of total retail sales of consumer goods to regional GDP. The variable names in the subsequent tables are represented by abbreviations of the variables in parentheses.

3.2 Model Construction

3.2.1 Benchmark regression model

$$CEP_{it} = \beta_0 + \beta_1^* GF_{it} + \beta_2^* Controls_{it} + \delta_i + \gamma_t + \varepsilon_{it} \tag{2}$$

where, i represents cities, t represents years, CEP_{it} represents carbon emission performance; GF_{it} represents green finance; $Controls_{it}$ represents control variables; γ_t, u_i, and ε_{it} represent time fixed effects, individual fixed effects, and random disturbance terms, respectively.

3.2.2 Mediation effect model construction

To test the mediation effect of industrial structure and green technological innovation, the following model is constructed on the basis of Model (2) to establish the mediation effect:

$$M_{it} = \alpha_0 + \alpha_1^* GF_{it} + \alpha_2^* Controls_{it} + \delta_i + \gamma_t + \varepsilon_{it} \tag{3}$$

$$CEP_{it} = \Phi_0 + \Phi_1{}^* GF_{it} + \Phi_2{}^* M_{it} + \Phi_3{}^* Controls_{it} + \delta_i + \gamma_t + \varepsilon_{it} \tag{4}$$

where, M_{it} represents the mediating variables of industrial structure and green technological innovation, and other variables are the same as in Eq. (2).

3.3 Data Sources and Descriptive Statistics

The original data mainly comes from the *China City Statistical Yearbook, China Regional Economic Database*, the statistical yearbooks of various provinces and cities, the National Patent Office, and the EPS database. The data was processed using Stata 15. Due to data availability, for prefecture-level cities with fewer missing data, linear interpolation is used to fill the gaps, while cities with more missing data are excluded. A total of 280 prefecture-level cities and above from 2012 to 2022 were selected as the research objects. Descriptive statistics of the variables are shown in Table 3.

Table 3. Descriptive statistics of variables

Variable Type	Variable Symbol	Sample Size	Mean	Standard Deviation	Minimum Value	Maximum Value
Dependent Variable	CEP	3080	0.332	0.129	0.020	1.178
Independent Variable	GF	3080	0.329	0.132	0.065	0.671
Mediating Variable	RIS	3080	0.276	0.218	-1.302	1.726
	AIS	3080	1.482	0.561	0.128	5.318
	GTP	3080	0.121	0.103	0.042	0.315
Control Variables	PD	3080	5.706	0.944	4.731	7.887
	FDI	3080	0.016	0.019	0	0.120
	HNC	3080	4.536	0.882	2.708	7.153
	GOV	3080	0.186	0.300	0.030	2.517
	INL	3080	0.381	0.217	0	2.832
	MTP	3080	0.352	0.112	0.001	1.159

4 Empirical Results Analysis

4.1 Benchmark Regression Analysis

Based on Model (2), the impact of green finance on carbon emission performance is tested. Table 4 reports the regression results. Column (1) does not include control variables or fixed effects, while column (2) adds individual and time fixed effects based on column (1), and column (3) includes control variables based on column (2). The regression results show that the coefficient of the core explanatory variable, GF, in columns (1), (2), and (3) is significantly positive at least at the 10% level. In column (3), the coefficient of the core explanatory variable is 0.372, indicating that a 1% increase in green finance leads to a 0.372% improvement in carbon emission performance. This suggests that the development of green finance can improve carbon emission performance, and Hypothesis 1 is confirmed.

4.2 Endogeneity Test

4.2.1 Instrumental variables method

Theoretically, the progress of green finance in the previous period can affect the development of green finance in the current period through the ratchet effect, thus impacting the current carbon emission level. Based on this, the development of green finance in the previous period satisfies the relevance condition as an instrumental variable. At the same time, since the current carbon emission level cannot reverse affect the previous period's green finance development, the development of green finance in the previous period satisfies the exogeneity condition. Therefore, this paper uses the development of green finance in the previous period as the instrumental variable and applies the Two-Stage Least Squares (2SLS) method for regression. From columns (1) and (2) of Table 5, the instrumental variable regression results show that the LM statistic of the instrumental variable is significant at the 1% level, rejecting the null hypothesis of instrument identification failure. The Wald F-statistic of the instrumental variable is greater than the critical value of 16.38 at the 10% significance level, rejecting the null hypothesis of weak instruments. This indicates that the chosen instrumental variable is reasonable. Also, the second-stage regression results show that the coefficient of GF is significantly positive, consistent with the previous findings, indicating the robustness of the research conclusions.

Table 4. Benchmark regression analysis results

Variable	(1)	(2)	(3)
GF	0.438** (2.206)	0.351* (1.753)	0.372*** (2.903)
PD			0.246* (1.883)
FDI			0.302 (1.248)
HNC			0.563** (2.116)
GOV			-0.473 (-1.552)
INL			-0.103** (-2.218)
MTP			
Individual	NO	YES	YES
Time fixed	NO	YES	YES
Constant	0.534 (0.839)	0.302** (2.176)	0.262* (1.747)
Individual	3080	3080	3080
R-squared	0.482	0.535	0.583

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

Table 5. Endogeneity regression results

Variable	(1) 2SLS First Stage	(2) 2SLS Second Stage	(3) GMM
$CEP_{i,t-1}$			0.102 (1.237)
GF		0.351*** (4.286)	0.372** (2.273)
IV1	0.204* (1.838)		
IV2			
Control	YES	YES	YES
Fixed effects	YES	YES	YES
LM	19.805***		
Wald(F)	28.746		
AR(2)			0.397
Sargan test			0.402
Individual fixed	YES	YES	YES
Time fixed	YES	YES	YES
Constant	0.554 (0.703)	0.304* (1.836)	0.114 (1.095)
Sample size	3080	3080	3080
R-squared	0.502	0.493	0.437

4.2.2 System GMM method

To reduce the endogeneity problem caused by time-dependent effects and omitted variables in carbon emission performance, i.e., the carbon emission performance level of a city in the current period may be influenced by its past carbon emission performance, this paper uses the System GMM method. Based on the benchmark regression model, the lag of carbon emission performance is added to construct the following dynamic panel model to address the endogeneity issue:

$$CEP_{it} = \beta_0 + \beta_1^* CEP_{i,t-1} + \beta_2^* GF_{it} + \beta_3^* Controls_{it} + \delta_i + \gamma_t + \varepsilon_{it} \tag{5}$$

where, $CEP_{i,t-1}$ represents the lag of carbon emission performance, and other variables are the same as in Eq. (2).

The regression results show that the AR(2) and Sargan test values are both greater than 0.1, indicating that the model's random disturbance term does not exhibit serial correlation. The model also passes the over-identification test, which makes it suitable to use the System GMM method. Additionally, as seen in column (3) of Table 5, the coefficient of the core explanatory variable GF is significantly positive, consistent with previous research conclusions, indicating the robustness of the study's findings.

4.3 Robustness Test

To ensure the robustness of the previous research results, this paper employs four methods for robustness testing. The first method changes the calculation method of the explanatory variable by replacing it with the commonly used green credit indicator to represent the degree of green finance development in academia, in order to verify the robustness of the conclusion. Due to data availability at the city level, the green credit at the city level is represented by the logarithm of interest expenditure on non-high-energy-consuming industries. The second method changes the calculation method of the explained variable by replacing the super-efficiency SBM model with the super-efficiency EBM model, and then performing the regression. The third method changes the research sample's time span, as the COVID-19 pandemic, which began in early 2020, had different short-term effects on cities across the country. To avoid interference from COVID-19, the sample for the period 2020–2022 is excluded, and the time span is adjusted from 2012–2022 to 2012–2019. The fourth method changes the regression model by replacing the OLS regression model with a Tobit model and performing the regression again. From the robustness regression results in Table 6, it can be seen that the core explanatory variable GF is significantly positive at least at the 10% level in all four methods. This confirms that the development of green finance can improve carbon emission performance, consistent with the previous research conclusions, indicating that the research conclusions are robust.

Table 6. Robustness test results

Variable	Change in Explanatory Variable	Change in Explained Variable	Change in Time Span	Change in Regression Model
GF	0.352*	0.294***	0.403**	0.376*
	(1.743)	(2.953)	(2.149)	(1.742)
Control variables	YES	YES	YES	YES
Constant	0.372	0.758**	0.303*	0.852**
	(0.483)	(2.003)	(1.911)	(2.184)
Individual fixed effects	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES
R-squared	0.487	0.537	0.582	0.672
Sample size	3080	3080	3080	3080

4.4 Mediation Effect Test

Based on the benchmark regression results, green finance development can improve carbon emission performance. Then, based on models (2) and (3), the mediation effect is tested. From the regression results in Table 7, it can be seen that the regression coefficients of GF in columns (1), (3), and (5) are significantly positive, indicating that green finance can promote industrial structure upgrading and green technology innovation. Meanwhile, the regression coefficients of GF in columns (2), (4), and (6) are also significantly positive. This shows that green finance can improve carbon emission performance by promoting industrial structure upgrading and green technology innovation. Therefore, Hypotheses 2a and 2b are confirmed.

4.5 Heterogeneity Analysis

4.5.1 Resource endowment heterogeneity analysis

China is vast, and there are significant differences between cities in terms of resource distribution, economic foundation, and other factors. This study refers to the classification standards in the State Council's *National Resource-based Cities Sustainable Development Plan (2013-2020)* and divides the selected sample cities into 109 resource-based cities and 171 non-resource-based cities for group regression analysis. According to the results in

Table 8, the development of green finance significantly improved the carbon emission performance of non-resource-based cities, but had no significant impact on the carbon emission performance of resource-based cities. This difference may be due to the diversity and flexibility of the economic structure in non-resource-based cities. These cities typically have a more balanced and diversified industrial system and do not rely on a single natural resource for extraction and processing. Therefore, non-resource-based cities demonstrate higher flexibility and efficiency in resource allocation and utilization. The development of green finance provides more financial support and green investment channels for non-resource-based cities, helping to promote the further optimization and upgrading of their industrial structure, transforming towards low-carbon, environmentally friendly, and efficient directions. Through the guidance and support of green finance, non-resource-based cities can accelerate the elimination of high-energy-consuming and high-emission traditional industries, develop low-carbon and circular economies, thereby significantly improving their carbon emission performance. In contrast, resource-based cities have long been dominated by resource extraction and processing industries, with relatively simple economic structures, making it more difficult to transform and upgrade. During the development of green finance, resource-based cities may face more technological and market risks, as well as huge financial investments required for transformation. These factors limit the promotion and application of green finance in resource-based cities. Therefore, despite the widespread attention and development of green finance globally, its impact on the carbon emission performance of resource-based cities is not significant. This suggests that, in promoting the green transformation of resource-based cities, more attention needs to be paid to their particularities, and targeted green finance policies and measures should be formulated to promote a significant improvement in their carbon emission performance.

Table 7. Mediation effect test

Variable	(1) RIS	(2) CEP	(3) AIS	(4) CEP	(5) GTP	(6) CEP
GF	0.103*	0.372**	0.246*	0.427***	0.274**	0.382**
	(1.854)	(2.372)	(1.738)	(3.855)	(2.304)	(2.482)
RIS		0.153**				
		(2.273)				
AIS				0.037**		
				(2.004)		
GTP						0.206**
						(2.263)
Control variables	YES	YES	YES	YES	YES	YES
Constant	0.258**	0.384	0.372*	0.749	0.358*	0.492
	(2.104)	(1.483)	(1.805)	(1.205)	(1.742)	(0.856)
Individual fixed effects	YES	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES	YES
Sample size	3080	3080	3080	3080	3080	3080
R-squared	0.305	0.503	0.472	0.553	0.602	0.573

Table 8. Heterogeneity analysis results

Variable	(1) Resource Based Cities	(2) Non-Resource Based Cities	(3) Eastern Region	(4) Central Region	(5) Western Region
GF	0.359	0.415***	0.371**	0.278	0.254
	(3.482)	(0.732)	(2.396)	(0.579)	(0.662)
Control variables	YES	YES	YES	YES	YES
Constant	0.572	0.378*	0.382	0.305**	0.119*
	(1.294)	(1.883)	(0.732)	(2.117)	(1.893)
Individual fixed effect	YES	YES	YES	YES	YES
Year fixed effect	YES	YES	YES	YES	YES
Sample size	1199	1881	1089	1056	935
R-squared	0.502	0.482	0.597	0.393	0.283

4.5.2 Regional heterogeneity analysis

China has a vast territory, and there are significant differences across regions in terms of economic development levels, industrial structures, and resource-environmental conditions. This study divides the sample cities into three major regions: the Eastern, Central, and Western regions, and performs group regression analysis. According to the results in Table 8, the development of green finance significantly improved the carbon emission performance in the Eastern region, while there was no significant impact on the carbon emission performance in the Central and Western regions. This regional difference may be closely related to the economic development level and industrial structure characteristics of the Eastern region. The Eastern region is economically developed, has a relatively well-established financial market system, and a high level of technological innovation, which provides favorable conditions for the development of green finance. At the same time, the industrial structure in the Eastern region is relatively optimized, with a high proportion of high-end manufacturing, services, and emerging industries, and low dependence on high-pollution, high-energy-consuming traditional industries. Therefore, the promotion and application of green finance in the Eastern region can more effectively direct funds to low-carbon, environmentally friendly, and high-benefit projects, promoting the further transformation of the industrial structure towards green and intelligent directions, thereby significantly reducing carbon emission intensity and improving carbon emission performance. In contrast, the Central and Western regions have economic development levels and industrial structures that lag behind the Eastern region. These regions tend to rely more on traditional resource-based industries such as coal, steel, and non-ferrous metals, and have relatively low technological innovation capabilities and less developed financial markets. During the development of green finance, the Central and Western regions may face more challenges, such as funding shortages, technological bottlenecks, and market risks. These factors limit the effectiveness of green finance promotion in these regions, making its impact on improving carbon emission performance not significant. Moreover, the green finance policy systems and market mechanisms in the Central and Western regions may still be imperfect, which affects the role of green finance. For example, issues such as insufficient innovation in green finance products, inadequate incentive mechanisms, and non-transparent information disclosure may all restrict the potential of green finance in promoting improvements in carbon emission performance.

5 Conclusion and Policy Recommendations

5.1 Conclusion

This study investigated the impact of green finance on carbon emission performance using panel data from 280 prefecture-level cities in China from 2012 to 2022. The main conclusions are as follows: (1) Green finance development can improve urban carbon emission performance. (2) Green finance development can improve urban carbon emission performance by promoting industrial structure upgrading and green technological innovation. (3) Heterogeneity analysis indicates that the impact of green finance on carbon emission performance is more significant in non-resource-based cities and the Eastern region.

5.2 Policy Recommendations

Government should develop differentiated green finance policies based on the characteristics of different regions. In non-resource-based cities and the Eastern region, the government should further increase support for green finance through fiscal subsidies, tax reductions, low-interest loans, and other preferential policies, encouraging more social capital to invest in green industries and green technological innovation. At the same time, green finance product innovation should be promoted, expanding green financing channels, reducing financing costs, and providing strong support for improving urban carbon emission performance. For resource-based cities, the Central and Western regions, the government should strengthen the promotion and guidance of green finance, raising the awareness and participation of enterprises and the public in green finance. Additionally, more investment should be directed to research and innovation in green technology, promoting the transformation of industrial structures towards greener and more advanced models in these regions.

Financial institutions should actively participate in the development of green finance. They should enhance credit support for green industries and reduce the financing costs of green projects. Moreover, more green finance products linked to carbon emission performance, such as green bonds and green funds, should be developed to provide more diversified funding support for improving urban carbon emission performance. Financial institutions should also strengthen the prevention and management of risks associated with green finance, optimize green financial services, and ensure the steady development of green finance.

Enterprises, as one of the main sources of urban carbon emissions, should embrace green finance and focus on green technological innovation and industrial upgrading. Enterprises should actively seek support from green finance, introducing advanced green technologies and equipment, optimizing production processes, improving resource utilization efficiency, and reducing carbon emission intensity. At the same time, enterprises should increase their investment in research and innovation in green technologies, enhancing their core competitiveness and contributing to the improvement of urban carbon emission performance.

The government should strengthen the regulation and standardization of green finance. A comprehensive legal and regulatory system for green finance should be established, clearly defining the scope, standards, and regulatory requirements for green finance. The government should enhance the review and supervision of green finance products to prevent abuse or misapplication. Additionally, the government should strengthen the monitoring and analysis of the green finance market, promptly identifying and addressing any issues or risks arising in the development of green finance, ensuring the healthy and orderly development of green finance and providing strong support for the improvement of urban carbon emission performance.

Author Contributions

Conceptualization, H.L. and L.L.S.; methodology, H.L. and L.L.S.; software, L.L.S. and Y.Y.; validation, L.L.S., Y.Y., and H.L.; formal analysis, H.L.; data curation, L.L.S., Y.Y., and H.L.; writing—original draft preparation, L.L.S. and H.L.; writing—review and editing, L.L.S., Y.Y. and H.L. All authors have read and agreed to the published version of the manuscript.

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Data Availability

The data used to support the research findings are available from the corresponding author upon request.

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Conflicts of Interest

The authors declare no conflict of interest.

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