Does Green Finance Influence CO_2 to Achieve Carbon Neutrality in China?

Xuemeng Liu, Fengtao Guang* and Yating Deng

Research Center of Resource and Environmental Economics, School of Economics and Management, China University of Geosciences, 430074, Wuhan, China

Abstract: The advancement of green finance plays a pivotal role in filling the financing gap of carbon neutrality and promote the low-carbon transformation. However, there are relatively few empirical studies directly analyzing the nexus of green finance and carbon emission intensity, as well as their impact mechanism, nonlinear effect and spatial effect. Therefore, based on the panel data of 30 provinces and cities in China from 2007 to 2019, using System GMM (SYS-GMM), KHB, panel threshold model and spatial Durbin model (SDM), this paper investigates the effect and impact mechanisms of green finance on carbon emission (CO_2). The results show that green finance significantly reduces CO_2 intensity, which is still valid after a series of robustness tests. Second, the CO_2 emission reduction effect of green finance exert asymmetric effects between financially developed and financially underdeveloped regions, industrially developed and industrially underdeveloped regions. Third, green finance mainly affects carbon emission intensity through factors such as FDI, energy consumption scale, energy intensity, green technology innovation, industrial structure upgrading and energy structure. Finally, CO_2 emission reduction effect of green finance demonstrates nonlinear characteristics with diminishing marginal effects and spatial effects. Drawing upon these findings, this paper puts forward specific proposals on developing and innovating green finance to promote CO2 emission reduction and realize carbon neutrality.

Keywords: Green finance, Carbon emission intensity, Nonlinear effects, Spatial spillover effects, China.

1. INTRODUCTION

Climate change affects the sustainable development of human society [1]. In recent years, extreme weather events such as extreme high temperatures, severe droughts and floods have made the issue of climate change the focus of all sectors of society. Therefore, countries all over the world have set carbon neutrality goals. As a responsible large country, China has put forward the goal of "30.60 carbon peak and carbon neutrality". Compared with developed countries, China is facing unprecedented pressure on emission reduction to achieve carbon neutrality in such a short time. The realization of carbon neutrality is not only related to the reform of energy and industrial structure, but also needs abundant financial support to promote the green transformation of many aspects of the economy and society. So, finance is the key element to achieve the goal of carbon neutrality. According to the calculation of the International Energy Agency, about $110 trillion needs to be invested to achieve global carbon neutrality [2]. As for China, Chinese authorities have estimated that an investment exceeding 100 trillion RMB will be required over the next four decades to achieve carbon neutrality [3]. However, the contribution rate of current financial investment is merely about 15%, and the rest of the capital gap should be filled by financial means. The development and innovation of green finance can help to fill the financing gap to achieve carbon neutrality. Does China's current rapid development of green finance effectively promote carbon emission reduction to achieve carbon neutrality? If this effect is confirmed, what is the emission reduction path? The answers to these questions cannot only provide references for China to optimize green financial policy design and achieve carbon neutrality, but also provide some references for other countries in the world.

Concerning the connotation of green finance, Salazar [4] reckoned that green finance is a financial service that promotes the development of environmental industry through business innovation. Labatt *et al*. [5] believed that green finance is a market-based financial product provided by financial institutions, including environmental protection factors. Taghizadeh *et al*. [6] documented that green finance is the product of the financial industry using financial leverage to select the environmental protection industry as the key support object, which can provide corresponding concessions in terms of capital acquisition, credit extension, interest rate and term. We can see that green finance is the product of a combination of financial industry and environmental industry. It is the inevitable result of financial institutions to avoid environmental risks and develop environmental businesses. According to existing literature, this paper provides the connotation of green finance, that is, green finance is a series of financial

*Address correspondence to this author at the Research Center of Resource and Environmental Economics, School of Economics and Management, China University of Geosciences, 430074, Wuhan, China;
E-mail: Guangft@126.com

E-ISSN: 2311-8741/23

activities carried out from the perspective of coping with climate change, improving resources and environment, and utilizing clean energy.

As for the study of green finance and carbon emissions, this paper first analyzes the overall research situation in this field by using the bibliometric analysis approach. In Figure **1**., we can see that although the number of papers published in this field generally shows an exponential growth trend, the total number of papers published is relatively small, indicating that there is relatively limited literature that directly explores the nexus of green finance and carbon emissions. The research status of highly cited papers, hot papers and review papers is shown in Appendix **A**. We can see that there are few empirical types of papers directly studying the relationship between green finance and carbon emissions. In addition, through reviewing literature systematically, it is found that only a few studies analyze the relationship between green finance and green low-carbon development. For example, Ren *et al*. [7] constructed the green finance development index and explored the relationship between the development level of green finance, non-fossil energy consumption and carbon intensity. They found that green finance development can help reduce carbon intensity. Zhang *et al*. [8], and Zhou *et al*. [9] asserted that green finance policies significantly decreased the interest-bearing debt financing and long-term debt of heavy polluting enterprises, increased the debt financing cost, and decreased the new investment significantly. Hu *et al*. [10] believed that if the market mechanism of green finance is reasonable, it can guide the flow of funds to the field of green development and promote the optimal allocation of resources. In addition, effective green financial policies can solve the problem of moral hazard. Through reviewing the previous research, it is found that most of the literature predominantly analyzes the energy saving and emission reduction effect of green finance from the perspective of green finance policy, or relies on a single indicator, such as the green credit indicator, as a proxy variable for green finance. However, there is a noticeable absence of comprehensive empirical studies that examine the emission reduction effect of green finance while building a multi-dimensional comprehensive evaluation index system. Moreover, few literature has delved into the spatial and nonlinear effects of green finance on carbon emissions, as well as the impact mechanism.

Therefore, within the framework of green finance in China, this paper constructs a comprehensive evaluation index system of green finance at the provincial level, grounded in scientific and rational principles. On this basis, this paper empirically investigates the impact of green finance on carbon emission intensity and its mechanism. Our results reveal that green finance demonstrates a carbon emission reduction effect, and the effect manifests asymmetrically between financially developed and financially underdeveloped regions, industrially developed and industrially underdeveloped regions. What's more, the emission reduction effect of green finance exhibits a nonlinear trait characterized by diminishing marginal effect, coupled with spatial spillover effects. Finally, it is worth noting that green finance mainly affects carbon emission intensity through FDI, energy consumption scale, energy intensity, green technology innovation, industrial structure upgrading, and energy structure.

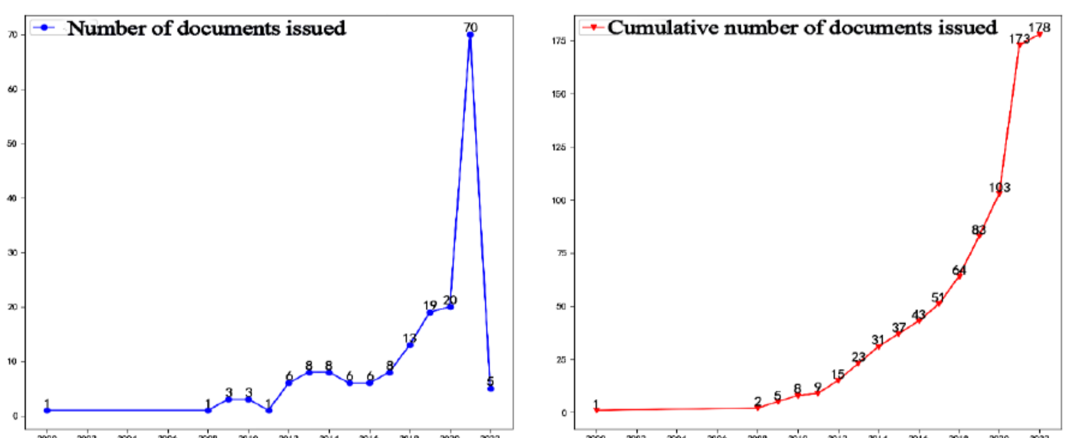

Figure 1: Chronological distribution map and chronological cumulative distribution map of international journal documents[1#].

[1#] Because the time of document retrieval is at the beginning of 2022, the number of documents counted in 2022 is incomplete and cannot represent the number of documents issued in the whole year of 2022. Therefore, the downward trend of document issuance trend in this stage from 2020 to 2022 in the chronological distribution map cannot represent the actual document issuance trend in this stage.

The contributions of this paper are as follows: first, this study constructs a comprehensive evaluation index system for green finance at the provincial level. This system encompasses various dimensions, including green credit, green securities, green insurance, green investment and government support. And the utilization of factor analysis ensures a scientifically grounded and rational measurement approach. Second, it enriches empirical research on green finance and carbon emissions. While existing literature tends to focus on the direct effects of green finance on carbon emissions, this paper goes beyond that by not only analyzing the mechanisms underlying this impact but also delving into the nonlinear and spatial spillover effects of green finance on carbon emissions. Finally, this study enhances the body of knowledge in the realm of green finance. The research findings presented furnish new empirical evidence and lend support for the advancement of contemporary green financial policies. Beyond informing China's green financial policy developments, it also offers valuable insights for the enhancement of green financial policies on a global scale, benefiting policymakers worldwide.

The rest of this paper is structured as follows. Based on the literature review, the second part puts forward the research hypothesis. The third part introduces the methods and data. The fourth part presents the research results and discussion. The fifth part provides policy suggestions of the research conclusions.

2. LITERATURE REVIEW AND RESEARCH HYPOTHESIS

2.1. Direct Effect of Green Finance on Carbon Emission Intensity

From the perspective of the three functions inherent to green finance, we first examine the market pricing function's impact on carbon emissions, as depicted in Figure **2**. Carbon emissions belong to global public goods. The rapid expansion of global green finance serves as a catalyst for cross-temporal and cross-regional financial service provision [11]. In doing so, it effectively alleviates the problem of information asymmetry, facilitates the demanders and suppliers to obtain sufficient information, boosts their willingness to buy or sell, forms an equilibrium price in the repeated game, and promotes the development of carbon trading, thereby influencing carbon emissions [12]. Second, the resource allocation function of green finance affects carbon emissions. By reducing the financing funds for high-emission enterprises and shortening the credit period, green finance promotes the flow of financial resources to low-carbon and environmental protection enterprises and optimize sthe allocation of financial resources [13], thus reducing CO_2 emission. Finally, the risk management function of green finance affects carbon emissions. Green finance reduces potential investment risks in the process of low-carbon economic transformation by carrying out environmental and climate risk stress tests [14], which further promotes the development of a low-carbon economy.

In terms of transmission mechanisms, first, at the macro level, green finance improves the quality of investment and facilitates the development of new energy development, low-carbon new infrastructure and digital economy [15-16]. In addition, with the establishment of international green finance standards, it has promoted the low-carbon transformation of international trade, and avoided the pollution shelter effect, thus contributing to carbon emission reduction. Second, at the micro level, on the one hand, green finance plays a pivotal role on the supply side. It accomplishes this by leveraging the information disclosure mechanism to discern between low-carbon, high-carbon, and negative carbon industries. Subsequently, it strategically channels funding, offers tailored financial products, and extends financing services to nurture the growth of low-carbon and negative carbon industries, as well as the advancement of low-carbon technologies. Additionally, the innovation of green financial products and services provides accurate and efficient financing support for the development of carbon capture and carbon storage technology, thus promoting the development of negative carbon industry. On the other hand, on the demand side, the proposal of the dual carbon goal has attracted great attention from all walks of life. Residents' low-carbon awareness has gradually strengthened. People's demand for low-carbon products and low-carbon projects forces the transformation of industrial structure, which then contributes to green finance innovation and develop low-carbon products and services to meet the environmental needs of [17]. Finally, at the micro level, on the one hand, green finance tends to produce financing constraints on high-carbon enterprises, force them to withdraw from the market, or carry out low-carbon technological innovation, thus transforming to a low-carbon production mode [18]. On the other hand, green finance alleviates the term mismatch and information asymmetry of low-carbon enterprises, and generates investment incentive mechanisms. For instance, it mitigates the investment risk associated with low-carbon enterprises through the innovation of financial products like green stocks, green bonds, and green funds. Additionally, it enhances the reputation of these enterprises by means of environmental information disclosure mechanisms, thereby internalizing their positive externalities. Thus, it empowers low-carbon enterprises to develop low-carbon technology, reduce energy consumption, improve energy efficiency and promote the transformation of energy structure.

Hypothesis 1. Green finance has a negative effect on CO_2 emission intensity.

2.2. Mediation Effect of Green Finance on Carbon Emission Intensity

The indirect impact channels of green finance on carbon emission intensity are as follows (see Figure **2**). To begin, green finance exerts its influence on carbon emission intensity via energy consumption factors, encompassing energy consumption intensity, energy consumption scale and energy consumption structure. The development of green finance generates various financing channels, financial products and services, which in turn foster improvements in energy efficiency [19]. Furthermore, a reduction in energy intensity and a more moderate energy consumption scale are achieved. In addition, through the financing constraint effect and incentive effect, green finance incentivizes and guides enterprises towards adopting clean and renewable energy within their production processes, thus optimizing the energy structure. As a result, this transformation facilitates carbon emission reduction. Second, green finance can affect carbon emissions through FDI. Green finance has improved the trade environment and terms of trade, and promoted the investment and development of global low-carbon projects. And the low-carbon technology spillover effect and demonstration effect of FDI exert a positive effect on the carbon emission reduction of the host country [20]. Third, green finance affects carbon emissions through industrial structure upgrading. The resource allocation effect of green finance contributes to the flow of financial capital from low value-added and high-emission industries to high value-added and low-emission industries [21], reducing the share of high-emission industries in the whole economic output, which then boosts carbon emission reduction. Fourth, green finance can affect carbon emissions via green technology innovation. Green finance offers financial support for green technology research and development [13]. Besides, it can reduce energy consumption and pollution emissions during production, improve resource utilization efficiency, and facilitate carbon emission reduction through product innovation and process innovation [22]. Finally, green finance can affect carbon emissions through environmental regulation. Green finance can be used as a market-oriented environmental regulation tool, thereby addressing the inherent limitations associated with government-imposed regulatory tools. As a result, it can complement other forms of environmental regulation tools, generating a synergistic role in emission reduction. Table **1** summarizes the impact of intermediary variables on carbon emissions.

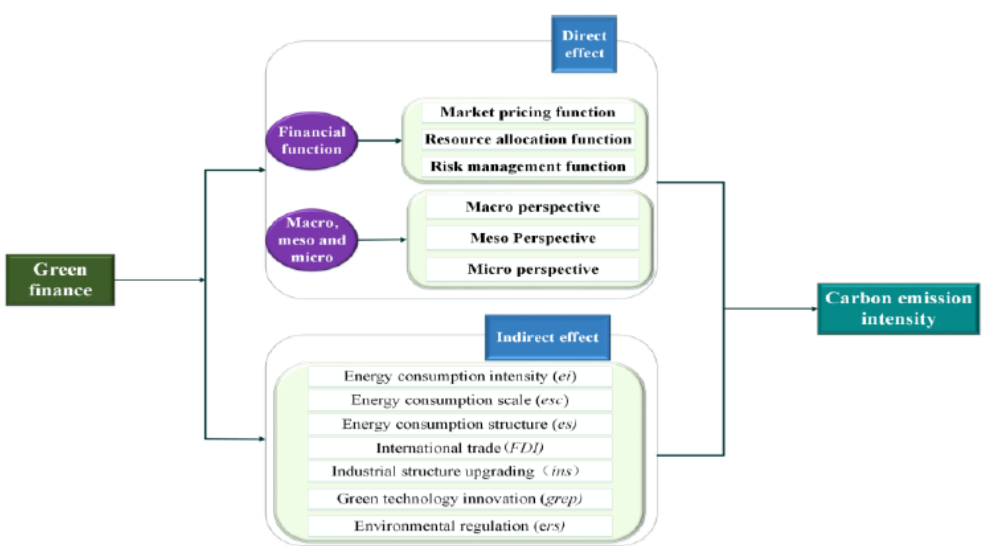

Figure 2: Effect mechanism of green finance on carbon emission intensity.

Table 1: Summary of Existing Studies on the Impact of Intermediary Variables on Carbon Emissions

Intermediary variable	Authors	Period	Sample	Method	Results
ei	Ulucak and Khan [23]	1985-2017	United States	ARDL	Energy intensity contributes to CO_2.
	Shahbaz *et al*. [24]	1980-2012	Sub Saharan African countries	VECM Granger causality	Energy intensity increases CO_2.
sec	Xu *et al*. [25]	1995-2011	China	LMDI	The factors that influence CO_2 due to energy consumption are energy structure, energy intensity, industry structure, economic output, and population scale effects.
es	Li *et al*. [26]	2011-2017	China	STIRPAT model	The energy structure based on coal has a positive effect on CO_2.
	Wang *et al*. [27]	2010-2050	China	a hybrid energy model based on energy demand and energy supply equilibrium	If the energy structure changes, that is, the nuclear energy to substitute for coal, carbon emissions can reach a peak.
FDI	Malik *et al*. [28]	1971-2014	Pakistan	ARDL; Non-linear ARDL	FDI intensify carbon emissions in both the long and short-run.
	Pazienza [29]	1989-2016	OECD	an equation model	As the scale of FDI increases, the level of CO_2 from fuel burning decreases.
	Wang *et al*. [30]	2004-2016	China	Dynamic spatial econometric model	FDI increases carbon emissions but with nonlinear relationship of “inverted-U” shape.
ins	Zhou *et al*. [31]	1995-2009	China	Dynamic panel data model	Industrial structural adjustment effectively reduced CO_2.
	Chang [32]	2007	China	Linkage analysis and multi-objective programming model	To reduce CO_2 emissions, China needs to change its industrial structure.
grep	Zeng *et al*. [33]	2001-2019	China	Spatial economic model and panel threshold model.	Green technology innovation plays a role in reducing CO_2 emissions.
	Töbelmann and Wendler [34]	2000-2013	China	SGMM	Environmental innovation is conducive for carbon reduction.
	Razzaq *et al*. [35]	1990-2017	BRICS countries	Non-linear model(including Quantile unit root, Quantile cointegration, Quantile causality, and Quantile on Quantile regression)	Green innovation reduce CO_2 emissions only at higher levels of emissions.
ers	Pei *et al*. [36]	2005-2015	China	Panel data analysis	Environmental regulation can reduce CO_2 emissions of the energy intensive industries.

Notes: CO_2(Carbon dioxide emissions), SGMM(generalized method of moments), LMDI(Logarithmic Mean Divisia Index), ARDL(Auto regressive distributive lag).

Hypothesis 2. Green finance can affect carbon emissions through energy consumption intensity, energy consumption structure, energy consumption scale, FDI, industrial structure upgrading, green technology innovation and environmental regulation.

2.3. Nonlinear Effect of Green Finance on Carbon Emission Intensity

Green finance's impact on carbon emissions varies with its development stage. In its early stages, green finance mainly increases the loan interest rate for high-emission and energy-intensive enterprises, thus forming a financing constraint effect. This, in turn, limits the investment and financing activities of polluting enterprises and reduces their production scale, thereby mitigating carbon emissions. That is, green finance can reduce carbon emissions from the terminal. Differently, as green finance matures and attains a more advanced stage, its focus shifts towards bolstering low-carbon technological development within enterprises. This is facilitated through mechanisms such as the issuance of green bonds and green stocks or the introduction of innovative green financial products and services. As

China is still in the industrial 2.5 stage at this stage, many fields are still at the low-end level in the global industrial chain, and the proportion of resource-based, high energy consumption and high emission enterprises is relatively high. Therefore, green finance mainly exerts the financing constraint effect to promote carbon emission reduction from the terminal, and the emission reduction effect is obvious. In contrast, low-carbon technology development activities have a long investment return cycle, high risk, high cost and low income. Green finance support for such projects lacks enthusiasm, and the carbon emission reduction effect of low-carbon technology development activities is not significant in the short term. Thus, the effect of green finance on carbon emission abate from the source is relatively weak. In addition, with the continuous improvement of the level of green finance, regional disparities in its development become more pronounced. In particular, against the backdrop of fiscal decentralization in China, local governments exhibit substantial variation in the implementation of green financial policies, which hinders the optimal realization of the carbon emission reduction effect associated with green finance. Therefore, it is posited that the carbon emission reduction effect of green finance may decrease with the continuous improvement of green finance. For example, Huang *et al*. [37] found that the impact of green finance on environmental quality has a double threshold effect, and with the continuous improvement of the level of green finance, its positive impact on environmental quality continues to weaken.

Hypothesis 3. Green finance has a nonlinear spillover effect on carbon emissions, that is, with the continuous improvement of the level of green finance, the marginal effect of carbon emission reduction of green finance is weakening.

2.4. Spatial Effect of Green Finance on Carbon Emission Intensity

Green finance demonstrates a strong positive externality, which can internalize the cost brought by carbon emissions. In addition, due to the close relationship between regional economic activities, the impact of green finance on carbon emissions has a spatial spillover effect. For instance, Wang *et al*. [38] found that green finance in China's Yangtze River economic belt generates a positive spatial spillover effect on the high-quality development of energy. Li and Gan [39] also found that the development of green finance not only improved the eco-environmental quality of the region, but also promoted the improvement of the eco-environmental quality of the surrounding areas. Lei *et al*. [40], taking China's provincial panel data as a sample, studied the impact of green credit on the green economy and its mechanisms by establishing a spatial Durbin model. The study found that green credit not only fosters local green economic development, but also exhibits spatial spillover effects, which can enhance the development level of the green economy in surrounding areas.

Hypothesis 4. The impact of green finance on carbon emissions has a spatial spillover effect.

3. METHODOLOGY AND DATA

3.1. Economic Model

Following the existing studies [41-42], the theoretical framework for this paper rests on a conceptual framework. The specific model is as follows:

$$pco_2 = F(Population, Affluence, Techno\log y) \quad (1)$$

where population, affluence, and technology are the influencing factors of carbon emission intensity. Additionally, according to Liu *et al*. [43], Pco_2 is also affected by other factors. And other factors are added to Model (1) and the model can be expressed as:

$$pco_2 = F(Population, Affluence, Techno\log y, Other\ Variables) \quad (2)$$

Other variables represent other factors that affect Pco_2. First, to investigate the impact of green finance on Pco_2, we add green finance to model (2). And, this paper constructs the dynamic panel model to alleviate the endogenous problem. The model is specified as:

$$Pco_{2it} = \delta_0 + \delta_1 Pco_{2it-1} + \delta_2 Gref_{it} + \delta_3 Z_{it} + \alpha_i + \varepsilon_{it} \quad (3)$$

where Pco_{2it} denotes the carbon emission intensity in i province at time t. Pco_{2it-1} is the lagging period of the explained variable. $Gref_{it}$ stands for the green finance level in i province at time t. Z_{it} represents the control variables. α_i refers to the individual effect. ε_{it} represents the random error term.

Second, in order to study whether the carbon emission reduction effect of green finance has nonlinear characteristics, the panel threshold model is constructed.

$$Pco_{2it} = \partial_0 + \partial_1 Gref_{it} \times I(Gref_{it} \le r_1) + \partial_2 (Gref_{it} > r_1) + \partial_3 Z_{it} + \mu_i + \varepsilon_{it} \quad (4)$$

where I (·) is an indicator function with a value of 1 or 0. The variables in Model (4) are the same as those in the Model (3).

Third, in order to study the action path of green finance affecting carbon emissions, the latest intermediary effect test method (KHB method) proposed by Kohler *et al*. [44] is employed. The intermediary effect model is set as follows:

$$Y_{it} = \beta_F + \beta_F X_{it} + \varphi_F Z_{it} + \vartheta_F C_{it} + \mu_i + \delta_t + \lambda_{it} \quad (5)$$

where *X* represents the decomposed variable, *Z* denotes the mediating variable, and *C* is control variables. Similarly, a reduction model without intermediate variables can be constructed.

$$Y_{it} = \beta_R + \beta_F X_{it} + \vartheta_F C_{it} + \mu_i + \delta_t + \gamma_{it} \quad (6)$$

Generally, R - F can obtain indirect effects. Further, the steps for using the HKB method to test the mediating effect are as follows. KHB method first calculates the *R* residual through the regression of the confounding factor *Z* to *X*. At this time, *R* and *X* are orthogonal.

$$R_{it} = Z_{it} - (a + bX_{it}) \quad (7)$$

Different from model (6), the residual *R* rather than the confounding factor *Z* is included in the regression equation.

$$Y_{it}^* = \widetilde{\beta_R} + \widetilde{\beta_R} X_{it} + \tilde{\gamma} R_{it} + \tilde{\vartheta} C_{it} + \mu_i + \delta_t + \lambda_{it} \quad (8)$$

Because $\widetilde{\sigma_R} = \sigma_F$, $\widetilde{\beta}_R = \beta_R$, where $\widetilde{\sigma_R}$, σ_F represents Ruler parameters, and $\widetilde{\sigma_R} \geq \sigma_F$, the indirect effect at this time can be expressed as:

$$\widetilde{b_R} - b_F = \frac{\widetilde{\beta_R}}{\widetilde{\sigma_R}} - \frac{\beta_F}{\sigma_F} = \frac{\beta_R - \beta_F}{\sigma_F} \quad (9)$$

Finally, to identify the spatial effect of green finance on carbon emission intensity, we construct a spatial panel model as follows:

$$\begin{aligned} Pco_{2it} = {} & \lambda_o + \rho w Pco_{2jt} + \phi w Gref_{jt} + \varpi_1 Gref_{it} + \phi_c w Z_{jt} \\ & + \phi_c Z_{it} + \mu_i(optional) + \zeta_t(optional) + \varepsilon_{it} \end{aligned} \quad (10)$$

3.2. Data and Variable Selection

3.2.1. Explained Variable

Carbon emission intensity (*Pco*$_2$) is measured by the ratio of the total carbon emission of each province to GDP, that is, CO_2/gdp. The carbon emission data is from China Emissions Accounts and Datasets, which is estimated by Shan *et al*. [45]. The total CO_2 emissions of each province are shown in Figure **3**. We can see that during sample periods, the overall trend of CO_2 emissions in China's provinces shows an upward fluctuation except for Beijing. Additionally, a similar

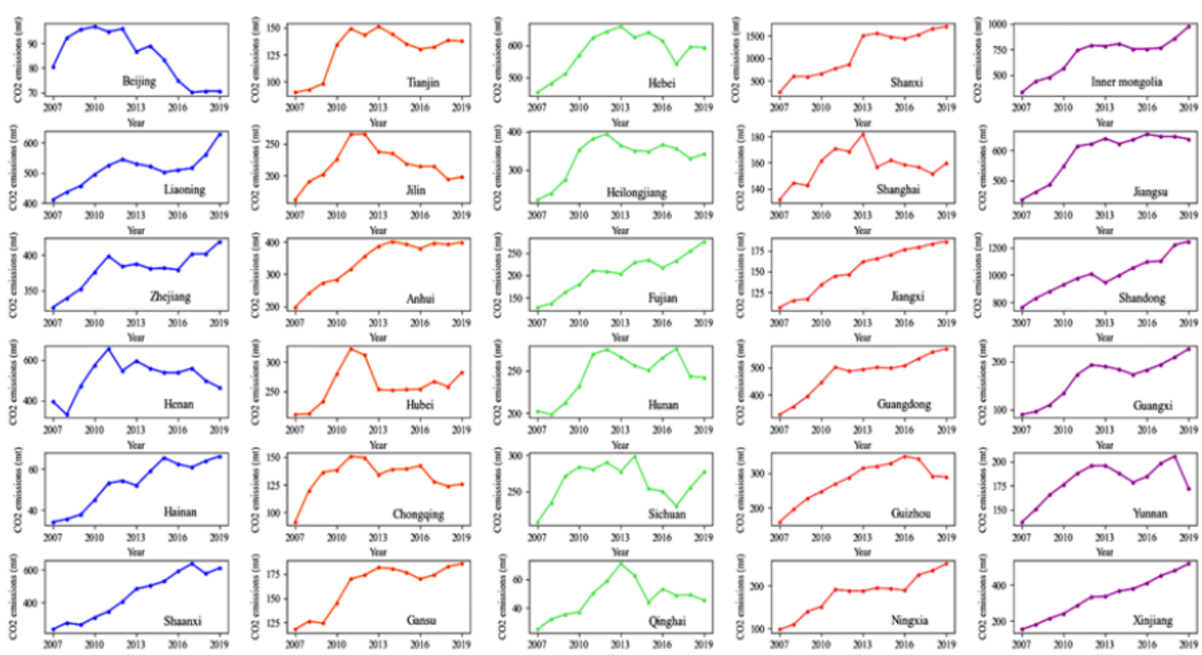

Figure 3: Total CO_2 emissions of each province in China.

trend is observed in the provinces of Tianjin, Hebei, Jilin, Heilongjiang, Shanghai, Anhui, Henan, Hubei, Chongqing, Sichuan, and Qinghai, with their total CO2 emissions reaching a peak, either just before or after 2013. The peak year in Guizhou, Hunan and Shaanxi is around 2016 (the specific reasons for this difference are shown in **Appendix C**). Notably, Beijing stands out as an exception, as its CO2 emissions have been consistently decreasing over the years. This decline can be attributed to Beijing's well-developed economy, advanced technology, rigorous environmental regulations, and a reasonable industrial structure. Moreover, Figure **5** illustrates the mean CO2 emission intensity for each province during the sample period, revealing an escalating gradient in Eastern, Central, and Western China as a whole.

3.3.2. Explanatory Variable

Green finance (*Gref*). Considering the availability of data and the comprehensiveness of the evaluation index system, this paper selected green credit, green securities, green investment green insurance and government support to build an evaluation system of green finance with five dimensions and six indicators (see Table **2**). We employ factor analysis approach to evaluate *Gref*. (the comprehensive score ranking of *Gref* is shown in Figure **4**).

Table 2: Green Finance Evaluation Index System

Primary Index	Characterization Index	Indicator Description	Index Attribute
Green credit	Proportion of interest expense of high energy consumption industry	Interest expense of six high energy consuming industries / Total industrial interest expenditure	-
Green securities	Proportion of market value of high energy consuming enterprises	Market value of a shares of high energy consuming enterprises / total market value of a shares of Listed Enterprises	-
Green investment	Proportion of investment in environmental pollution control in GDP	Completed amount of environmental governance investment /GDP	+
	Proportion of energy conservation and environmental protection expenditure	Energy conservation and environmental protection expenditure / total financial expenditure	+
Green insurance	Depth of agricultural insurance	Agricultural insurance income / gross agricultural output value	+
Government support	Proportion of fiscal environmental protection expenditure	Financial environmental protection expenditure / financial general budget expenditure	-

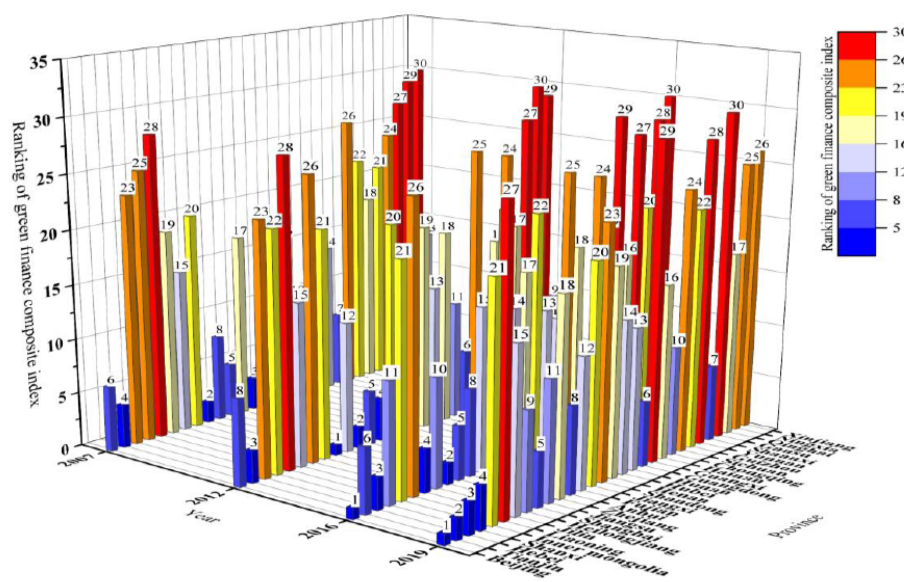

Figure 4: Spatial distribution of green finance and carbon emission intensity[2#].

[2#] Due to space constraints, only the ranking of green finance comprehensive index of 30 provinces in year 2007, 2012, 2016 and 2019 is shown here. The reasons for choosing the above years as representative years are as follows. First, year 2007 and 2019 are the beginning and end years of the study sample, respectively. Second, in year 2012 and 2016, China issued two important green finance policies, which is of great significance. One is *the guidelines on green credit* issued in 2012; the other is seven ministries and commissions including the people's Bank of China and the Ministry of Finance jointly issued *the guidance on building a green financial system.*

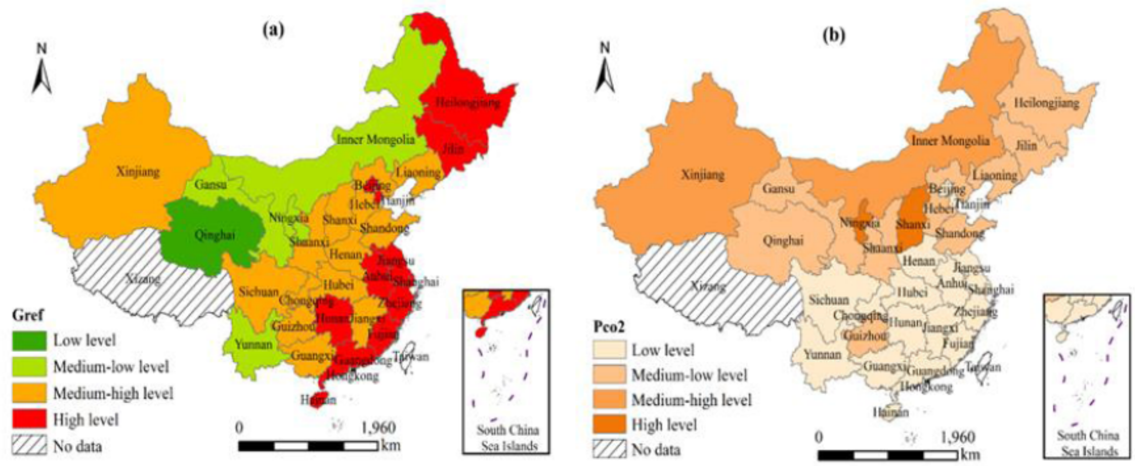

Figure 5: Spatial distribution of green finance (**a**) and carbon emission intensity (**b**)[3#].

[3#] The figure shows the average value of green finance and carbon emission intensity from 2007 to 2019.

Comprehensive score ranking of *Gref* of 30 provinces in year 2007, 2012, 2016 and 2019 are shown in Figure **4**,

We can see that the top three provinces of the green finance composite index in 2007 were Guangdong, Shanghai and Fujian. In 2012, the top three provinces were Shanghai, Zhejiang and Tianjin. In 2016, the top three provinces were Beijing, Shanghai and Hebei. In 2019, the top three provinces were Beijing, Tianjin and Hebei.

In Figure **5**., we can see that regions with high level of green finance demonstrate relatively low CO_2 emission intensity, which potentially indicates that green finance is associated with CO_2 emission reduction.

3.3.3. Control Variables

According to the IPAT model and the existing studies [46-49], the selected control variables are as follows. Population size index (*pop*) was measured by the urban population density of each province; Wealth index was represented by per capita GDP (*pgdp*) of each province; Technical indicator (tech) was denoted by the proportion of provincial science and technology expenditure in general financial budget expenditure; Industrial agglomeration (*agg*) was calculated by measured with location entropy index, and the specific model is as follows.

$$agg_{it} = \frac{X_{it}/X_t}{Q_{it}/Q_t} \tag{9}$$

where agg_{it} indicates industrial concentration level in province *i* at time *t*; X_{it} represents the national industrial added value in province *i* at time *t*; X_t denotes the national industrial added value at time *t*; Q_{it} indicates the GDP in province *i* at time *t*; Q_t refers to the national GDP in *t* year. The level of human capital (*hr*) is calculated by the method of years of education per capita.

Table 3: Descriptive Statistics

Var Name	Obs	Mean	SD	P5	Median	P95
Pco_2	390	2.3712	2.0639	0.6100	1.7200	6.8200
Gref	390	0.2740	0.1231	0.0814	0.2826	0.4738
pop	390	2.8163	1.1984	1.2510	2.6315	5.1460
pgdp	390	4.6463	2.6730	1.4649	4.0416	10.3796
agg	390	1.0203	0.2112	0.4783	1.0804	1.2580
hr	390	8.9197	0.9704	7.4739	8.8329	10.9627
tech	390	2.0078	1.4155	0.7817	1.3335	5.3274

Table 4: Representation and Measurement of Mediating Variables

Mediating Variables	Specific Measurement Methods
Energy consumption intensity（*ei*）	It is measured by the ratio of DMSP / OLS and VIIRS night light data[4#] to GDP.
Energy consumption scale（*esc*）	It is denoted by the ratio of the total energy consumption of each province to the total population at the end of the year.
Energy consumption structure（*es*）	It is quantified by the ratio of natural gas consumption to total energy consumption.
International trade（*FDI*）	It is measured by the ratio of actually utilized foreign direct investment to GDP.
Industrial structure upgrading（*ins*）	It is computed by Moore index (see more details for **Appendix D**).
Green technology innovation（*grep*）	Combined with China's patent data and the "green list of International Patent Classification" launched by the World Intellectual Property Organization (WIPO) in 2010, the green patent data of sample provinces are screened and extracted according to the international patent classification number.
Environmental regulation（*ers*）	A comprehensive rating index system from the perspective of emission and governance was constructed, and measured by the factor analysis approach[5#].

[4#] From the National Oceanic and Atmospheric Administration (NOAA), the data contains the stable night light values of local cities after removing background noise and interference.

[5#] Emission indicators include: industrial wastewater emission per unit output value, industrial waste gas emission per unit output value, industrial SO_2 emission per unit output value, and general solid waste generation per unit output value. Treatment indicators include: industrial wastewater treatment capacity, industrial waste gas treatment capacity, solid waste disposal rate and comprehensive utilization rate of solid waste.

3.3.4. Mediating Variables

To study the impact path of green finance on carbon emission intensity, according to existing studies [22, 50-52], the selection of intermediary variables is reported as follows (see Table **4**).

4. EMPIRICAL RESULTS AND DISCUSSIONS

4.1. Preliminary Empirical Observation

This paper makes a preliminary empirical observation on the relationship between green finance and CO_2 emissions (see Figure **5**). It can be seen that the relationship between green finance and CO_2 emission intensity is negative.

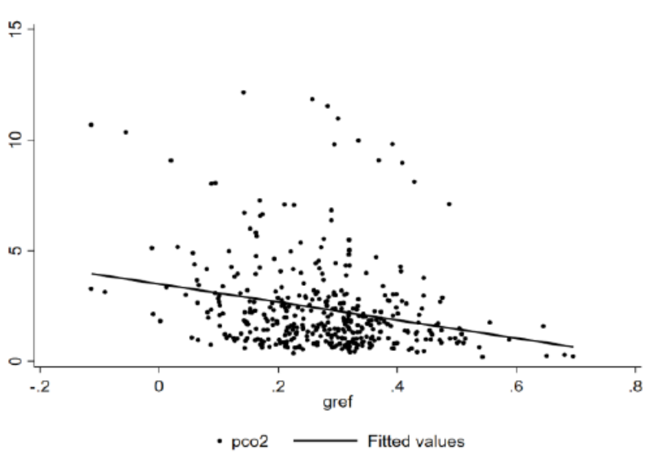

Figure 5: Fitting diagram of the relationship between green finance and CO_2 emission intensity.

4.2. Benchmark Regression Results

We employ SYS-GMM to estimate Model (1). The estimation results (as shown in Column (1) and (2) of Table **5**) show that green finance promotes CO_2 emission reduction at the significance level of 1% in the presence and absence of control variable. That is to say, green finance exerts a significant effect on mitigating CO_2 emissions. The possible reasons are as follows: On the one hand, green finance restricts capital allocation to industries marked by high energy consumption and emission. This compels them to scale down, exit, or embrace technological shifts for emission abatement. On the other hand, green finance bolsters capital access for environmentally focused enterprises, spurring R&D investments and enabling the provision of more low-carbon products and services. This conclusion verifies the **Hypothesis 1**.

4.3. Robustness Test

In order to test the robustness of the regression results, a series of robustness tests were carried out on the benchmark regression results. First, the influence of extreme values is removed. The core explanatory variables and the explained variables are reduced. It can be seen that the impact coefficient of green finance on Pco_2 is consistent with the benchmark regression results (see Column (3) and (4) of Table **5**). Second, the research sample period is adjusted to 2007-2018. The results (see Column (5) and (6) of Table **5**) show that the carbon emission reduction effect of green finance is still justified. Third, in order to account for the

Table 5: Benchmark Regression Results and Robustness Estimation Results of the Model (1).

	(1)	(2)	(3)	(4)	(5)	(6)
	Pco_2	Pco_2	Pco_2	Pco_2	Pco_2	Pco_2
L.Pco2	0.9328[a]	0.9261[a]	0.9190[a]	0.9174[a]	0.8707[a]	0.8332[a]
	(700.3605)	(69.4874)	(1031.5030)	(126.5921)	(331.9586)	(83.9240)
Gref	-0.4926[a]	-0.5960[a]	-0.4632[a]	-0.5456[a]	-0.6253[a]	-0.5770[a]
	(-16.8583)	(-13.3389)	(-17.6259)	(-9.0241)	(-17.2964)	(-9.5610)
CV	NO	YES	NO	YES	NO	YES
_cons	0.2021[a]	-0.7634[a]	0.2190[a]	-0.4986[a]	0.3260[a]	0.644[a]
	(21.3153)	(-3.5053)	(18.8989)	(-2.9390)	(17.8550)	(3.9734)
N	360	360	360	360	360	360
AR (2)	-0.1962 [0.8444]	-0.2845 [0.7760]	0.2856 [0.7752]	0.2137 [0.8308]	0.5431 [0.5871]	0.4137 [0.6791]
Sargan	28.4873 [0.9999]	23.0964 [1.0000]	27.2137 [1.0000]	23.6815 [1.0000]	28.4209 [1.0000]	26.9794 [1.0000]
	(9)	**(10)**	**(11)**	**(12)**	**(13)**	**(14)**
	Pco_2	Pco_2	Pco_2	Pco_2	Pco_2	Pco_2
L.Pco2	0.9348[a]	0.9346[a]	0.9196[a]	0.9279[a]	0.9244[a]	0.9281[a]
	(1247.7655)	(128.5088)	(1064.8654)	(55.3061)	(495.8145)	(62.5653)
Gref	-0.4842[a]	-0.6425[a]	-0.5427[a]	-0.5482[a]	-0.5498[a]	-0.6915[a]
	(-19.8827)	(-13.9015)	(-27.3305)	(-11.8337)	(-16.6529)	(-13.7934)
fin/treat			0.1577[a]	0.1711[a]	-0.0486[a]	-0.1513[a]
			(21.4318)	(6.7762)	(-5.0253)	(-9.1331)
CV	NO	YES	NO	YES	NO	YES
_cons	0.1898[a]	-1.3086[a]	0.2163[a]	-1.2589[a]	0.2721[a]	-1.8708[a]
	(23.1457)	(-5.6154)	(27.6804)	(-4.4531)	(14.5719)	(-6.4498)
N	330	330	360	360	360	360
AR (2)	-0.2539 [0.7996]	-0.4224 [0.6728]	-0.2533 [0.8001]	-0.3536 [0.7236]	-0.1654 [0.8687]	-0.3211 [0.7481]
Sargan	29.2277 [0.9992]	28.0423 [0.9996]	28.0863 [1.0000]	24.7457 [1.0000]	27.7651 [1.0000]	23.7198 [1.0000]

Notes: "*L*" in the Table denotes the first-order lag of the variable. [a], [b], and [c] denote significance at the 1%, 5% and 10% level, respectively. The values in () represent the *t* statistics and in [] represent the *P* value. The SYS-GMM estimation results show that the *P* value of AR (2) are all greater than 0.1, indicating that there is no second-order autocorrelation in the random disturbance term. Sargan test also show that selected instrumental variables are effective.

influence of the 2008 financial crisis on China's economic and social development, as well as its subsequent impact on Pco_2, the dummy variable *fin* is introduced into Model (1). To address any potential lag effects stemming from this event, the time represented by the dummy variable lags by one period. Specifically, if the research sample falls within the years 2008 to 2009, *fine* equals to1, otherwise the value of this variable is 0, and the empirical results (as shown in Column (7) and (8) of Table **5**) are still basically in line with the benchmark regression results. In conclusion, the research conclusions of this paper are robust. It is noteworthy that the coefficient value of *fin* is positive. The reason may be that the 2008 financial crisis originated in western developed countries, causing relatively minimum economic turbulence in China. In addition, in response to the impact of the financial crisis, the Chinese government implemented a 200 billion economic stimulus plan, resulting in a large amount of energy consumption and increased carbon emissions.

4.4. Regional Heterogeneity Analysis

China's extensive geographical expanse encompasses significant disparities in socio-economic development levels across regions. Consequently, the influence of green finance on carbon emission intensity might exhibit notable regional heterogeneit. First, according to *the Report of China's Marketization Index by Provinces*, we divide the sample regions into financially developed regions and financially underdeveloped regions [18]. Specifically, regions where the sample regional marketization index surpasses the average threshold are categorized as financially developed regions, while those falling below the average are classified as financially underdeveloped regions financially developed financially underdeveloped. Second, recognizing that CO_2 emissions of industry accounts for about 70%, and given the varying degrees of industrialization across regions, the impact of green finance on CO2 emission reduction may vary. Thus, we group the sample regions into industrially developed and underdeveloped regions according to regional industrialization level.

The measurement steps of regional industrialization level are as follows. First, this paper selects 13 indicators from six dimensions: industrial economic development, foreign trade, technological innovation, labor cost, urbanization level and ecological environment to build a comprehensive evaluation index system for China's provincial industrial economic development level (see Table **6**). Second, we employ the factor analysis approach to calculate the factor score of industrialization level of each province in China. Finally, according to the total score of industrialization level of each province in China, we categorize regions exceeding the average level of industrialization as industrially developed regions, while those falling below the average are denoted as industrially underdeveloped regions industrially developed industrially underdeveloped.

In Column (1) and (2) of Table **7**, the coefficients of green finance in financially developed and financially underdeveloped regions are both negative at a 5% significance level. However, the impact coefficient in financially underdeveloped regions is greater than that in financially developed regions. This conclusion is not consistent with Zhang *et al*. [18]. He believed that the effect of green credit in financially developed regions on PM2.5 is significant, but insignificant in financially underdeveloped regions. The reason may due to the distinguish among the research objects and indicators. From the perspective of research indicators, this paper constructs a comprehensive index system of green finance, including five dimensions: green credit, green securities, green insurance, green investment and government support. Compared with a single green credit policy, multi-dimensional green finance can provide diversified financing products and services for

Table 6: comprehensive Evaluation Index System of Provincial Industrialization Level in China

Primary Index	Characterization Index	Indicator Description	Index Attribute
Industrial economic development	Income indicators	per capital GDP	+
	Structure index	Proportion of added value of secondary and tertiary industries in GDP added value of the year	+
Foreign trade	Dependence on foreign trade	Proportion of total import and export in GDP	+
	Foreign direct investment	FDI as a percentage of GDP	+
Technological innovation	Development of high-tech industry	Total profits of high-tech industries	+
	Scientific and technological level	Number of patents authorized	+
Labor cost	Total actual wages	Total wages of employees in urban units	+
Urbanization level	Urbanization rate	Proportion of urban population	+
	Dual economic structure（DES）	(Proportion of output value of secondary and tertiary industries / proportion of employees in secondary and tertiary industries) / (Ratio of output value proportion of primary industry / number of employees of primary industry)	+
Ecological environment	Waste water	Industrial wastewater discharge	-
	Waste gas	Total industrial SO_2 emission	-
		Total industrial waste gas emission	-
	Solid waste	Output of general industrial solid waste	-

Table 7: Regional Heterogeneity Regression Results

	(1)	(2)	(3)	(4)
	Financially Developed Regions	**Financially Underdeveloped Regions**	**Industrially Developed Regions**	**Industrially Underdeveloped Regions**
	Pco₂	*Pco₂*	*Pco₂*	*Pco₂*
L.Pco2	0.7859[a]	0.9097[a]	1.3830[a]	0.7758[a]
	(20.0661)	(31.8695)	(2.6231)	(14.8713)
L2. Pco2			-1.3361[b]	
			(-2.1537)	
Gref	-0.1707[b]	-0.5604[b]	-0.2663[c]	-0.5382[b]
	(-2.4132)	(-2.1863)	(-1.8816)	(-2.0784)
cv	Yes	Yes	Yes	Yes
_cons	1.1830[a]	-4.1643[a]	5.3250[c]	-0.5637
	(3.9210)	(-4.4506)	(1.8135)	(-0.7960)
N	168	192	121	228
AR (2)	0.2350 [0.8142]	-0.6071 [0.5438]	-0.1263 [0.8895]	-0.2889 [0.7726]
Sargan	7.0481 [1.0000]	12.2958 [1.0000]	1.3378 [1.0000]	7.8420 [1.0000]

Notes: "*L*" in the Table denotes the first-order lag of the variable. [a], [b], and [c] denote significance at the 1%, 5% and 10% level, respectively. The values in () represent the *t* statistics and in [] represent the *P* value. The SYS-GMM estimation results show that the *P* value of AR (2) are all greater than 0.1, indicating that there is no second-order autocorrelation in the random disturbance term. Sargan test also show that selected instrumental variables are effective.

regional energy conservation and emission reduction activities. Thus, both financially developed regions and financially underdeveloped regions will be affected by green finance, and, particularly, the emission reduction effect is more pronounced in financially underdeveloped regions. This may be due to the increased vitality of financial markets in financially developed regions, accompanied by the relatively lower financing costs for enterprises. Financially developed Enterprises in these regions often have abundant funds to carry out technological innovation, improve energy utilization efficiency and engage in low-carbon and environmental protection production. Consequently, they are less susceptible to the influence of green financial policies. Additionally, most of the financially developed regions are economically developed regions, with advanced industrial structure. Enterprises in these regions (such as Jiangsu, Beijing and Shanghai) face a high level of environmental regulation and then cultivate a strong awareness of low-carbon environmental protection [53]. Therefore, the emission reduction effect of green financial policies has been weakened by other policies. By contrast, the level of environmental regulation in financially underdeveloped regions (such as Shanxi, Inner Mongolia, Qinghai, and Guangxi) is notably lower. Besides, the government's commitment to low-carbon environmental protection is considerably mild, and the enforcement is less stringent. Consequently, low-carbon environmental protection policies in these areas tend to be single, resulting in a less pronounced policy impact. Thus, the carbon emission reduction effect of green finance assumes greater significance in these regions. Moreover, the existing research also documents that green finance mainly affects the production mode among enterprises through the financing constraint effect [54]. Concerning this, the development of green finance in financially underdeveloped regions can reduce the production scale of high emission enterprises or force them to withdraw from the market through the punishment effect, thereby increasing the financing cost of these enterprises and reducing their capital financing channels, which then leads to a pronounced carbon abatement effect associated with green finance.

In Column (3) of Table **7**, the impact of green finance in industrially developed regions on Pco_2 is negative at 10% significance level. In Column (4) of Table **7**, the impact of green finance in industrially underdeveloped regions on Pco_2 is negative at 5% significance level. It indicates that the CO_2 emission reduction effect of green finance is more obvious in industrially underdeveloped regions. This is because that financial institutions and enterprises in industrially developed regions are reluctant to engage in the development of the negative carbon industry, and this reluctance can be attributed to the following reasons: Firstly, this activity represents a public and societal endeavor, featuring external benefits that are broadly distributed and challenging to internalize. Consequently, financial institutions and enterprises lack the incentive to pursue negative carbon technology development. Secondly, negative carbon technology is characterized by high cost and low income. For the purpose of maximizing profits, financial institutions and enterprises are disinclined to invest in the field of negative carbon industry. Thirdly, studies have shown that green finance has not yet formed a "compensatory benefit" exceeding the cost of innovation at this stage [55], and the development cost of negative carbon technology is very high, so financial institutions will not choose to invest in this field.

4.5. Mechanism Analysis

Based on the analysis of the second part of this paper, we can see that existing literature has discussed that green finance can affect various intermediary variables and each intermediary variable can affect carbon emissions. To empirically reveal the carbon emission reduction path of green finance, KHB approach is furtherly used to analyze the intermediary effect. The results of Table **8** show the estimation results of simplified model (Reduced), the complete model (Full), and the estimated difference between the two (Full). The effect of Reduced estimation is total effect, Full estimation is direct effect, and Diff estimation is indirect effect. In Table **8**, we can see that the Diff effect of *ei, es, esc, FDI, ins,* and *grep* passed the 5% or 1% significant level. It indicates that green finance can reduce energy intensity, optimize energy consumption structure, reduce the scale of energy consumption, improve the level of opening to the outside world, promote the upgrading of industrial structure, and improve the level of green technology innovation, so as to promote CO_2 emission reduction. What's more, considering that compared with other mediation effect test methods, Bootstrap has higher statistical effect, so we employ Bootstrap method for mediation effect analysis again (the results are shown in Appendix **F.**).

There's evidence that green finance reduces carbon emission intensity through the channel of energy intensity, energy structure, energy consumption scale, FDI, industrial structure upgrading, and green technology innovation, which verifies **Hypothesis 2**. However, there's no evidence that green finance reduces CO_2 emission intensity by improving environmental regulation level, which is not consistent with **Hypothesis 2**. The reason may be the current green financial mechanism is imperfect so that it cannot make up for the shortcomings of environmental regulation in the implementation process. So, it doesn't cooperate with environmental regulation tools to play a role in CO_2 emission reduction.

Table **9** shows the contribution of mediating effects of each mediating variable. The first two columns show the effect difference (indirect effect) and its standard error of each intermediary, the third column shows the contribution of each intermediary to the indirect effect, and the last column shows how many total effects are due to their respective intermediary confusion.

The results show that the contribution of each intermediary variable from large to small is FDI，energy consumption scale, energy intensity, green technology innovation, industrial structure upgrading, and energy structure. It indicates that the resource allocation, risk management and market pricing functions of green finance, as well as the green financial standard system, environmental information disclosure framework, green financial incentive and restraint mechanism, green financial products and service system and international cooperation with

Table 8: Regression Results of Mediating Effect

Dependent variable= ***Pco_2***	**M=*ei***	**M=*es***	**M=*esc***	**M=*FDI***	**M= *ins***	**M=*grep***	**M=*ers***
Independent variable=*Gref*	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Reduced	-4.0884 [0.0000]	-4.0884 [0.0000]	-4.0884 [0.0000]	-4.0884 [0.0000]	-4.0884 [0.0000]	-4.0884 [0.0000]	-4.0884 [0.0000]
Full	-2.5834 [0.0000]	-3.7497 [0.0000]	-2.8491 [0.0000]	-2.2314 [0.0100]	-3.1633 [0.0000]	-2.7430 [0.0010]	-4.0614 [0.0000]
Diff	-1.5050 [0.0010]	-0.3387 [0.0440]	-1.2393 [0.0020]	-1.8570 [0.0000]	-0.9251 [0.0010]	-1.3454 [0.0000]	-0.0270 [0.5890]

Table 9: Contribution of Mediating Effects of Various Mediating Variables

M	Coef	Std_Err	P_Diff	P_Reduced
ei	-0.8610	0.2781	18.80	21.06
es	-0.2695	0.1330	5.88	6.59
esc	-0.9039	0.3038	19.73	22.11
FDI	-1.1078	0.3017	24.19	27.10
ins	-0.6401	0.2354	13.97	15.66
grep	-0.7980	0.2346	17.42	19.52

green finance, force enterprises to transform their production to energy-saving and environmental protection production mode, and guide the whole society to establish the concept of low-carbon development. It reduces energy consumption and waste, thus promoting carbon emission reduction. In addition, the contribution of intermediary effect of energy structure is the smallest, and the reason may be that coal has played an important role in China's energy consumption for a long time. Residents' consumption of coal has formed a rigid demand, and the proportion of renewable energy consumption is still low [22, 52]. It is difficult to change the energy structure greatly in the short term. However, the change of energy structure is rather crucial for achieving carbon neutrality. Therefore, in the future, it is necessary to strengthen the investment of green finance in renewable energy and clean energy, reshape the energy system and promote the optimization and upgrading of energy structure.

4.6. Nonlinear Effect Analysis

In order to test whether the CO_2 emission reduction effect of green finance has nonlinear characteristics, we estimate the panel threshold Model (4). Before the threshold regression, the existence test of panel threshold effect is carried out. The results show that the impact of green finance on Pco_2 have passed the single threshold test, but not the double threshold test.

In Column (1) of Table **10**, we can see that when the development level of green finance is lower than the threshold value (0.2316), the impact coefficient of green finance on Pco_2 is -2.7523 at the significance level of 1%, indicating that the carbon emission intensity decreases by 2.7523 units for each unit of increase in the development level of green finance. When the development level of green finance is higher than the threshold, its inhibitory effect on carbon emission intensity gradually weakens, and the influence coefficient is -0.8055 at the significance level of 10%. The results confirm the **Hypothesis 3.** And the threshold estimation test also verifies the original assumption that the threshold estimation of the model is the real threshold (see Figure **7**).

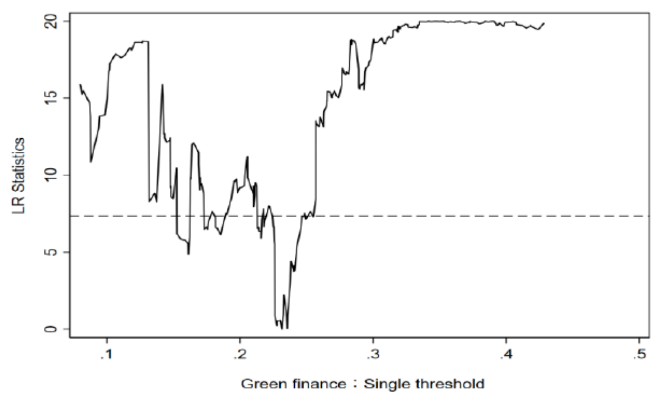

Figure 7: Authenticity test of green finance threshold estimation.

The reason may be that in the early stage of the development of green finance, its impact on carbon emissions is mainly reflected in the financing constraints on high emission enterprises. It promotes a large number of high carbon enterprises to withdraw from the market or force them to transform and upgrade, resulting in a more obvious emission reduction effect. When green finance develops to a high level, its impact on carbon emissions is mainly reflected in the innovation support for green enterprises. More funds flow to green enterprises to promote the rational allocation of financial resources. However, considering the high cost and low income of low-carbon technology innovation, green enterprises have insufficient power in low-carbon technology development and innovation, so the emission reduction effect is relatively weak. The conclusion also reflects that the constraint effect of green finance on high-carbon enterprises and the resulting carbon emission reduction effect is greater than that of incentive effect on green enterprises. It also confirms the existing research view that green finance has not significantly alleviated the financing constraints of green enterprises [55], and encouraged them to develop low-carbon technologies.

Table 10: Threshold Model Regression Results of Green Finance Affecting Carbon Emission Intensity

Threshold Value（q_1）	0.2316
gref·I (Th≤q1)	-2.7523[a]
	(-4.1285)
gref·I (Th>q1)	-0.8055[b]
	(-2.2720)
fin	
cv	Yes
Cons	6.8362[a]
	(6.2723)
Observations	390
R^2	0.338

Notes: [a], [b] and [c] denote significance at the 1%, 5% and 10%levels, respectively. The values in () represent the *t* statistics.

We also perform a series of robustness tests to ensure the robustness of the nonlinear regressions result. Similar to the robustness test of benchmark regression, this paper tests the robustness of the nonlinear effect of green finance on *Pco$_2$*. The estimations' results of Columns (2)-(4) of Table **10** show that the carbon emission reduction effect of green finance shows the nonlinear characteristic of diminishing marginal effect, which still holds, indicating that the benchmark threshold regression result is robust.

4.7. Spatial Effect Analysis

In order to analyze the spatial effect of green finance on carbon emission intensity, firstly, the global Moran's I index is used to test the spatial correlation of core variables. In Figure **8**, we can see that the Moran's I index of carbon emission intensity and green finance passed the significance test in most years, which indicates that in the sample period, there is a spatial correlation between green finance and carbon emission intensity.

Moran's I scatter plot is used to study the local spatial characteristics. It can divide the spatial correlation degree of each region into four different attributes, which are located in the first quadrant (H-H), the second quadrant (L-H), the third quadrant (L-L) and the fourth quadrant (H-L). The first quadrant (H-H) indicates that areas with high carbon emission intensity and green financial development level are surrounded by high value areas. The second quadrant (L-H) indicates that areas with low carbon emission intensity and green financial development level are surrounded by high-value areas. The third quadrant (L-L) indicates that areas with low carbon emission intensity and green financial development level are surrounded by low value areas. The fourth quadrant (H-L) indicates that areas with high carbon emission intensity and green financial development level are surrounded by low value areas. The first and third quadrants indicate that there is a spatial positive correlation between green finance and carbon emission intensity, and the second and fourth quadrants are spatial negative correlation. In Figure **9**, we can see that there is a spatial positive

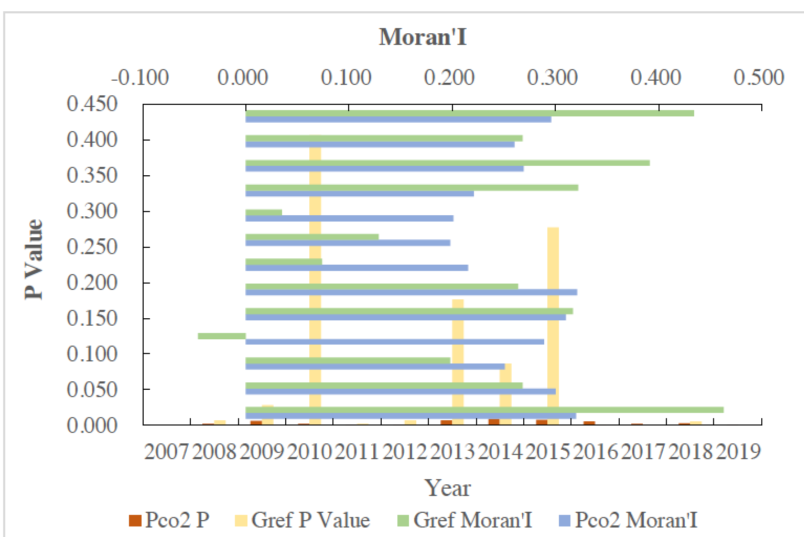

Figure 8: Global Moran's I index of green finance and carbon emission intensity in 2007-2019.

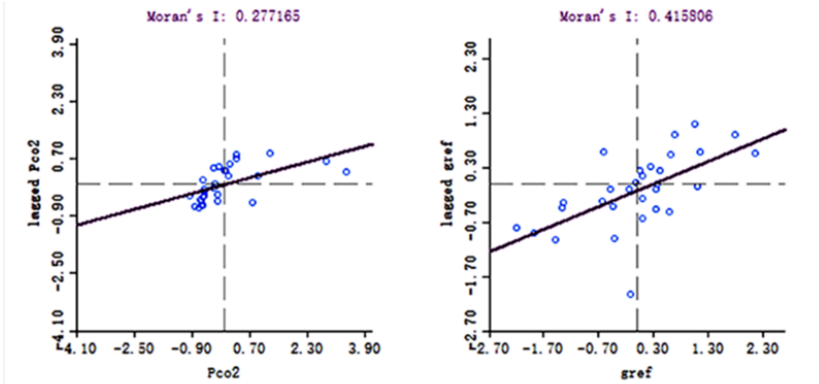

Figure 9: Moran scatter plot of green finance and carbon emission intensity[6#].

[6#] The Moran scatter plot drawn by the mean value of green finance and carbon emission intensity from 2007 to 2019. Pco2 represents carbon emission intensity and gref represents green finance level (Gref).

correlation between green finance and carbon emission intensity in the sample period.

LM, LR test and fixed effect results indicate that the spatial SDM model with time fixed effect is suitable for regression estimation (see more details for Appendix **G**). Elhost [56] reckoned that when the global effect is included in the setting of spatial econometric model, the point estimation result of spatial econometric model itself does not represent the marginal impact of explanatory variables. So, it is necessary to further calculate the direct and indirect effects of explanatory variables according to the point estimation result of the model. LeSage and Pace [57] also believed that the point estimation of spatial regression model to test whether there is spatial spillover effect will lead to many errors. Moreover, the change of variables in the model setting affects the partial differential equation.

Therefore, it is crucial to further measure the direct and indirect effects of green finance on carbon emission intensity. Table **8** shows the regression

Table 11: The Direct, Indirect and Total Effect of the Spatial Estimations' Results of the Model 10

	(1)	(2)	(3)	(4)
	pco2	pco2	pco2	pco2
Spatial:				
rho	0.4072[a]	0.1424[c]	0.4345[a]	0.1825[b]
	(6.1613)	(1.7076)	(7.6076)	(2.3445)
LR_Direct:				
gref	-3.4093[a]	-2.1614[b]	-3.4034[a]	-1.8546[a]
	(-3.8755)	(-2.3351)	(-6.6976)	(-3.5094)
CV	No	Yes	No	Yes
LR_Indirect:				
gref	-9.5822[a]	-2.8713[c]	-7.5690[a]	-3.0799[a]
	(-4.9410)	(-1.7107)	(-6.1680)	(-3.0309)
CV	No	Yes	No	Yes
LR_Total:				
gref	-12.9915[a]	-5.0327[a]	-10.9724[a]	-4.9346[a]
	(-6.0788)	(-2.6541)	(-8.0693)	(-4.2925)
CV	No	Yes	No	Yes
Variance:				
sigma2_e	3.0861[a]	2.5096[a]	1.0176[a]	0.8156[a]
	(13.6375)	(13.9090)	(13.6849)	(13.8962)
N	390	390	390	390

Notes: [a], [b], and [c] denote significance at the 1%, 5% and 10% level, respectively. The values in () represent the t statistics.

results of direct effect, indirect effect and total effect of green finance on carbon emission intensity. In Table **11**, we can see that the coefficient of spatial lag effect value of Pco_2 is positive, indicating that carbon emission intensity has spatial autocorrelation, which verifies the previous spatial autocorrelation test results.

In addition, by gradually adding control variables to test the impact of green finance on Pco_2, it is observed that green finance has a negative impact on the carbon emission intensity of the province and its neighbors. Wang *et al*. (2021) found that green finance in China's Yangtze River economic belt has a positive impact and spatial spillover effect on the high-quality development of energy. This is similar to the results of this paper. It indicates that the carbon emission reduction effect of green finance has both local and external effects, which verifies **Hypothesis 4**.

5. RESULTS AND POLICY IMPLICATIONS

From the perspective of carbon emission reduction, this paper analyzes how green finance affects carbon emission to achieve carbon neutrality. Specifically, based on China's provincial panel data from 2007 to 2019, and on constructing the provincial level green finance development index, this paper studies the impact of green finance on carbon emission intensity and its impact mechanism by using SYS-GMM, KHB, panel threshold regression and spatial Durbin model. The results show that: first, green finance has the effect of carbon emission reduction. This conclusion is still valid after a series of robustness tests. Second, the carbon emission reduction effect of green finance presents an asymmetric effect between financially developed areas and financially underdeveloped areas, industrially developed areas and industrially underdeveloped areas. Specifically, the negative impact of green finance on carbon emission intensity in financially underdeveloped areas and industrialized underdeveloped areas is more obvious. Third, the main channels for green finance to promote carbon emission reduction are: FDI, energy consumption scale, energy intensity, green technology innovation, industrial structure upgrading, and energy structure. Finally, the impact of carbon emission intensity of green finance has nonlinear spillover effect and spatial spillover effect.

Based the above conclusions, this paper puts forward the following policy suggestions. First, it is important to vigorously develop green finance. It is necessary to establish the strategic thinking of collaborative development of green financial system. The construction of green financial system is a systematic project, which needs to gather all forces in the field of green finance (including the state monetary administration, various departments, local governments, financial institutions and enterprises) to cooperate with each other and share information, improve the regulatory rules of green finance, unify the industrial standards of green finance, promote the sharing of environmental data and information, strengthen the carbon information disclosure of enterprises, innovate institutional arrangements, and build a reasonable policy framework and incentive mechanism to stimulate the enthusiasm of green finance to support low-carbon (negative carbon) projects, such as tax subsidies for low-carbon projects, the establishment of monetary policy tools for carbon emission reduction, and the establishment of national low-carbon transformation fund, etc.

Second, it is important to implement differentiation strategies according to the characteristics of different regions. Taking China as an example, for financially developed regions, it is important to strengthen the synergistic emission reduction effect of green financial policies and other environmental protection policies, and comprehensively strengthen the incentive and restraint mechanism of green investment and financing. In addition, it can also give play to the capital advantages of financially developed regions, establish a green investment fund with the participation of social capital, give play to the guiding role of public funds and reduce the overall investment risk. For financially underdeveloped regions, it is needed to improve residents' awareness of low-carbon environmental protection, innovate green financial products and services, improve the financing capacity of low-carbon compensation projects. For industrially developed regions, it is important to establish and strengthen the incentive mechanism of green finance to support low-carbon (negative carbon) industries. Government should clarify the development direction of low-carbon industry, formulate incentive policies such as tax relief, financial interest discount and provision before tax, provide risk compensation and establish guarantee fund, and give financial institutions incentives, interest discounts, risk sharing, linked financial deposits and other support to carry out green financial business. For industrially underdeveloped regions, it is necessary to promote the mandatory ESG information disclosure system. Enterprises should take the initiative to disclose carbon information, and various financial institutions should also play the role of financial leverage to promote invested enterprises and loan enterprises to improve environmental management and information disclosure. At the same time, it is needed to regularly evaluate green financial projects, establish a perfect supervision and information disclosure system, and promote financial institutions to bear and fulfill the social responsibility of environmental protection while preventing risks.

Third, it is necessary to furtherly deepen the level of opening-up, reduce the scale of energy consumption, reduce the intensity of energy consumption, strengthen green technology innovation, and promote the upgrading of industrial structure and the transformation of energy structure. First of all, it is necessary to strengthen global cooperation, improve the international trade environment and conditions, establish an incentive mechanism for international cooperation supporting carbon neutralization by green finance, and strengthen the cooperation supervision and restriction mechanism among countries to prevent carbon leakage. Then, it is crucial to strengthen the financing restraint mechanism and punishment mechanism of green finance for high energy consumption enterprises, force them to withdraw from the market, or reduce the scale of energy consumption through technological transformation, improve energy efficiency and reduce energy consumption intensity. At the same time, provide diversified financing support for enterprises providing low energy consumption products, and provide subsidies to consumers who buy low-carbon and energy-saving products, improve the utility level of consumers. What’s more, it is important to strengthen the support of green finance for green technology innovation. It is needed to consolidate the foundation of the government, improve the coordination and linkage of policies, strengthen the market synergy, establish a comprehensive financial support mechanism, improve the recognition and the loan efficiency for green technology projects. Furtherly, the leverage of green finance should play an important role in promoting the upgrading of industrial structure and the transformation of energy system. On the one hand, from the production side, it is needed to control and tighten the production investment loans related to coal industry, encourage the upgrading and transformation of coal and other industries, and support the development and use of alternative energy (natural gas, wind energy, hydropower and solar energy). On the other hand, from the consumer side, it should support the development and use of efficient energy consumption technologies and promotes the optimization and adjustment of regional industrial and energy structure. Last but not least, it is important to strengthen the support of green finance for government and public environmental regulation tools, reduce the financial burden of the government, guide the public to establish the concept of low-carbon development, complement each other with different environmental regulation tools to play a crucial role in reducing carbon emission.

Fourth, it is crucial to enhance the incentive effect of green finance on carbon emission reduction. The carbon emission reduction effect of green finance has the nonlinear feature of diminishing marginal effect, which reflects that the constraint effect of green finance is greater than the incentive effect. While reducing the financing scale of high-carbon enterprises, it inhibits the technological innovation of these enterprises, and does not significantly alleviate the financing constraints of low-carbon innovative enterprises. Therefore, on the one hand, we need to increase financial support for the transformation and upgrading of high-carbon enterprises, guide enterprises to increase innovation investment, and encourage enterprises to achieve low-carbon development through technological transformation, process improvement and product innovation. In addition, it is also necessary to improve the carbon information disclosure mechanism, energy conservation and emission reduction information sharing mechanism and credit investment tracking mechanism between financial institutions and high-carbon enterprises, increase financial support for enterprises actively seeking transformation. On the other hand, we need to increase financial support for low-carbon innovative enterprises, increase the financing channels and long-term financing scale of low-carbon enterprises, innovate financial products and services, such as carbon credit, carbon trust, carbon futures, carbon options and other financial products, and promote the integration of green finance with financial technology and digital finance, innovate the service means and mode of green finance to support low-carbon enterprises, and provide accurate, efficient and sustainable financial support for low-carbon enterprises. Last but not the least, the spatial spillover effect of green finance on carbon emission intensity shows that regions should strengthen cooperation and innovate green financial products and services so as to give full play to the carbon emission reduction effect of green finance to a greater extent.

Although this paper quantitatively analyzes how green finance influence carbon emissions to achieve carbon neutrality in China, and provides new empirical evidence and some important insights, there is still much room for improvement in this research. Firstly, there are very significant differences in the economic and social development of cities in China's province. In the future, when the research data are available, we can further analyze how green finance promotes carbon neutralization from a more micro urban level to enhance the explanatory power. Secondly, fintech has developed rapidly in recent years, which has a great impact on economic and social life. In the future, we can make an in-depth analysis from the perspective of how fintech can enable green finance to realize carbon neutrality. Third, this paper does not discuss how green finance can promote carbon neutrality from the perspective of carbon sink, which can be studied in the future. Moreover, in the future, we can analyze the carbon emission reduction effect of green finance among different countries from an international perspective.

DECLARATIONS

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

Data are available from the National Bureau of Statistics of China or can be obtained from the authors on reasonable request.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

APPENDIX A

Table A.1: Summary of Highly Cited Literature, Hot Papers and Review Papers

Type	Authors	Journal	Contends	Method	Results
Highly cited literature	An *et al*.(2021)	European Journal of Operational Research	Design green credit financing (GCF) model subject to hard emission constraint. Compare GCF with trade credit financing (TCF) in supply chain context.	Equilibrium model analysis	Both GCF and TCF can effectively restrain the manufacturer's carbon emission. There exist win-win situations for the manufacturer and the supplier.
	Le *et al*. (2020)	Finance Research Letters	Examine the impact of financial inclusion on CO_2 emissions in Asia from 2004 to 2014.	Driscoll-Kraay standard errors for linear panel models	Financial inclusion increases CO_2 emissions.
	Lund *et al*.(2017)	World Development	This paper analyzes forest policy (Participatory Forest Management (PFM) and REDD+) change in Tanzania over three decades.	Comparative research method	Both forest policy epochs feature initial enthusiasm and substantial donor financing. Neither policy has achieved much beyond policy development and pilot projects.
	Nikolaeva *et al*. (2019)	Transactions of the Institute of British Geographers	Drawing on a global comparative research of low-carbon mobility transitions, this paper criticises the logics of scarcity that are ubiquitous in debates surrounding mobility and society in the 21st century.	Comparative research method	A logic of scarcity has been a driver for aspiring to greener, "smarter," and cheaper mobilities. Two responses to the logic of scarcity, that is, the logics of austerity and the logics of commoning.
	Sun *et al*. (2020)	Science of the Total Environment	This paper aims to investigate the achievements of sustainable development in Sub-Sahara Africa.	Autoregressive Distributed Lag model	There is an an inverted U-shaped Environmental Kuznets Curve in Sub-Saharan Africa. Environmental entrepreneurship could improve environmental quality.
Hot papers	Umar *et al*. (2021)	Journal of Environmental Management	This paper assesses the impact of carbon-neutral lending on the credit risk in the Eurozone.	Panel fixed effect model	Green loans improve the asset quality of banks. It is because of the low cash flow volatility of carbon-neutral obligors.

Review papers	Abolhosseini and Heshmati (2014)	Renewable and Sustainable Energy Reviews	This paper compares three main support mechanisms employed by governments to finance renewable energy development programs: feed-in-tariffs, tax incentives, and tradable green certificates.	Comparative research method	Employing a carbon emission tax or emission trading mechanism could be considered ideal policies to mitigate emissions at the lowest cost.
	Kennedy *et al.* (2016)	Engineering	Estimates of financing requirements are provided for multiple sectors. This paper discusses the context of China's green financing.	Literature research method	China has implemented many successful policies in the building sector, but there is still considerable scope for improvement in the energy efficiency of Chinese buildings.
	Fieldman (2020)	Sustainability	This article explains to the kind of regulation and public investment necessary, how to address the climate emergency and other environmental problems.	Literature research method	The levels of public and private investment are inadequate, both generally and in areas crucial to reduce carbon emissions.
	Woo *et al.* (2021)	Building and Environment	Systematically reviewed about applying blockchain technology for building energy performance measurement, reporting, and verification (MRV) and the carbon credit market.	Literature research method	Lowering the industry's carbon footprint has not been embraced by building owners. The building industry has not been able to participate in the carbon credit markets as well.
	Patel and Patel (2012)	Renewable and Sustainable Energy Reviews	This paper exhibits the green initiatives taken by Claris Lifesciences Ltd.	Literature research method and case study method	Claris has access to monetary incentives by way of revenue generation from trading of carbon credits.

The references in **Table A.1** are as follows.

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APPENDIX B

We selected these data due to the following reasons. First, the dataset includes 20 types of energy consumption and further considers the CO_2 emissions from cement production processes, which makes emissions data more comprehensive and accurate[7#]. Second, most existing studies used the default emission factors recommended by the IPCC, which has been shown by scholars to be higher than China's survey values (Liu *et al*., 2015). Third, the dataset includes energy consumption and CO_2 emissions data of China's 30 provinces from 2000 to 2019, which provides data support for the further analysis of China's environmental issues. The data can be downloaded freely from China Emission Accounts and Datasets, and these data have been used by a number of scholars (Shan *et al*., 2018; Li *et al*., 2019; Zheng, *et al*., 2019).

[7#] The 20 energy sources are raw coal, cleaned coal, other washed coal, briquettes, coke, coke oven gas, other gas, other coking products, crude oil, gasoline, kerosene, diesel oil, LPG, refinery gas, other petroleum products, natural gas, heat, electricity, and other energy.

APPENDIX C

The reason for this difference is that most of the provinces with carbon peak around 2013 are located in the Middle or Eastern China, and the early industrialization development has led to a sharp rise in carbon emissions. Then, with the introduction of China's low-carbon policy and economic transformation, the awareness of low-carbon environmental protection in these provinces has been strengthened. In addition, the pollution control fund is relatively abundant, so its economic development model changes rapidly. Therefore, the peak appears earlier. Most of the provinces with the peak around 2016 are located in western China, with lagging economic development and slow transformation of industrial and energy structure, so the peak appears later. However, the CO_2 emissions in Fujian, Guangdong, Jiangxi, Guangxi, Shandong, Hainan, Gansu, Shanxi, Inner Mongolia, Zhejiang, Ningxia, Liaoning and Xinjiang have not peaked, and the total CO_2 emissions have been on the rise. The main reason is that these provinces have rapid economic development, high population density and serious resource consumption. What's more, some provinces are resource-based provinces, fossil fuels account for a large proportion in the industrial structure and energy consumption is large. Some provinces are located in western China, and their industrial structure lags behind, resulting in a large number of carbon emissions.

APPENDIX D

There are many methods to measure the upgrading of industrial structure. This paper uses Moore index to measure the upgrading of industrial structure. The industry is divided into m industrial sectors. The ratio of m industrial output value to total output value constitutes an m-dimensional vector. If the industrial structure of the same region will change in phase t and phase t +1, an included angle will be formed between the m-dimensional vectors of phase t and phase t+1. The cosine value of the included angle is used to measure the upgrading degree of industrial structure. After the industrial structure of region i from phase t to phase t+1, the Moore value is calculated as follows.

$$Moore^{i}_{i,t+1} = \mathrm{Cos}(\theta^{i}_{i,t+1}) = \sum\nolimits_{j=1}^{m}(p^{j}_{i,t} \bullet p^{j}_{i,t+1}) \,/\, \sqrt{\sum\nolimits_{j=1}^{m}(p^{j}_{i,t})^{2} \bullet \sum\nolimits_{j=1}^{m}(p^{j}_{i,t+1})^{2}} \quad (15)$$

where $p^{j}_{i,t}$ represents the ratio of industrial output value of region i in phase t to current GDP. Although model 10 can represent the overall degree of cross period industrial structure change in a region, it cannot reflect the direction of industrial structure change. According to *Zhang Yong, PU Yongjian. Industrial structure change and its effects on energy intensity [J]. Industrial economic research, 2015, No. 75 (02): 15-22 + 67. DOI:10.13269/j.cnki.ier.2015.02.002..* The measurement method is improved. The industrial level is divided into six industries from low to high, and the change degree of each industry is calculated.

The calculation method is based on Model 10. When calculating the Moore value of industry *j* in region *j*, first assume that the proportion of other industries other than industry j in phase t is the same as that in phase t, and then assume that the proportion of other industries in phase t in region i is the same as that in phase t+1. Calculate the Moore value of industry j from phase t to phase t+1 under different assumptions. Then, take the geometric average of two Moore values as the upgrading degree of the j industry in region i from phase t to phase t+1. Finally, the Moore values of all industries are aggregated, and the industries arranged at position j are repeatedly superimposed j times to indicate the direction of industrial structure upgrading. In addition, the weight of each industry is fully considered when calculating the Moore value of region i.

First of all, this paper calculates the transition of the jth industry in region I, using the $Moore_{i,t+1}^{i,j}$ of the transformation that is from the tth period to the t+1 period.

$$Moore_{i,t+1}^{i,j} = \sqrt{\left[\frac{\sum_{k\neq j}(p_{i,t}^{k})^2 + p_{i,t}^{j} \bullet p_{i,t+1}^{j}}{\sqrt{\sum_{k=1}^{m}(p_{i,t}^{k})^2 \bullet \left[\sum_{k\neq j}(p_{i,t}^{k})^2 + (p_{i,t+1}^{j})^2\right]}}\right]} \bullet \sqrt{\left[\frac{\sum_{k\neq j}(p_{i,t+1}^{k})^2 + p_{i,t}^{j} \bullet p_{i,t+1}^{j}}{\sqrt{\sum_{k=1}^{m}(p_{i,t}^{k})^2 \bullet \left[\sum_{k\neq j}(p_{i,t+1}^{k})^2 + (p_{i,t}^{j})^2\right]}}\right]} \quad (16)$$

Then, we calculate the industrial structure change values $Moore_{i,t+1}^{i}$ of the t and t+1 periods in region i.

$$Moore_{i,t+1}^{i} = \sum_{j=1}^{m}\left[j \bullet p_{i,t}^{j} \bullet Moore_{i,t+1}^{i,j} \right] \quad (17)$$

Specifically, this paper selects the added value of 6 industries in 30 provinces of China from 2007 to 2019 (Tibet, Hong Kong, Macao and Taiwan are excluded due to too many missing data), including primary industry, industry, construction industry, transportation, warehousing and postal industry, retail accommodation and catering industry, real estate and financial industry, measure the upgrading degree of industrial structure of 30 provinces and cities by using Moore index, and the specific calculation process is available.

APPENDIX E

Financially developed regions include: Beijing, Tianjin, Liaoning, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Shandong, Henan, Hubei, Guangdong, Chongqing, Sichuan.

Financially underdeveloped regions include: Hebei, Shanxi, Inner Mongolia, Jilin, Heilongjiang, Jiangxi, Hunan, Guangxi, Hainan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang.

Industrially developed regions include: Beijing, Tianjin, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Shandong, Hubei, Guangdong, Chongqing.

Industrially underdeveloped regions include: Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Jiangxi, Henan, Hunan, Guangxi, Hainan, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang.

APPENDIX F

Compared with other mediation effect test methods, Bootstrap has higher statistical effect, so we use Bootstrap approach to analyze the mediation effect to verify the robustness of the mediation analysis results. In Table **F.1.,** we can see that taking *ei*, *es*, *esc*, *FDI*, *ins* and *grep* as intermediary variables, the indirect effect coefficient value passed the significance test, and the confidence interval of _ bs_ does not contain 0. Results show that the original hypothesis was rejected, so the mediation effect was established, which verifies the robustness of KHB mediation effect estimation method.

Table F.1: Intermediary Test Results of Bootstrap Approach

M=*ei*			
	Observed coefficient	Z	[95% conf. interval]

_bs_1	-1.5050 (0.4856)	-3.10	(-2.4478, -0.5357) (P)
	[0.0020]		(-2.5204, -0.6402) (BC)
_bs_2	-2.5834 (0.7308)	-3.53	(-3.9761, -1.0164) (P)
	[0.0000]		(-3.9181, -0.9662) (BC)

M=*es*			
_bs_1	-0.3387 (0.1447)	-2.34	(-0.6271, -0.0486) (P)
	[0.0190]		(-0.7133, -0.0880) (BC)
_bs_2	-3.7497 (0.9213)	-4.07	(-5.4553, -2.0111) (P)
	[0.0000]		(-5.5049, -2.0585) (BC)
M=*esc*			
_bs_1	-1.2393 (0.3801)	-3.26	(-1.9588, -0.4503) (P)
	[0.0010]		(-1.9745, -0.4805) (BC)
_bs_2	-2.8491 (0.8234)	-3.46	(-4.4821, -1.2571) (P)
	[0.0010]		(-4.4900, -1.2750) (BC)
M=*FDI*			
bs_1	-1.8570 (0.3599)	-5.16	(-2.6157, -1.2367) (P)
	[0.0000]		(-2.6113, -1.2167) (BC)
bs_2	-2.2314 (1.0301)	-2.17	(-4.2720, -0.1985) (P)
	[0.0300]		(-4.4020, -0.5213) (BC)
M= *ins*			
bs_1	-0.9251 (0.2273)	-4.07	(-1.3936, -0.5150) (P)
	[0.0000]		(-1.4370, -0.5422) (BC)
bs_2	-3.1633 (0.9536)	-3.32	(-4.9535, -1.2643) (P)
	[0.0010]		(-5.0417, -1.4049) (BC)
M=*grep*			
bs_1	-1.3454 (0.2599)	-5.18	(-1.8546, -0.8378) (P)
	[0.0000]		(-1.9547, -0.8760) (BC)
bs_2	-2.7430 (0.9142)	-3.00	(-4.5841, -0.9407) (P)
	[0.0030]		(-4.5863, -0.9643) (BC)
M=*ers*			
bs_1	-0.0270 (0.0695)	-0.39	(-0.1928, 0.0936) (P)
	[0.6970]		(-0.3392, 0.0318) (BC)

bs_2	-4.0614 (0.8964)	-4.53	(-5.8013 -2.2211) (P)
	[0.0000]		(-5.7283, -2.1472) (BC)

Notes: _bs_1: r(ind_eff) denotes indirect effects. _bs_2: r (dir_eff) denotes direct effects. P denotes Percentile, and BC is Bias-corrected. Standard errors of Bootstrap are in (). P value is in [].

APPENDIX G

LM test results show that the panel model should include spatial effects. The robust LM test results show that under the condition of pointing to the spatial lag model, the original hypothesis cannot be rejected, that is, the robust LM test points to the spatial lag model. However, the LR test results show that the spatial Durbin model should be selected. According to *Elhorst, J. P. (2014). Matlab software for spatial panels. International Regional Science Review, 37(3), 389-405.*, a more general spatial SDM model can be used for spatial econometric estimation. In addition, the fixed effect test results show that the spatial SDM model containing time fixed effect should be selected for regression estimation.

Table G.1: Model Selection Tests

LM test	LM (lag)	LM (error)	Robust LM (lag)	Robust LM (error)
	7.260*** [0.007]	15.909*** [0.000]	0.223 [0.637]	8.872*** [0.003]
LR test	H_0: SAR model		H_0: SEM model	
	16.43** [0.0116]		18.70*** [0.0047]	
Fixed effects test	H_0: Province fixed effects		H_0: Time fixed effects	
	14.40 [0.1556]		804.76*** [0.0000]	

Note: The values in [] are P statistics.

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Received on 23-11-2023 Accepted on 15-12-2023 Published on 23-12-2023

DOI: https://doi.org/10.12974/2311-8741.2023.11.08

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