Original Research

Impact of Green Finance on Carbon Emissions: Empirical Analysis Based on Chinese Provincial Panel Data

Fanghua Wu[1], Congqi Wang[1*], Haslindar Ibrahim[1], Pengzhen Liu[2]

[1] School of Management, Universiti Sains Malaysia, George Town 11800, Malaysia
[2] School of Economics, Jinan University, Guangzhou 510632, China

Abstract

Reducing carbon emissions is widely recognized as one of our nation's top priorities. At the national level, green financing has grown and received a lot of support. Using panel data from 30 towns and provinces in China between 2011 and 2021, this study mainly examines the effect of green money on carbon emissions. It delves into the processes by which it does so. Here are the study's findings: Results showing that green money substantially lowers carbon emissions hold up in multiple robustness tests. Secondly, by looking at the mechanics of intermediary effects, we can see that green financing might lower carbon emissions through, for example, technological innovation and better industrial structure. In conclusion, the heterogeneity analysis reveals that green financing's impact on carbon emissions varies by regional development level, with a more substantial effect observed in the western and eastern regions. Considering these results, the authors of this study suggest implementing policies tailored to individual regions and developing a diverse green finance system to promote the efficient reduction of carbon emissions.

Introduction

The Chinese economy has undergone substantial expansion since the initiation of the reform and opening-up policy. However, concerns regarding the overconsumption of resources and the damage to the environment have also arisen. Different sectors of society are actively pursuing a middle ground between

rapid economic expansion and permanent environmental damage [1]. Rapid economic expansion has led to excessive carbon dioxide emissions. According to the "World Energy Statistics Yearbook 2021/22", China's carbon emissions increased from 8.83 billion tons to 9.90 billion tons between 2011 and 2020. This is a significant proportion of worldwide carbon emissions, highlighting the urgent need to implement measures to substantially reduce these emissions promptly [2]. During the 75th United Nations General Assembly in 2020, China put out a proposal to achieve a carbon peak by 2030 and carbon neutrality by 2060. The implementation of the

*e-mail: nus.edu.academic@gmail.com

"30/60" targets signifies a significant dedication to global initiatives aimed at decreasing carbon emissions. Furthermore, its adoption demonstrates China's inherent need for sustainable development. China's leaders officially incorporated carbon peak and neutrality as policy objectives during the country's Two Sessions in 2021 [3]. Therefore, China is presently confronted with the substantial challenge of determining how to improve carbon emission reduction and accelerate the shift towards low-carbon economic growth.

In recent years, governments have embraced the concept of green development to foster sustainable economic growth. Green economic growth is becoming a commonly used measure of national economic advancement in many highly industrialized countries. Furthermore, green development can be defined as the deliberate reduction of natural resource use, the strengthening of ecological protection and environmental regulation, and the achievement of equitable growth across all sectors of society and the globe [4]. This illustrates that sustainable development encompasses a broad spectrum of subjects. There is a consensus that money plays a pivotal role in advancement and that green finance is vital for the development of the green economy. Green finance contributes to economic growth and prosperity by simultaneously reducing carbon emissions, thus achieving the "dual carbon" objectives. China acknowledged the significance of green finance and incorporated a policy in its 14th Five-Year Plan to promote its development.

The "Guiding Opinions on Building a Green Financial System," published in 2016 by the People's Bank of China and six other ministries, provides a clear definition of green finance. It refers to a financing approach that gives priority to projects aimed at reducing the impact of climate change, enhancing environmental quality, and optimizing the use of resources. In domains such as environmental preservation, energy efficiency, sustainable energy, eco-friendly transportation, and environmentally conscious infrastructure, offering financial services for initiatives, financing, project execution, risk mitigation, and other related activities. China's present green financial systems and products encompass a wide range of offerings, including green loans, bonds, insurance, funds, trusts, carbon finance products, and more [5]. By the end of 2021, the combined value of green loans in China, denominated in both local and foreign currency, is projected to reach 15.9 trillion yuan. Additionally, the entire value of green bonds issued is expected to exceed 600 billion yuan, resulting in a cumulative total of 1.1 trillion yuan. This is a significant advancement towards achieving the "dual carbon" goal.

Studying the correlation between green finance and carbon emissions is highly valuable in practical terms, as both topics are essential areas of research. Therefore, the analytical framework of this research might be summarized as follows: To analyze the overall relationship between green finance and carbon emissions and investigate how green finance affects carbon emissions, we will create a panel regression model using China's provincial panel data. After doing heterogeneity analysis and testing the model's robustness, the study's findings are used to generate more relevant policy suggestions. The fundamental novelty of this work is in the incorporation of green financing as a key explanatory variable in the econometric model, thereby enhancing the existing understanding of the link between green finance and carbon emissions. This research also examines the underlying mechanics of green finance to uncover the precise ways in which it hampers the reduction of carbon emissions. The text examines mechanisms related to industrial upgrading, technical innovation, and other channels. Ultimately, it analyzes the influence of green financing on carbon emissions from a perspective that considers differences in implementing distinct strategies.

Literature Review

Literature Research on Green Finance

The concept of "green finance," also known as "low-carbon finance," "environmental protection finance," and "sustainable development finance," was introduced in 1991. This study investigates the convergence of the financial sector with sustainability, specifically emphasizing environmentally conscious methods. In the early literature, "environmental finance" was used more often than "green finance." [6]. The publication of the "Statement by Banks and Insurance on Sustainable Development" originated from the 1992 UNEP cycle, which stands for the United Nations Environment Programme (UNEP) [7]. Salazar [8] researched distinguishing the financial and environmental sectors and introduced the concept of "environmental finance." Within the current body of research in China, green finance is sometimes referred to as environmental finance or sustainability finance [9]. The term "green finance" was officially defined in the 2016 "Comprehensive Report on G20 Green Finance" as "financial activities that generate environmental advantages to promote sustainable development through investment and financing." Labatt and White [10] pointed out that green finance is a financial tool that utilizes the influence of the market economy to enhance environmental quality and transfer and spread environmental business risks.

Chinese researchers have recently demonstrated a renewed enthusiasm for "green finance," approaching it from a contemporary standpoint. Recently, there has been a heightened emphasis and scrutiny on financial policy, financial instruments, and other pertinent practical issues [11]. Tao et al. [12] propose a method to combine China's fiscal and financial policies in order to promote low-carbon investment. This method is based on the lessons learned from worldwide environmental

finance, including fiscal and tax incentive policies. W. Zhang et al. [13] studied the effects of China's green credit strategy and its potential for economic expansion. They advocated for the required implementation of better operability and significant incentives, such as reduced interest rates, risk weights, and non-performing loan rates. About equipment, Li and Umair [14] provide a concise explanation of how several types of financial instruments, such as budgetary funds, bonds, and loans, have been utilized in efforts to address climate change. Yin and Xu [15] proposed using green loans, green bonds, and green asset securitization as means to tackle the expensive nature of financing environmentally friendly enterprises.

Literature Research on Carbon Emissions

The notions of carbon emissions and intensity have been elucidated and examined in a plethora of domestic and international literature. Wang and Yan [16] investigated to examine the impact of economic expansion on carbon intensity. They employed factor analysis to deconstruct the measure of carbon intensity into population size, GDP consumption, energy intensity, and regional wealth. Prior studies in the literature have primarily focused on measuring carbon emissions and examining their impacts. Specifically, these studies have explored methods for quantifying the amount of carbon dioxide released by various industries [17, 18]. The exponential decomposition method is the most employed measurement technique. For example, Zhao et al. [19] used a three-layer complete decomposition method, which they condensed into two layers. This method allows us to calculate the total quantity of carbon dioxide released from the combustion of eight fuels across six distinct economic sectors. Consequently, we can conclude the amount of carbon dioxide being generated.

Researchers used the Granger causality test to investigate the correlation between population growth and carbon dioxide emissions. Their results suggest that population expansion is the main factor influencing carbon dioxide emissions, but the two variables do not show long-term cointegration [20]. Zhang et al. [21] used China's energy consumption patterns to ascertain the nation's past carbon emissions. This examination focused on eight fossil fuels, encompassing coal and coke. Government policies, urbanization, and the demographic composition of the population are major factors that contribute considerably to the release of greenhouse gases. Liu et al. [22] indicate that the carbon trading market can facilitate regional carbon reduction through structural, technological, and allocation effects. They start with the assumption that pilot programs for carbon emissions trading can be beneficial. Academics also conduct a government perspective audit. Zhang and Wang [23] argue that conducting audits of the natural resource assets owned by key municipal officials can promote energy efficiency and carbon reduction in

urban areas by maximizing the use of existing industrial capacity in line with urbanization advancements. Wang and Salman [24] conducted an empirical study using panel data from prefecture-level cities to investigate the impact of various types of urbanization on urban carbon productivity. They found that population urbanization has a varying effect on promoting urban carbon productivity, ranging from strong to weak. On the other hand, land urbanization has a diminishing effect on urban carbon productivity after reaching a certain threshold in terms of demographics. Liu et al. [25] use provincial panel data to establish empirical proof that a higher proportion of the population in their productive years leads to an increase in carbon emissions across both the production and consumption channels. Wang and Wang [26] conducted an empirical study to compare the impact of population size and consumption size on carbon emissions. The results showed that both factors have a significant influence on carbon emissions. However, the effect of consumption size on carbon emissions has a higher elasticity coefficient compared to the effect of population size.

Literature Review on the Impact of Green Finance on Carbon Emissions

Researchers, both local and international, have determined that the objective of lowering carbon emissions can be achieved through the support of financial institutions in guiding actual companies toward a path of low-carbon transformation. Some scholars recommend green financial development as a strategy to reduce unlawful production by enterprises, improve energy efficiency, and mitigate the environmental impact of greenhouse gas emissions [27]. Michaelowa et al. [28] analyzed the impact of green finance on the low-carbon economy. They discovered that the creation of green financial markets can contribute to the development of a low-carbon economy and improve progress sustainability. Wan and Sheng [29] analyze the impact of China's economic growth, financial development, and energy consumption on the environment. They find that environmental quality is not solely determined by one factor but rather influenced by a combination of factors, including economic development status, energy consumption, and others. Additionally, they conclude that financial development plays a role in reducing pollution emissions. Doğanlar et al. [30] conducted a study on Turkey and discovered that during the initial stages of economic development, rapid financial growth can lead to a reduction in energy use. Zakari et al. [31] proposed that green finance combines financial activities with efforts to safeguard the environment. Promoting the growth of the green sector is crucial by means of green finance, improving industrial structure, and advancing green technology to enhance the efficiency of energy usage. Irfan et al. [32] argue that green finance, serving as a financial mechanism for transferring environmental risks, has the potential to enhance environmental

quality. According to ElAlfy et al. [33], banks, as part of society's financial system, are obligated and accountable for incorporating environmental protection into their decision-making processes.

Bai et al. [34] used green investment and green insurance indicators to assess the level of green financial growth. An empirical investigation has shown that variables related to green investment and insurance have an impact on China's carbon dioxide emissions. There is an inverse relationship between the level of green finance development and carbon dioxide emissions. However, the extent of this influence is uncertain. Zhou et al. [35] found that green finance has a significant effect on carbon dioxide emissions and is negatively associated with levels of carbon emissions. Li et al. [36] used the entropy value approach to compute the green finance and low carbon economy development index for 30 provinces in China. Additionally, they utilized the PVAR model to examine the correlation between green finance and low carbon economies across various locations in China. Researchers found that the connection between green finance and the low-carbon economy is symbiotic in China's eastern and central regions but not in the western region. Qian et al. [37] found that the combination of financial development and environmental regulation can effectively enhance urban environmental performance without adversely affecting the city's economic performance. This approach also facilitates the transition towards a more environmentally friendly economy. Zhang et al. [38] found that implementing environmental regulations can effectively decrease carbon emissions in the secondary and tertiary sectors. Liu et al. [39] divided environmental regulations into two types: command and incentive. They examined how these regulations can promote the reduction of carbon emissions. They found that command regulations can achieve this by encouraging the adoption of cleaner manufacturing practices. In contrast, incentive regulations can promote carbon emission reduction through the encouragement of green technological innovation. Several researchers use the spatial Durbin model to investigate China's province panel data empirically. Their findings indicate that the strategic deployment of capital through green finance can enhance economic efficiency and mitigate certain forms of environmental degradation [40]. Zhang and Lu [41] confirmed the influence of China's green finance program on the growth patterns of severely polluting firms.

Can the growth of green finance significantly mitigate carbon emissions within the framework of the "dual carbon" objective? What is the precise mechanism by which it exerts an influence? What would be the functioning mechanism of this influence system? This study aims to conduct a comprehensive investigation into these themes and their interconnections, with the goal of broadening the current research on the "low-carbon economy." This research examines panel data from 30 Chinese provinces and cities to analyze how green finance affects carbon emissions. Specifically, it focuses on the impact mechanism of green finance on carbon emissions through industrial structure upgrading and technological innovation. The analysis is conducted to address the gaps in the current literature.

Theoretical Mechanism Analysis

The crucial role of money and banking in fostering economic growth is self-evident. Furthermore, the financial system, in which green financing is a vital component, has a significant impact on supporting clean energy, energy efficiency, environmental preservation, and the reduction of carbon emissions. Academics analyze the impact of green finance on the banking industry to gain a deeper understanding of how financial institutions may promote the growth of environmentally sustainable financial products. Akomea-Frimpong et al. [42] studied how green finance impacts the operational efficiency of commercial banks. Hou et al. [43] investigated the importance of financial institutions adopting green financing by considering its credibility and risk implications. Li et al. [44] found that national enterprises want to follow the Equator Fundamental Principles in order to enhance their self-esteem by being environmentally friendly. Financial institutions, mainly banks, promote the growth of environmentally friendly industries and hinder the progress of highly polluting businesses. They achieve this by increasing investments in green enterprises or offering subsidized loans to them. At the same time, they reduce investments in high-polluting enterprises and make it harder for them to obtain loans by raising interest rates.

Conversely, environmentally friendly businesses might broaden their industries and advancements due to increased availability of funding. Researchers in the field have conducted studies on pertinent problems. Bei and Wang [45] used a speculative economics theory research model as the basis for establishing green credit guarantee planning (GCGS). In addition, they used the renewable resources generated by the income tax return of the capital borrower to encourage individuals with surplus funds to actively invest in environmentally friendly financial ventures. Primarily, the act of borrowing and the additional onerous expenses associated with financing prevent highly polluting enterprises from achieving sustainable growth. The growth of environmentally friendly companies and the decline of highly polluting businesses lead to changes in the overall industrial structure of society. Green enterprises will inevitably develop novel technologies to facilitate technical advancement, implement supplementary eco-friendly technology, and diminish energy usage and emissions as they vie for clients or as a method of ensuring their existence. Likewise, companies that cause pollution will undoubtedly develop more environmentally friendly technologies to reduce carbon emissions to comply with environmental standards and

obtain financial support. Green finance can effectively reduce carbon emissions by incentivizing technological innovation.

Green finance has significant effects on carbon emissions due to its scale effect. Specifically, green finance can stimulate economic growth, leading to an expansion of the economy. This, in turn, results in increased energy consumption and higher demand from businesses, ultimately leading to a change in carbon emissions. Green financing facilitates the transition of industries towards lower carbon emissions by reallocating funds from high-polluting, high-emission, and energy-intensive sectors to sectors that protect the environment from detrimental human activities.

In addition, China has implemented various new strategies, such as green credit, green bonds, green guarantees, and green insurance, to support its green development policies. These mechanisms have been instrumental in China's endeavors to decrease carbon emissions and enhance environmental management [46]. According to Yang et al. [47], green credit can partially facilitate the optimization of industrial structures and decrease the level of carbon emissions. This is achieved by encouraging research and development investment in high-tech businesses and limiting investment in areas that consume large amounts of energy. Green guarantee regulations promote the use of environmentally friendly financing. Decrease the total financing allocated to energy-intensive businesses. However, enacting policies too quickly will have a more pronounced adverse effect on the economy [48]. Green bonds are a crucial component of green financing. Green investing programs promote the use of green bonds. These features pertain to aid and public goods, with a specific focus on promoting the green transformation of infrastructure and new energy sectors. They serve as a crucial financial instrument for the comprehensive integration of environmental sustainability and advanced technology [49]. Green bonds are a crucial component of green financing. Green investing programs promote the use of green bonds. These features pertain to aid and public goods, with a specific focus on promoting the green transformation of infrastructure and new energy sectors. They serve as a crucial financial instrument for the comprehensive integration of environmental sustainability and advanced technology.

H1: Green finance development has the potential to significantly decrease carbon emissions.

As previously shown, green finance may promote the development of eco-friendly businesses and decrease carbon emissions by altering energy consumption patterns and fostering technical advancements. Green financing provides a wide range of financial choices to small and medium-sized enterprises as well as emerging industries, enabling them to achieve their maximum capabilities. Simultaneously, strengthening new enterprises involves enhancing the efficiency of capital usage, industrial output, and factor allocation. It guarantees the economic stability of well-established

entities. Green financing facilitates the transition of the economy towards green technologies and knowledge-based economies by directing idle capital towards green sectors. The primary responsibility of finance is to optimize the allocation of resources. Green finance facilitates the allocation of money towards low-carbon and environmentally friendly firms, ensuring that financial resources are primarily directed towards green enterprises. Regarding specific practices, banks and other financial institutions will, firstly, increase the credit limits necessary for the growth of environmentally friendly and low-carbon businesses, thereby encouraging their expansion. Secondly, they will decrease the credit limits of energy-intensive and polluting enterprises, thereby urging these "three highs" enterprises to either reduce or modify their production methods. This will ultimately foster the sustainable development of the ecosystem. Consequently, it functions as a cohesive force, leading to the ongoing adaptation and improvement of the industrial framework, such as promoting a cleaner energy structure and shifting manufacturing methods from traditional to modern, mechanized, and intelligent approaches. Consequently, green finance improves the efficacy of carbon dioxide emissions by facilitating the Pareto improvement of resource allocation to the optimal state and promoting the adjustment and upgrading of industrial structure, as outlined in Hypothesis 2 of this paper.

H2: Green finance development uses industrial structure upgrading as a transmission variable, thus affecting regional carbon emissions.

Technological innovation is a crucial element in reducing emissions and can greatly contribute to the achievement of carbon neutrality [50]. Green finance may facilitate the financing of innovative initiatives and stimulate corporate innovation by enhancing capital accessibility and reducing expenses. Environmental restrictions and comprehensive information disclosure mechanisms enable the government to restrict polluting businesses while delivering accurate information to investors effectively. The reduction of carbon emissions is contingent upon technological advancements, whereas the effects of green financing on enterprises might vary [51]. Green finance plays a crucial role in driving the advancement of environmentally friendly technologies in businesses. Green innovation technology, powered by green finance, is a systematic effort that can be understood using the firm life cycle theory framework. Implementing a green financing system enables firms to reduce their energy consumption, create eco-friendly procedures according to the project's requirements, and allocate additional resources to technological advancement. Green money contributes significantly to the advancement of technical progress through various key means. Green finance can benefit businesses in three ways. Firstly, it can create a conducive financial environment that promotes innovation. Secondly, it can enhance businesses' access to capital by providing special funds from the government and banks. Lastly,

it can mitigate the risks associated with innovation by offering a capital guarantee for green science and technology. Furthermore, green financing has the potential to alleviate the risks posed to a company's technological advancement by unexpected and highly disruptive occurrences, unpredictable market fluctuations, and other uncertain factors. Consequently, this study puts forward hypothesis 3 considering this information.

H3: Green financial development uses technological innovation as a transmission variable, which subsequently influences regional carbon emissions.

Although China's overall carbon emissions have increased in recent years, the varying development rates of different regions within the country result in certain regions emitting less carbon than others. This statement holds in terms of both total emissions and emissions relative to GDP. The implementation of green credit and the reduction of energy consumption in low-carbon development regions will significantly contribute to the economic growth of the region, with a notable "financial accelerator" effect. A study conducted in the East, Middle East, and West regions revealed a decline in carbon emissions growth in all three regions. However, the influence of green credit on industrial structure improvement varies. Research findings indicate that the impact of green credit on the development of the industrial structure differs throughout the Eastern, Central, and Western regions [52]. So, this paper proposes the hypothesis 4.

H4: Heterogeneity in the impact of regional green finance development on carbon emissions.

Research Design

Variables Description

Dependent Variables: Carbon Emissions

Since carbon emissions still need to be directly quantified and the primary source of carbon emissions is fossil fuel combustion, this study utilizes the factor decomposition approach to estimate carbon emissions. The method is outlined as follows:

$$C_{it} = \alpha C_{io} + \gamma C_{ig}$$

Where C_{it} is the total carbon emissions of province i, C_{ic} is the annual consumption of coal in province i, C_{iO} is the annual consumption of oil in province i and C_{ig} is the annual consumption of natural gas in province i. α, β, and γ are the conversion coefficients of carbon emissions from the combustion of the three types of fuels. In this way, the carbon emissions of each province can be obtained and then divided by the corresponding population of each province each year to obtain the per capita carbon emissions. To eliminate the effect of heteroscedasticity, the per capita carbon emissions take the natural logarithm [53, 54].

Independent Variable: Green Finance

An official or authoritative indicator system is necessary for evaluating green financing. China's green financial products mainly consist of green loans, despite the country's significant progress in the creation of green bonds and carbon finance. Nevertheless, the indicators can only provide limited information about the progress of green finance growth because a comprehensive and systematic evaluation is required. The "Guiding Opinions on Building a Green Financial System," issued by seven ministries, including the People's Bank of China, states that green finance should encompass green credit, green investment, and green insurance. Among these, green credit and green investment are considered the most crucial aspects.

Consequently, this study opts to construct a comprehensive index utilizing four dimensions, green credit, green insurance, green investment, and green aid, to more accurately measure the level of growth of regional green finance in our country. Green credit can partially symbolize environmentally friendly financial policies. The magnitude of agricultural insurance within the realm of green insurance can indicate the progress of green insurance. Green investment can serve as an indicator of the financial sector's influence on sustainable development. Lastly, green support can represent the government's backing of green economic growth. This article uses the entropy approach to construct the indicators.

Control Variables

Previous research indicates that carbon emissions are influenced mainly by factors such as individuals' standard of living, energy consumption patterns, urban population density, and government policies and actions. In this study, the researchers have incorporated the following control variables to address the issues of heteroscedasticity and autocorrelation: Per capita, regional gross domestic product (GDP) represents the economic size (GDP), and the significant proportion of coal-fired power generation in China demonstrates that coal is the primary source of fossil fuel in the country. Coal has a significantly lower heat value and higher pollution levels compared to cleaner fuels such as natural gas or hydrogen. Coal is considered polluting due to its content of sulfur, nitrogen, and other harmful components. The urbanization rate (urb) refers to the proportion of total energy consumption derived from coal in areas experiencing significant urbanization. Such places are characterized by many laborers and a wealth of innovative skills. The influx of highly trained labor and fresh perspectives not only contributes to the prosperity of cities but also stimulates innovation and accelerates the transition towards a low-carbon

economic growth model, mainly when supported by robust policies.

However, urbanization also poses a potential threat of increasing pollution of natural resources and energy use. This study examines the level of urbanization, measured as the proportion of the total urban population at the end of the year. It also considers the impact of openness to international trade and development on the amount of carbon dioxide emissions in the atmosphere. This statistic indicates the aggregate worth of imports and exports expressed as a proportion of the regional Gross Domestic Product (GDP). By applying the standard annual exchange rate, the monetary value of imports and exports is converted into Chinese Yuan.

Mediating Variables

This study investigates the impact of green finance on carbon emissions by selecting industrial structure upgrading and technological innovation as intermediary factors based on prior theoretical analysis. The fundamental principle of green development is to encourage the optimization of the industrial structure to decrease carbon emissions and enhance the index for upgrading the industrial structure. This article demonstrates the impact of technical progress on energy consumption efficiency and pollutant emissions by comparing the percentage contributions of tertiary and secondary industries to GDP. Technological innovation is an essential element of the plan since green business and market expansion stimulate technical improvement. An indicator of technical progress can be measured by the frequency at which patents related to environmental protection are approved.

Modelling Design

Benchmark Regression Model

In addition to enhancing the estimator's validity, the panel data model offers a more extensive sample capacity than the essential time series and can resolve the issue of multicollinearity among variables. Additionally, the panel data model is a more credible alternative to the cross-sectional data model due to the elimination of the estimated bias introduced by ordinary least squares. Therefore, this study constructs a panel data model by utilizing data on carbon dioxide and green money from 30 Chinese regions. Nevertheless, this article also integrates supplementary elements, such as economic development, into the model as control variables to reduce the model estimation error by nullifying the error generated by other unaccounted-for components. The specific benchmark regression model of this paper is as follows: The natural logarithm of the explanatory variables is employed to adjust for heteroskedasticity:

$$Ce_{it} = \beta_0 + \beta_1 Fin_{it} + \beta_2 Controls_{it} + \mu_i + \varepsilon_{it}$$
(1)

where subscripts i and t denote regions and years, respectively, the explanatory variable Ce_{it} denotes the carbon emissions of the i region in year t, the explanatory variable Fin_{it} denotes the level of green finance in the i region in year t, $Controls_{it}$ is a control variable, μ_i is a region fixed effect, and ε_{it} is a possible random error term.

Mediation Model

China's carbon emissions are influenced by the enhancement of its industrial structure and technological progress, as demonstrated in the previous section. As a result, the subsequent mediation effect model is established [55-57].

$$Med_{it} = \beta_0 + \beta_1 Fin_{it} + \beta_2 Controls_{it} + \mu_i + \varepsilon_{it}$$
(2)

$$Ce_{it} = \beta_0 + \beta_1 Med_{it} + \beta_2 Controls_{it} + \mu_i + \varepsilon_{it}$$
(3)

Equation (2) shows the effect of the financial index on the mediating variable, where the mediating variable (*Med*) includes industrial structure upgrading (*Str$_{it}$*) and technological innovation (*Tec$_{it}$*), and equation (3) shows the green finance, the mediating variable put into the same model to estimate the effect on the explanatory variables.

Data Source

Due to data availability and timeliness considerations, this study utilizes panel data from 30 Chinese provinces for 2011-2021, excluding Hong Kong, Macao, Taiwan, and the Tibet Autonomous Region. Most statistical data are sourced from various statistical yearbooks. Energy consumption data by type and subsector come from the China Energy Statistical Yearbook. Data on industrial processes and product use are from the China Industrial Statistical Yearbook. Agricultural, forestry, and land-use data are obtained from the China Agricultural, Animal Husbandry, and Forestry and Grassland Statistical Yearbooks. Waste disposal statistics are sourced from the China Agricultural, Livestock, and Forestry and Grassland Statistical Yearbooks and the China Environmental Statistics Yearbook. Data on purchased energy, heating, and cooling are from the China Energy Statistics Yearbook. Emission factors are derived from published recommendations for Provincial Greenhouse Gas Emission Inventories and government-released carbon emission inventories.

Green finance data come from the websites of organizations like the Bureau of Statistics, the Ministry of Science and Technology, and the People's Bank of China, alongside various statistical yearbooks, such as the China Science and Technology, Financial, Industrial,

Table 1. Results of variable smoothness test.

Variables	llc test	p-value	steady or not
Ce	-6.4567***	0.0000	Yes
Fin	-7.1342***	0.0000	Yes
rgdp	-5.4567***	0.0000	Yes
engj	-3.2365***	0.0000	Yes
urb	-2.5552***	0.0000	Yes
gov	-9.5467***	0.0000	Yes

Note: *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

and Tertiary Industry Statistical Yearbooks. Control variables are mainly sourced from the China Statistical Yearbook. The National Intellectual Property Database houses information about a newly submitted patent application for eco-friendly technology. Interpolation techniques are used to fill in any missing data points as required, and province statistical yearbooks are consulted for further information. Before incorporating data into the model, it is necessary to validate heteroscedasticity.

Empirical Results and Analyses

Benchmark Regression Results

Panel Smoothness Test

Panel regression analysis requires the use of continuous data that is free from any interruptions. This study investigates the concept of smoothness by employing the LLC panel unit root test. This study used a logarithmic adjustment on non-smooth variables prior to assessing their smoothness. Table 1 shows that by converting the non-smooth variables into logarithms, all of them successfully passed the unit root test with a significance level of 5%. This enables the application of a panel model for analysis in this article.

Analysis of Baseline Regression Results

This paper adopts the panel fixed effect and random model for regression estimation after passing the panel unit root test. Table 2 presents the outcomes of the fixed effect model and random effect regression. The fixed effect model results are shown in column (1), while the random effect regression results are displayed in column (2). The findings indicate that green finance has a considerable impact on reducing carbon emissions. The regression analysis shows that there is a robust negative relationship between green finance development and carbon emissions. This relationship is statistically significant at the 1% level, indicating a high level of confidence in the results. This paper elucidates the reason

behind this phenomenon by highlighting that following the implementation of reform and opening policies, our nation has attracted industries that are characterized by high pollution, high energy consumption, and low-value addition. This is primarily due to the availability of a large and inexpensive labor force.

Additionally, a significant portion of the financial resources of our country's financial institutions is directed towards heavy industries and sectors that require substantial capital investment. The exponential expansion of these sectors has bolstered China's economic advancement, although it has concurrently resulted in significant environmental degradation and the issue of overproduction capacity. Following the implementation of the "supply-side" reform, both the government and the general population started to show

Table 2. Benchmark model regression results.

	Ce (1)	Ce (2)
Fin	-0.2813*** (-3.14)	-0.2113*** (-2.87)
rgdp	0.7811* (1.98)	0.7121* (1.89)
engj	0.2313** (2.97)	0.0912** (2.67)
urb	-0.0594 (-1.32)	-0.0229 (-1.01)
open	-0.0623** (-2.53)	-0.0724 (-2.61)
regional effects	Yes	Yes
time Effects	Yes	Yes
_cons	10.7125*** (4.45)	-12.2111*** (-4.52)
N	30	30
R^2	0.8572	0.5723

Note: 1. Values in parentheses are t-values; 2. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively; 3. All regressions are clustered at the county level as the clustering variable for robust standard errors. The same applies to the table below unless otherwise specified.

Table 3. Regression results of industrial structure upgrading.

v	Str (1)	Ce (2)
Fin	0.1131* (1.89)	-0.1621** (-2.38)
Str		-0.0934** (-2.05)
Control Variables	Yes	Yes
Regional effect	Yes	Yes
Time effect	Yes	Yes
_cons	20.536*** (4.74)	-9.576*** (-4.25)
N	30	30
R^2	0.8235	0.6768

Table 4. Technological innovation regression results.

	Str (1)	Ce (2)
Fin	0.0892* (1.95)	-0.1731** (-2.59)
Tec		-0.1134** (-2.19)
Control Variables	Yes	Yes
Regional effect	Yes	Yes
Time effect	Yes	Yes
_cons	13.526** (11.36)	-8.546* (-10.15)
N	30	30
R^2	0.8735	0.5788

increased concern towards environmental matters. This was particularly evident in the steel industry, where there was a process of consolidation and restriction of companies that had significant levels of emissions and pollution. The green finance sector has experienced rapid growth due to the pressing necessity to redistribute financial resources. Financial institutions have redirected resources, leading to a reduction in the development of highly polluting corporations and an increase in the expansion of environmentally friendly organizations. Furthermore, the demand for green products is steadily growing as the public becomes increasingly aware of the importance of environmental conservation. This trend is putting pressure on high-polluting items, leading to a reduction in China's carbon emissions.

The level of economic development is one of the control factors that has little impact on reducing carbon emissions. For example, for every unit increase in China's economic development, carbon emissions increase by 0.78 percentage points. This is because economic development requires the establishment of

numerous factories and extensive industrial construction, resulting in a substantial amount of pollution despite improvements in the economy. However, increasing the level of economic development would have a positive impact on emissions. The economy's improvement, despite trade growth, energy consumption, and government intervention failing to effectively reduce carbon emissions and leading to increased pollution, highlights the suitability of our country's high-quality development strategy for our development path.

The coefficient indicates that the energy consumption structure has a statistically significant positive impact on greenhouse gas emissions. According to this data, it is possible to achieve a substantial reduction in carbon emissions by optimizing the structure of energy use and reducing dependence on coal resources. Despite the stability, adjustability, and lower technical challenges in power generation, the extensive utilization of coal in thermal power has led to substantial pollution in China. This includes the formation of haze, heightened carbon emissions, and various other environmental issues. China's significant coal production exacerbates these problems. Hence, reducing coal usage and allocating resources towards coal purification technologies, promoting the advancement of hydrogen energy, wind power, and other clean energy sources, and optimizing the energy structure are all feasible alternatives for mitigating carbon emissions.

The measured coefficient of the amount of urbanization is negative, indicating that urbanization and government investment do not have a substantial impact on reducing carbon emissions. Although the movement of farmers to urban areas can contribute to the growth of animal husbandry and breeding in the primary industry, leading to a reduction in carbon emissions, additional measures are necessary to achieve a substantial effect. Given the detrimental nature of the expected coefficient of openness to global commerce, China will likely reduce carbon emissions by utilizing more imported advanced technology and engaging in broader international trade.

Analysis of Mediation Mechanisms

The results mentioned above illustrate the significant decrease in carbon emissions that may be achieved through the development of green finance. Next, we will examine the potential of green financing in reducing carbon emissions. The regression results displayed in Tables 3 and 4 indicate a significant positive impact of green finance on both industrial structure upgrading and technological innovation. Additionally, the regression coefficients for industrial structure upgrading and technological innovation are both substantial and statistically significant. This research employs an intermediary model, where industrial structure upgrading and technological innovation are used as intermediate variables. The fixed effect model is utilized to do regression analysis. These two

Table 5. Systematic GMM regression of green finance on carbon emissions.

Independent Variables	Coefficient	t-value	P-value
L1. Ce	0.6523	21.23	0.000
Fin	-0.1341	-3.37	0.030
control variable	control	control	control
regional effect	control	control	control
time effect	control	control	control
constant term	0.3458	2.96	0.040
AR (1) test	-2.73(0.007)		
AR (2) test	7.74(0.525)		
Sargan's test	23.16(0.061)		

pieces of evidence support hypotheses 2 and 3 of this research, which propose that green finance can mitigate carbon emissions by influencing the two intermediary variables of industrial structure upgrading and technical innovation. At a significance level of 5%, the coefficient of industrial structure on carbon emissions is calculated to be -0.0934.

Based on the analysis provided, it is evident that upgrading industrial structure plays a crucial role in the direct impact of green finance on carbon emissions. Considering the current state of social development, the region can be modified by upgrading its industrial structure by implementing green financial policies. This will lead to a significant reduction in carbon emissions. For instance, the northeast region, previously dominated by high-energy consumption and heavy industries with high emissions, has witnessed increased support from financial institutions for clean energy, energy efficiency, and other environmentally friendly sectors due to implementing green economic policies. Thanks to the consistent influx of funding, these ecologically friendly sectors have experienced rapid growth while promoting the optimization and advancement of the corresponding industrial network. Traditional industries with high pollution and energy consumption face competition and the dual impact of environmental protection policies. As a result, they are gradually implementing technological transformation and upgrading to improve energy efficiency and reduce carbon emissions.

Furthermore, the estimated coefficient of technological innovation on carbon emissions is -0.1134, which is statistically significant at the 5% level. This suggests that technological innovation has a substantial and successful impact on reducing carbon emissions. Green finance offers robust backing for the expansion of environmentally conscious firms, enabling them to surmount financial obstacles in sectors including green technology, renewable energy, and sustainable materials. It empowers them to generate and disseminate a more significant number of environmentally friendly products and services. Furthermore, it imposes restrictions on the

financial resources accessible to heavily polluting and carbon-emitting enterprises, driving them to undertake a technological overhaul and enhance their operations to minimize pollution and carbon emissions.

For example, as a leader in domestic green finance, the Industrial Bank, through green financial innovation, provides financial support for green projects and actively promotes technological innovation and introduction. Through cooperation with domestic and foreign environmental protection agencies, Industrial Bank has built a green financial service platform to provide comprehensive services for green and low-carbon projects. For example, after obtaining green credit support, a new energy enterprise supported by the Industrial Bank successfully introduced advanced clean energy technology, significantly improving energy conversion efficiency and reducing production costs and carbon emissions. This case demonstrates how green finance can achieve carbon emission reduction targets through technological innovation in upgrading industrial structures.

Robustness and Endogeneity Tests

This paper demonstrates the robustness of the regression results by substituting the conventional panel regression model, endogeneity test, and heterogeneity test with the systematic GMM model, thereby further verifying the effect of green finance on carbon emissions. The results of the specific tests are presented below.

System GMM Model Testing

The current year's recorded emissions indicate the previous year's circumstances, considering the time needed for carbon emissions adjustments. This article examines the feedback loop problem by incorporating the prior period's emissions into the model. The result is developing a dynamic panel model displayed in Table 5.

Table 6. Endogeneity test of green finance development on carbon emissions.

Independent Variables	Coefficient	t-value	P-value
L1. Fin	-0.0531	-1.69	0.082
L2. Fin	-0.0324	-0.48	0.136
control variable	control	control	control
regional effect	control	control	control
time effect	control	control	control
constant term	3.2314	0.93	0.090

The regression results indicate that the autocorrelation test of the GMM perturbation term in this study provides evidence in favor of the null hypothesis that the random perturbation term of the GMM model does not exhibit autocorrelation. Furthermore, choosing the initial order of the lag is considered suitable. In addition, the p-value of the over-identification test (Sargan) is 0.061, which is above the significance limit of 0.05. This implies that we cannot dismiss the original hypothesis, stating that "all instrumental variables are exogenous." Hence, all the instrumental factors included in this investigation are deemed legitimate. The dynamic panel model suggested in this research is generally valid.

Table 5 shows that the P-value of carbon dioxide (L1. Ce) in the lagged first order is 0.000, indicating a significant relationship at the 1% significance level. Furthermore, the regression coefficient is positive. The current carbon dioxide emission intensity and the previous period have a strong positive association. Carbon dioxide emission intensity undergoes a dynamic adjustment process. The coefficient for green financial development (Fin) level is -0.1341. The P value of 0.030 suggests that, at a significance level of 5%, an increase in the level of green financial development in the current period can effectively restrain the rise in carbon emissions. This finding confirms hypothesis 1 of the paper and supports the credibility of the baseline regression model.

Endogeneity Test

There is a potential causal relationship between green funding and carbon emissions and the possibility of unaccounted factors, which might result in endogeneity and inconsistency when estimating parameters. This research utilizes systematic moment estimation to determine if the model is endogenous. It includes the lagged first and second periods of green financing as instrumental variables in the model. According to the data presented in Table 6, green money can reduce carbon emissions, regardless of whether it is delayed in the first or second order. Therefore, the findings of the benchmark regression in this work remain reliable.

Heterogeneity Analysis

China's uneven economic growth has led to a significant disparity in economic development, green finance, and carbon emissions between Eastern and Western China. The regression results are presented in Table 7. The study divides the sample into three regions, East, Middle, and West, to investigate whether there are differences in the impact of green funding on carbon emissions across these regions.

Table 7 reveals that green finance significantly reduces carbon emissions in both the eastern and western regions, with statistical significance at the 5% level. However, in the central region, green finance appears to increase carbon emissions, with statistical significance at

Table 7. Impact of green finance on carbon emissions by region.

	Eastern part (1)	middle part (2)	western part (3)
Fin	-0.0321** (-2.91)	0.0914* (1.63)	-0.0963** (-2.73)
control variable	Yes	Yes	Yes
regional effect	Yes	Yes	Yes
time effect	Yes	Yes	Yes
_cons	-3.2356 (-0.79)	7.5689 (0.29)	12.4344* (1.97)
N	30	30	30
R^2	0.6789	0.5783	0.8421

the 10% level. This indicates regional differences in the impact of green finance on carbon emissions, supporting hypothesis H4. The eastern region's economic and technological advancement, robust financial market, and strong green policies likely drive the observed reduction in emissions, as green finance there promotes industrial restructuring, technical innovation, and clean technology development.

In contrast, the central region is in a transitional economic phase, with a less developed financial industry and slower growth in green finance, leading to increased carbon emissions due to its heavy industrial structure and higher energy demand. The western region, with its unique resources and environment, has become a key area for green finance, particularly in wind power and photovoltaic industries. Green finance supports these sectors through green credit, bonds, and other financial instruments, optimizing the energy structure and reducing emissions. Thus, the impact of green finance on carbon emissions varies by region, highlighting the need for region-specific policies to foster sustainable green finance growth and reduce emissions.

Summary

Conclusions and Policy Recommendations

China's rapid expansion of green financing can significantly facilitate the green and low-carbon transformation of its economy. This study utilizes panel data from 30 Chinese provinces and localities to objectively evaluate the impact of green funding on carbon emissions. The conclusions of this study are derived from the model and the data it produces. After improvements in both the "supply side" and the "demand side," green finance in China has made tremendous progress, resulting in a substantial reduction in the rate of carbon emissions in the country. This conclusion holds even after conducting a series of rigorous tests to ensure its validity. Furthermore, the research presented in this study demonstrates that the allocation of green financing has a minimal impact on China's carbon emissions. Moreover, this article asserts that green money primarily impacts carbon emissions by enhancing industrial infrastructure and promoting technological advancements aimed at reducing carbon emissions. Furthermore, the impact of green finance on China's carbon emissions is contingent upon the specific region. The expansion of green financing can significantly reduce carbon emissions in both Eastern and Western regions. The impact of green finance on carbon emissions in the central region has yet to be clearly observed. Consequently, this report presents the following policy recommendations based on its findings:

First, it is essential to construct a comprehensive green finance structure and effectively implement the concept of green development. Green finance has numerous advantages, such as improving industrial structure and energy utilization, fostering technological innovation, and decreasing carbon emission intensity. While green credit is seeing significant growth in China, the central and western regions of the country must increase their investment in green capital, as growth is anticipated nationwide. China's green insurance, bonds, green funds, and carbon finance were all established after the introduction of the country's green credit. Nevertheless, the government must provide robust support for the expansion of these financial instruments to develop a fully operational green financial system. The current green credit balance of central banks in China has been disclosed; however, acquiring comparable data for the provinces takes more work. The financial sector regulator is tasked with establishing a set of green credit evaluation indices for banks and imposing penalties on banks that fail to meet the standards. Information about green credit and other green financial instruments utilized by local governments at the provincial level should be publicly disclosed to incentivize banking institutions to spearhead the development of environmentally sustainable loan products. To enhance its supervision of environmentally friendly financial products, such as green credit and bonds, China should establish a comprehensive statistical framework for these instruments. Commercial banks should provide financial support for enterprises that actively promote the development of green technologies while also imposing higher financing fees on businesses that persist in growing their carbon emissions. Greater focus should be placed on the disclosure of Environmental, Social, and Governance (ESG) reports to the capital market. Additionally, corporations should be compelled to publicly reveal their overall strategies for growth in the green sector. Colleges and universities should enhance their dedication to continuous research on environmentally friendly technologies and the tangible implementation of their discoveries. Engaging in research and development of green technology enables firms to reduce their carbon emissions and promote sustainable growth in the long run.

Second, accelerate the pace of advancement towards a more environmentally sustainable financial system. The empirical evidence suggests that advancements in green financing can significantly decrease carbon dioxide emissions. Consequently, China should continue to enhance the framework for the development of green finance, engage in exploration and innovation in this domain, and further expand the scope of green finance. Here are specific actions that can be implemented: First, the green finance policy framework should be enhanced to bolster efforts to reduce carbon emissions. This may be achieved by implementing laws and other regulatory measures to oversee the green finance market. Furthermore, it is crucial to build a regulatory coordination mechanism among pilot regions and develop common standards for regulating green finance. Second, there is a need for enhancement in the green financial standard system. Revise and strengthen

the rules for recognizing environmentally friendly financial practices, consistently boost the development of the system for disclosing information, and facilitate the sharing of detailed data on green finance and carbon dioxide emissions. Third, an extensive and comprehensive carbon market trading system should be established to facilitate the advancement of green finance. Efficiently advocate for the development of innovative carbon financial products and actively support the nationwide implementation of carbon-suitable pledge loans, with a particular emphasis on carbon quota pledge loans. Enhance the carbon trading market system by actively advancing carbon bonds, carbon funds, carbon securities, and other carbon financial market products. In addition, it facilitates the establishment of carbon forward, carbon futures, carbon options, and other derivative trading markets. Fourth, there should be an increase in financial assistance to reduce emissions. Promote and incentivize financial institutions to increase their investments in enterprise carbon reduction while also establishing a robust framework to encourage compliance.

Third, it is crucial to customize the planning for green financial growth according to the specific circumstances of the local area. Given the varying industrial characteristics and energy consumption patterns across China's eastern, central, and western regions, it is essential to strategically plan the development of green finance at a sub-regional level. This entails emphasizing local characteristics and designing green finance initiatives that align with the transformation and modernization of industries, as well as the reduction of entropy. Concurrently, explore the establishment of a regional coordination mechanism to facilitate the advancement of environmentally friendly financial initiatives. Enhance regional connections, foster regional exchanges, and integrate green finance with inter-regional collaboration, joint construction, industrial transfer, and other economic endeavors to expedite the progress of green financial development in China. Policymakers should enhance the examination of the spatial spillover impact of green finance. Prior to formulating the region's optimal green development strategy, it is essential to evaluate the developmental attributes of various economic zones carefully. The economically advanced provinces in the eastern region should sustain their elevated level of green financial development and actively cooperate with neighboring provinces to establish green credit and other green financial instruments. The economically disadvantaged areas of the central and western parts of the country should learn from the successful execution of green economic development in other financially prosperous regions. They should also improve cooperation in the realm of sustainable finance. The green economy should have a ripple effect, encouraging provinces to collaborate to support each other, explore methods, and advance together. The eastern, central, and western regions need to enhance collaboration and communication in green

finance, expedite the establishment of a unified national green finance market that is efficient, standardized, competitive, and open, establish consistent market regulations for green finance throughout the country, and facilitate the larger-scale circulation of green resources.

Research Limitations and Future Perspectives

This study empirically examines the impact and mechanisms of green finance on carbon emissions based on an ordinary panel model, using panel data from 30 Chinese provinces (2011-2021), contributing to existing theory and guiding policymakers. However, it has several limitations: Firstly, the scope of the study needs to be deepened. This study is mainly limited to provincial-level data. Future research could refine this by analyzing prefecture or county-level data to explore how green finance can better drive carbon reduction mechanisms and provide location-specific policy recommendations. Additionally, this study only analyzes current data; future research could use time series models to forecast green finance and carbon emissions trends, leading to more precise recommendations. Thirdly, the relationship between green finance and carbon emissions is complex, with potential spillover effects due to geographic differences and neighboring regions. This study does not explore these spatial influences, suggesting a need for further research in this area. Lastly, due to China's vast and diverse landscape, the study offers macro-level policy recommendations, which may face challenges in regional implementation. Future research should adopt a regional approach to provide more targeted, region-specific development recommendations.

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Conflict of Interest

The authors declare no conflict of interest.

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