The impact of green finance on low carbon economic development in the context of carbon neutrality: evidence from China

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Abstract

The global climate crisis has become the focus of attention, and China vigorously pursues low-carbon economic development, for which the implementation of green finance is continuously enhanced, so does the development of green finance contribute to low-carbon economic development? This paper constructs a green finance and low carbon economic development index system containing several indicators, and measures them using the entropy weight method of spatial-temporal extreme difference. This paper conducts an empirical study based on the data of 30 provinces and cities from 2005 to 2020, and the results of the study find that green finance has policy incentive effect and institutional incentive effect, and can significantly and positively affect the development of low-carbon economy, and the findings still hold after endogeneity test and robustness test. The mechanism test shows that green finance can influence low-carbon economic development by promoting industrial structure upgrading, green technology innovation and FDI inflow; moreover, the positive promotion effect of green finance is more obvious in the western region and non-Yangtze River Economic Zone region; finally, the moderating effect test reveals that the institutional environment and the level of technology market development can enhance the relationship between green finance and low-carbon economic development.

1. Introduction

Since 1978, China has experienced rapid economic growth, but some problems in the process of economic development, such as overcapacity, sloppy production methods and environmental pollution, need to be addressed urgently, not only for the development of a low-carbon economy, but also for sustainable economic development. China's economy is not only facing the problems described earlier, but it is also suffering from severe tests under the influence of factors such as the new crown pneumonia, trade protection, and reverse globalization, and along with the global climate crisis, natural disasters are occurring frequently, and ecological environmental protection issues are drawing more attention and importance.

It is a common problem for the world to deal with global climate change, and developing countries in particular are facing the contradiction between economic development and carbon emission reduction, and it is a major challenge to achieve the goal of carbon emission reduction while economic development. Compared with other types of greenhouse gases, carbon dioxide has the characteristic that it cannot be eliminated by chemical methods, so the only solution to the current situation of climate warming is to try to reduce carbon dioxide emissions. Now that China has risen to the first place in the world in terms of carbon emissions, there is a great concern whether it can effectively control the intensity of carbon emissions and further improve the efficiency of carbon emissions. Chinese President Xi Jinping has proposed that China will strive to peak its carbon dioxide emissions by 2030 and strive to achieve carbon neutrality by 2060. The application of science and technology is only one aspect of how to achieve peak carbon and carbon neutrality in this context, while another important aspect is how to better handle the relationship between the economy and carbon emissions.

At present, China's environmental governance system and approach are undergoing a huge transformation. Under the requirement of high-quality development, China attaches great importance to the development of low-carbon economy, and the concept of green development is gaining popularity. Green finance is a financial measure taken by China to reduce energy consumption, increase the use of new energy and achieve low-carbon environmental protection, including green credit, green bonds and green insurance. Among them, green credit is an important part of green finance. By the end of 2020, the balance of green loans in China's domestic and foreign currencies was nearly 12 trillion yuan, the largest in the world, and the impact of green finance on supporting the achievement of carbon peaking and carbon neutral goals is gradually expanding. Building a green financial system through government guidance and using the financial services industry to support the development of green industries is a more important and long-term means and support for reducing carbon emissions, and is also a concrete form of market-incentivized environmental regulation policy. In the process of China's modernization, environmental protection, green and low carbon will become more and more prominent, so this study introduces green finance into the low carbon economy research framework in line with the current development context of China.

It can be seen that green finance plays an important role in the development process of low carbon economy. This paper uses data from 30 Chinese provinces and cities to measure the green finance and low-carbon economic development index by the entropy weighting method of spatio-temporal extreme difference, and discusses its impact on low-carbon economy from the perspective of green finance. In the context of China's current deepening reform and pursuit of high-quality development, it is important for achieving low-carbon economic growth. The marginal contributions of this paper may be the following three points: (1) measuring the green finance and low-carbon economic development index by the entropy weighting method of temporal and spatial extreme differences, which combines green finance and low-carbon economic development and enriches green finance research, providing relevant perspectives and empirical methods for subsequent studies; (2) empirically analyzing the impact of green finance on low-carbon economy and finding that green finance can promote low-carbon economic development, complementing the research on the mechanisms by which finance affects the development of low-carbon economy; (3) regional heterogeneity is found in the promotion effect of green finance, and the institutional environment and the level of technology market

development can play a positive moderating role.

2. Literature review

The study of carbon emissions firstly focuses on the measurement of its emission intensity, such as Hammond and Norman (2012), Hasanbeigi et al. (2016), Zhang (2008), and Du et al. (2010), who have conducted studies on carbon emissions accounting. More literature support can also be found in the studies of factors affecting carbon emissions, Chen (2011) argues that changes in energy structure play the most critical role in achieving a decrease in carbon emission intensity of Chinese industries; Lin and Li (2015) similarly argues that upgrading energy structure can maintain economic growth and reduce carbon emissions; Yu et al. (2015) argue that for most provinces and regions in China carbon emission intensity, the increase in the share of the third industry and the rise in per capita GDP both have the effect of reducing the carbon emission intensity of industries; Yan et al. (2017) found that there is a significant negative effect of carbon price policy on carbon intensity; Guo and Feng (2019) verified that one of the main factors to promote the reduction of carbon emission intensity is technological progress. As for the research on low-carbon economy, there is still less literature, and a part of scholars study the impact of carbon finance on enterprise technology innovation from the perspective of low-carbon economy (Li et al., 2023), the impact of low-carbon city pilot on enterprise performance and export product quality (Tian et al., 2022; Sha and Peng, 2023), the impact of green industrial policy on low-carbon economy (He et al.) and the impact of urban innovation on the development of low-carbon economy (Wang et al., 2022); another part of scholars have made comprehensive measurements of low-carbon economy (Ding et al., 2023; Wu, 2022; Liu et al., 2021; Zhou and Qin, 2020); and from the perspective of green finance, the study of its impact on low-carbon economy has gradually attracted the attention of scholars, but it is still relatively lacking .

Pan and Dong (2023) argue empirically that the implementation of FET and RECT can not only reduce CO2 emissions but also increase the share of tertiary sector and new energy use. Yu et al. (2022) find that the implementation of green digital finance can reduce energy dependence, promote new energy use and reduce carbon emissions. Lee et al. (2023) argued that the promotion and implementation of green finance can contribute to the development of a low-carbon economy, and that the effect of green finance is more significant in regions with stronger carbon emissions, while financial development and the level of higher education play a moderating role between them. Du (2023) argued that green finance can reduce carbon emissions, and the effect is verified both in the short and long term, while the increase in renewable energy technologies and the use of renewable energy technologies are also verified in the long term. Li et al. (2023) argue that increased green financing can reduce CO_2 emissions. Other scholars have reached similar conclusions (Imran et al.,2023; Zhang,2022; Sun,2023; Jin et al.,2023; Qin et al.,2023). Green finance as a financial policy, Chinese scholars have focused their research on whether green finance policy has an impact on corporate behavior and economic conditions, and related studies such as green credit has a significant inhibitory effect on investment and financing of heavy pollution enterprises (Su and Lian, 2018), is conducive to industrial upgrading of China's secondary industry, and is an important way of industrial upgrading in China (Li et al. 2020), green credit promotes the growth of green economy through technological progress (Xie and Liu, 2019), and Yin et al. (2019) found that green credit has a positive effect on reducing carbon emission intensity using provincial data in China. Some scholars have also directly conducted empirical studies on the relationship between both green finance and low-carbon economy. Based

on Chinese provincial and municipal data, Li and Liu (2023) developed a spatial econometric model and found that green finance can promote the development of low-carbon economy and there is a spillover effect. Guo (2022) used Chinese provincial and municipal data to construct a spatial association equation, and the empirical results found that there is a significant positive relationship between green finance and low carbon economy.

Synthesizing the above studies, it can be seen that scholars at home and abroad basically believe that green finance can reduce carbon emissions and promote the development of low-carbon economy, but there are some differences between existing studies on the measurement of green finance and low-carbon economy, and there is room for improvement. This paper measures the development of China's low-carbon economy by the entropy weight method of spatio-temporal extreme difference, and, by using multiple indicators to synthesize the green finance index, it can more comprehensively and reasonably represent its development level and make the empirical results more robust and reliable. Meanwhile, the influence mechanism of green finance on the development of low-carbon economy also needs to be supplemented and improved, and can be studied in a more detailed way. Therefore, it is of great practical significance to study the relationship between green finance and low-carbon economy on this basis.

3. Theoretical analysis and research hypothesis

3.1 The impact of green finance on low carbon economy

The implementation of green finance can produce policy incentive effect, local governments will actively respond to the call of the central government to vigorously promote green finance, and in the process of local government work will constantly emphasize the importance of green finance, require regional financial institutions to actively promote its implementation, give financial support to the implementation of green finance in the region, increase the investment of various green funds, support the development of green low-carbon industries, and expand its financing channels, and under the role of monetary policy, it can effectively expand credit allocation (Campiglio, 2016), enhancing the positive impact of green finance; at the same time, green finance will also produce corresponding institutional incentive effects, which can prompt investors to pay more attention to carbon emission-related information, promote the improvement and development of carbon information disclosure system, and guide enterprises to carbon emission reduction. Moreover, it helps to promote the carbon trading system, drive more enterprises to participate in carbon trading, and accelerate the process of carbon neutrality. Based on the above analysis, this paper proposes research hypothesis 1:

Hypothesis 1: Green finance can promote the development of low-carbon economy.

3.2 The impact of green finance on industrial structure upgrading

The development of China's economy relies heavily on a complete industrial system, and the growth of industrial enterprises has promoted employment, increased tax revenue and driven the development of upstream and downstream industries, but the high proportion of industrial enterprises in the national economy has also produced some negative effects, such as air pollution, river pollution and greenhouse gas emissions. In particular, the high carbon emissions have caused huge economic and environmental losses to the economy and society, and the transformation of industrial structure is a real economic problem for China. In the development

and promotion of green finance, on the one hand, it can promote the flow of capital to the clean production industry, increase the financing constraints of the polluting production industry, so that factors flow to the clean production sector, expand the proportion of the clean production industry in the economy, promote the upgrading of industrial structure, reduce carbon emissions and promote the development of low-carbon economy; on the other hand, green finance can force enterprises with high carbon emissions to reform and optimize, either by introducing advanced carbon emission reduction technologies, improving production methods or developing new products, continuously promoting the transformation and upgrading of enterprises, and promoting their green and sustainable development. Based on the above analysis, this paper proposes research hypothesis 2:

Hypothesis 2: Green finance can promote low-carbon economic development through industrial structure upgrading.

3.3 The impact of green finance on green technology innovation

Innovation plays a key role in a country's economic growth, and China is currently facing economic transformation, which makes the importance of technological innovation even more prominent in the context of promoting double-cycle and high-quality development. High-quality development requires the reduction of carbon emissions, and in order to achieve carbon peaking and carbon neutrality and promote low-carbon economic development, green technology innovation is indispensable. On the one hand, green finance can expand the proportion of clean and environmentally friendly enterprises, which will continue to gain a competitive advantage in the market, and the cash flow and profit performance of enterprises will be better, and enterprises will invest funds in scientific and technological research and development to promote green technological innovation; on the other hand, green finance will make enterprises with high carbon emissions face development challenges, and enterprises will face increased pressure in terms of bank credit and local government regulation, which will force On the other hand, green finance will make enterprises with high carbon emissions face development challenges, and the pressure of enterprises in terms of bank credit and local government regulation will increase, which will force enterprises to carry out green technology innovation, change the status quo of high carbon emissions and promote green production. Based on the above analysis, this paper proposes research hypothesis 3:

Hypothesis 3: Green finance can promote the development of low-carbon economy through green technological innovation.

3.4 The impact of green finance on FDI

The high growth of China's economy cannot be separated from the contribution of FDI, and the continuous large inflow of FDI indicates the development potential of the Chinese market. In international trade, due to the strong environmental control in developed countries or regions, enterprises in developed countries or regions will move outward, however, the transferred industries are not clean and pollution-free, but mostly still industries with lower technology level, higher pollution and energy consumption, because the economic development of other countries or regions is more backward, people's income level is lower, and the expansion of industrial scale

is more needed, these FDI inflows will increase the environmental pollution in these countries or regions. Under the development of green finance, local governments will prefer enterprises with less pollution and low carbon emissions when selecting foreign investment, and those FDI enterprises with high quality and less pollution will be more willing to enter the Chinese market under the vigorous development of green finance and low carbon economy in China. Based on the above analysis, this paper proposes research hypothesis 4:

Hypothesis 4: Green finance can promote the development of low-carbon economy by attracting FDI inflows.

4.   Study Design

4.1. Building a green finance and low carbon economy indicator system

At present, the measurement of green finance is mostly measured by the entropy method, but the selection of indicators can be further expanded, because green finance contains multiple aspects. Therefore, in this paper, based on previous studies, the comprehensive measurement of green finance is based on seven aspects: green credit, green investment, green insurance, green bond, green support, green fund and green equity. The specific indicators of green finance are shown in Table 1.

As to how to measure the development of low carbon economy in China, there is no unified way to measure the low carbon economy in the current study, because the development of low carbon economy involves many aspects, therefore, this paper draws on the formulation and indicator construction of low carbon economy by Fu et al. (2010), and measures it through the entropy weight method. The specific indicators of low-carbon economy are shown in Table 2.

The data utilized are from China Statistical Yearbook of Science and Technology, China Statistical Yearbook of Energy, China Financial Yearbook, China Statistical Yearbook of Agriculture, China Statistical Yearbook of Industry, China Statistical Yearbook of Tertiary Industry, and the State of the Environment Bulletin. For the measurement of green finance and low-carbon economy, the spatio-temporal extreme difference entropy weight method is used, drawing on the method of Zhang et al. (2020).

Table 1 Green finance index system construction

Level 1 indicators	Secondary indicators	Measurement Methodology	Indicator Direction
Green Credit	Percentage of credit for environmental projects	Total credit for environmental projects in the province/Total credit in the province	+
Green Investment	Investment in environmental pollution control as a percentage of GDP	Investment in environmental pollution control/GDP	+
Green Insurance	Extent of promotion of environmental pollution liability insurance	Environmental pollution liability insurance income / Total premium income	+
Green Bond	Degree of green bond development	Total green bonds issued/Total all bonds issued	+
Green Support	Percentage of financial environmental protection expenditure	Financial environmental protection expenditure/Financial general budget expenditure	+
Green Fund	Percentage of green fund	Total market value of green funds / Total market value of all funds	+
Green Rights	Green equity development depth	Carbon trading, energy use rights trading, emission rights trading / Total equity market trading	+

Note: "+" indicates a positive indicator, and "-" indicates a negative indicator.

Table 2 Construction of low-carbon economy index system

Level 1 indicators	Secondary indicators	Measurement Methodology	Indicator Direction
Low Carbon Output Indicators	Carbon productivity	GDP/Carbon emissions	+
	Energy processing conversion efficiency	Energy input volume/Energy output volume	+
Low Carbon Consumption Indicators	Carbon emissions from residential consumption	Carbon emissions/Household consumption expenditure	-
	Government consumption carbon emissions	Carbon emissions/Government consumption expenditure	-
Low Carbon Resource Indicators	Zero carbon energy share	Zero carbon energy consumption/Energy consumption	+
	Energy carbon emission factor	Carbon emissions/Energy consumption	-
	Carbon sink density	Carbon sink volume/Area	+
Low Carbon Policy Indicators	Low carbon economic development planning	Yes or No	+
	Establishing carbon emission monitoring, statistics and supervision system	Yes or No	+
	Level of public knowledge of low-carbon economy	Prevalence %	+
	Implementation rate of environmental protection and energy saving standards	Degree of implementation %	+
	Carbon tax policy	Yes or No	+
Low Carbon Environmental Indicators	Carbon emission intensity of waste	Waste carbon emissions / Waste generation	-
	Industrial waste treatment index	Treatment rate %	+

Note: "+" indicates a positive indicator, and "-" indicates a negative indicator.

4.2. Model setup and data sources

To empirically investigate the impact of green finance on the low carbon economy, hypothesis H1 was tested and the following model was constructed:

$$lced_{it} = \beta_0 + \beta_1 gf_{it} + X'_{it} + \alpha_i + \delta_t + \varepsilon_{it} \quad (1)$$

In model (1), the subscript i is the province and city, t is the year, the explained variable $lced_{it}$ represents the low-carbon economic development level of each province and city, and the explanatory variable gf_{it} represents the green finance development level of a province and city.

X'_{it} represents some provincial-level control variables that will affect the development of low-carbon economy, α_i is the provincial fixed effect, δ_t is the time fixed effect, and ε_{it} is the random error term. In order to eliminate the possible impact of outliers, this paper performs a shrinking treatment of bilateral elimination of 1% for all variables. At the same time, in view of data limitations, this paper selects the panel data of 30 provinces and cities in China for empirical research, excluding the Tibet Autonomous Region and Hong Kong, Macao and Taiwan regions, and the time span is 2005-2020. The data comes from the statistical yearbooks of various provinces and cities from 2006 to 2021.

The specific definitions and measurements of the variables are shown in Table 3.

Table 3 Variable description

Variable Name	Variable Symbols	Variable Meaning	Measurement Method
Explained variable	lced	Low carbon economic development	Spatio-temporal extreme difference entropy weight method synthesis
Explanatory variable	gf	Degree of green finance	Spatio-temporal extreme difference entropy weight method synthesis
Control variables	lvh	Degree of greening in the built-up area	Greening coverage of built-up areas
	indus	Industrialization level	Value added of secondary industry/GDP
	lnpe	Population density size	Population density is taken as logarithm
	tran	Traffic convenience	Urban road area per capita is taken as logarithm
	gs	Government size	Government budget expenditure/GDP
	er	Environmental regulation	Industrial pollution control completed investment / Secondary industry added value
	ee	The importance the government places on education	Government education expenditure/Government budget expenditure

Table 4 shows the results of descriptive statistics. It can be seen that the minimum value of low carbon economic development is 0.0711 and the maximum value is 0.978, which indicates that the level of low carbon economic development in China is still low and there is a large gap between regions; the minimum value of green finance is 0.514 and the maximum value is 0.866, which is at a low level overall.

Table 4 Descriptive statistics

Variable	Obs	Mean	Std.Dev.	Min	Max
lced	480	0.464	0.258	0.0711	0.978
gf	480	0.684	0.0985	0.514	0.866
lvh	479	0.356	0.107	0	0.484
indus	480	0.358	0.0856	0.118	0.547
lnpe	479	7.812	0.496	6.209	8.689
tran	480	2.596	0.371	1.413	3.244
gs	480	0.238	0.107	0.0962	0.706
er	480	0.00345	0.00284	0.000210	0.0152
ee	480	0.144	0.0594	0	0.212

In order to be able to show a more intuitive overview of the development of green finance and low carbon economy in China, this paper selects the 2019 data of green finance and low carbon economy development and draws the corresponding maps using ArcMap10.2. From Figure 1 and Figure 2, we can see the performance of green finance and low carbon economy development in different regions. From Figure 1, it can be seen that the overall level of green finance development is still at a low stage, and only a few provinces have a high degree of green finance, but the proportion of the 30 provinces and cities is still very low. From Figure 2, it can be seen that only a few coastal provinces have a high level of low carbon economy development in China, while other regions have a low level of low carbon economy development. It indicates that China needs to continuously increase the implementation of green finance in its future economic development to enhance the development of low-carbon economy.
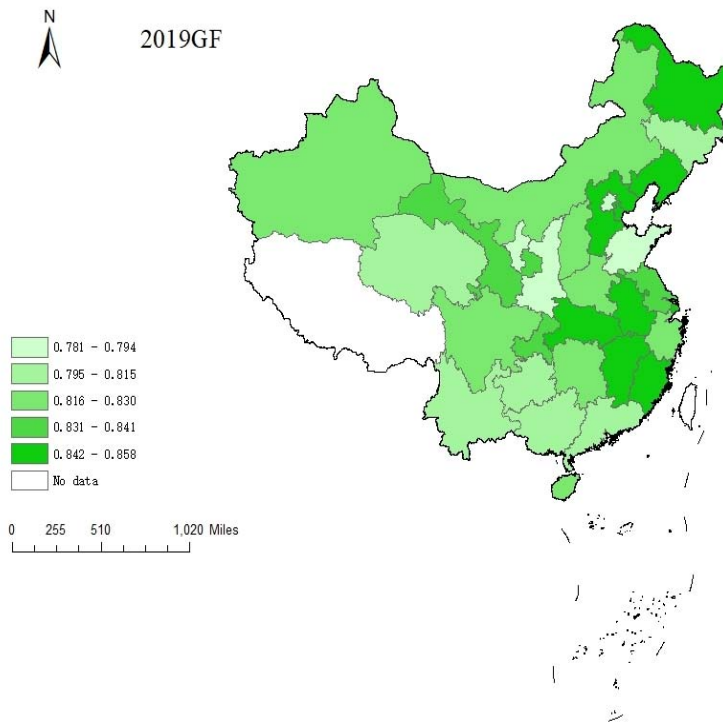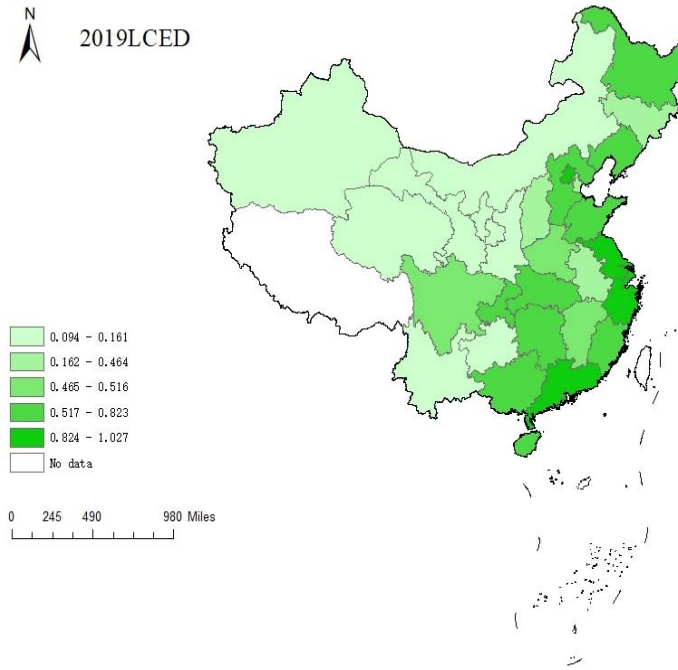

Fig. 1. Green finance developments in 2019

***Fig. 2.** Low carbon economic development in 2019*

5. Empirical result analysis

5.1. Analysis of baseline regression results

The table below shows the baseline regressions at the overall level of this paper, and the results are shown in Table 5. Column (1) is the regression result controlling for provincial and municipal fixed effects without adding control variables and time fixed effects; column (2) is the regression result adding provincial and municipal fixed effects and control variables without adding time fixed effects; column (3) is the regression result adding province fixed effects, time fixed effects and control variables at the same time. It can be found that the coefficients of green finance (gf) in columns (1), (2) and (3) are 0.662, 0.721 and 0.216, respectively, with all positive coefficients, among which the coefficients in columns (1) and (2) are significant at 1% significance level, and the coefficient in column (3) is significant at 10% significance level. The empirical results indicate that green finance can significantly promote the development of low-carbon economy. It indicates that green finance generates policy incentive effect and institutional incentive effect, widens the financing channels of low-carbon enterprises, expands the production scale of low-carbon industries, and makes more enterprises participate in the process of carbon information disclosure and carbon trading, which promotes enterprises to reduce carbon emissions and thus improves the development of low-carbon economy, which verifies hypothesis 1.

11

Table 5 Baseline regression results

Variables	(1) lced	(2) lced	(3) lced
gf	0.662***	0.721***	0.216*
	(10.07)	(8.12)	(1.94)
Province FE	YES	YES	YES
Year FE	NO	NO	YES
Control Variables	NO	YES	YES
Number of code	30	30	30
Observations	480	478	478
R-squared	0.599	0.631	0.669

*Notes: *, ** and *** represent significant levels of 10%, 5%, and 1%, respectively.*

5.2. Robustness tests

First, endogeneity test. In order to avoid the possible influence of endogeneity problem, this paper draws on the method of Xie and Hu (2023) and uses the product of the first-order difference between the lagged period of green finance and the first-order difference of green finance as the instrumental variable, and then conducts 2SLS regression, the results of which are shown in column (1) of Table 6. Among them, the value of K-P LM is 28.103, which indicates that the instrumental variable in this paper is not an unidentifiable instrumental variable; moreover, the values of C-D Wald F and K-P Wald F are 560.727 and 4868.073, respectively, which pass the test, indicating that there is no problem of weak instrumental variables and the instrumental variable in this paper is valid. It can be seen through column (1) that green finance can still significantly promote the development of low-carbon economy, which supports the conclusion of this paper.

Second, the effect of municipalities directly under the central government is excluded. Because Beijing, Shanghai, Tianjin, and Chongqing belong to the municipalities in China and have unique political status, they may have an impact on the results, and the regressions are conducted after excluding the municipalities, and the results are shown in column (2) of Table 6. It can be seen that the coefficient of green finance (gf) is 0.307, which is significant at the 5% significance level, further verifying the findings of this paper.

Third, control variables are added. Considering the problem of possible omitted variables, this paper adds a control variable, which is the degree of local emphasis on science and technology (measured by the proportion of local expenditure on science and technology to local expenditure), and then conducts a regression, and the specific results are shown in column (3) of Table 6. As can be seen, the coefficient of green finance (gf) is 0.219, which is significant at the 10% significance level, indicating that the conclusions of this paper remain robust.

In summary, through the endogeneity test and other robustness tests, the positive promotion effect of green finance on the development of low carbon economy remains significant, indicating the reliability of the findings.

Table 6 Robustness tests

Variables	(1) lced	(2) lced	(3) lced
gf	0.276***	0.307**	0.219*
	(2.72)	(2.58)	(1.96)
Province FE	YES	YES	YES
Year FE	YES	YES	YES
Control Variables	YES	YES	YES
Number of code	30	26	30
Observations	449	416	478
R-squared	0.641	0.664	0.670

*Notes: *, ** and *** represent significant levels of 10%, 5%, and 1%, respectively.*

5.3. Mechanism testing

In the theoretical analysis and research hypotheses of this paper, we can know that green finance can affect the development of low-carbon economy by upgrading industrial structure, promoting green technology innovation and attracting FDI inflow. In order to test the influence channel of green finance on the development of low-carbon economy, this paper uses $structure$ to represent the upgrading of industrial structure. The ratio of the added value of the primary industry to GDP is multiplied by 1, the ratio of the added value of the secondary industry to GDP is multiplied by 2, and the ratio of the added value of the tertiary industry to GDP is multiplied by 3, and the three are added to obtain the industrial structure upgrading coefficient; use gt to represent green technology innovation, and use the proportion of green invention patent applications in green patent applications to measure; use $lnfdi$ to represent foreign direct investment, and use the number of foreign enterprises to obtain Logarithms are measured. At the same time, referring to Jiang (2022) explanation and analysis of intermediary effects, this paper only examines the impact of green finance on $structure$, gt, and $lnfdi$. The specific results are shown in Table 7.

Column (1) is the regression result of green finance on industrial structure upgrading. It can be seen that the coefficient of green finance (gf) is 0.121, which is significant at the 10% significance level, indicating that green finance can significantly promote the upgrading of industrial structure ; column (2) is the regression result of green finance on green technology innovation, from which we can see that the coefficient of green finance (gf) is 0.263, which is significant at the 5% significance level, indicating that green finance promotes green technology innovation ; column (3) is the regression result of green finance for foreign-invested enterprises, it can be seen that the coefficient of green finance (gf) is 0.675, which is significant at the 10% significance level, indicating that green finance can attract FDI inflows. Thus, Hypothesis 2, Hypothesis 3 and Hypothesis 4 are verified.

Table 7 Mechanism tests

Variables	(1) structure	(2) gt	(3) lnfdi
gf	0.121*	0.263**	0.675*
	(1.86)	(2.41)	(1.78)
Province FE	YES	YES	YES
Year FE	YES	YES	YES
Control Variables	YES	YES	YES
Number of code	30	30	30
Observations	478	478	478
R-squared	0.882	0.420	0.759

*Notes: *, ** and *** represent significant levels of 10%, 5%, and 1%, respectively.*

5.4. Regional heterogeneity

Since there are differences in China's economic development in different regions, this paper divides China's 30 provinces and cities into east-central and western regions, Yangtze River Economic Belt region and non-Yangtze River Economic Belt region, and then regresses in groups to examine whether the impact of green finance on low-carbon economic development differs in different regions. The specific results are shown in Table 8.

Column (1) is the regression result of the impact of green finance on low-carbon economic development in the east-central region, and column (2) is the regression result of the impact of green finance on low-carbon economic development in the western region. It can be seen that the coefficient of green finance (gf) is not significant in column (1) and is significantly positive in column (2), indicating that the promotion effect of green finance on low-carbon economic development is more significant in the western region, probably because the number of industrial enterprises in the western region is smaller and the production mode is easier to be changed, while the number of enterprises in the east-central region is larger and the proportion of carbon emissions is larger, so the improvement effect of green finance in the short term is not obvious. Column (3) is the regression result of the impact of green finance on low-carbon economic development in the Yangtze River Economic Belt region, and column (4) is the regression result of the impact of green finance on low-carbon economic development in the non-Yangtze River Economic Belt region. It can be seen that the coefficient of green finance (gf) is not significant in column (3) and significantly positive in column (4), indicating that the promotion effect of green finance on low-carbon economic development is more significant in the non-Yangtze River Economic Zone region, probably because the Yangtze River Economic Zone region has a higher level of economic development, dense population, higher energy input and consumption, and the role of green finance is not obvious for the time being.

Table 8 Heterogeneity regression results

	East-Central	West	Yangtze River Economic Zone	Non-Yangtze River Economic Zone
	(1)	(2)	(3)	(4)
Variables	lced	lced	lced	lced
gf	0.122	0.293***	0.050	0.292*
	(0.76)	(5.54)	(0.32)	(1.93)
Province FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Control Variables	YES	YES	YES	YES
Number of code	19	11	11	19
Observations	302	176	176	302
R-squared	0.760	0.500	0.742	0.637

*Notes: *, ** and *** represent significant levels of 10%, 5%, and 1%, respectively.*

5.5. Further Analysis

Since the development status of a region's institutional environment affects many aspects of the economic growth process, the institutional environment may moderate the relationship between green finance and low-carbon economic development. Therefore, this paper draws on the measure of regional institutional environment by Zhao et al. (2019) and uses the marketability index to indicate the institutional environment of a region; the larger the index, the better the institutional environment. The results of the moderating effect of institutional environment can be seen in column (2) of Table 9. Moreover, the higher the level of technology market development in a region, the more conducive to the diffusion and application of technological innovation, which can regulate the relationship between both green finance and low carbon economy. In this paper, the technology market development level is expressed by the ratio of technology market turnover to GDP, and the results of the moderating effect of technology market development level can be seen in column (3) of Table 9.

From column (2), it can be seen that the coefficient of the cross product of green finance and institutional environment ($gf * market$) is significantly positive, indicating that the institutional environment can positively regulate the relationship between green finance and low carbon economy development. From column (3), it can be seen that the coefficient of the cross product of green finance and the level of technology market development ($gf * mtech$) is significantly positive, indicating that the level of technology market development can enhance the role of green finance in promoting the development of low carbon economy.

Table 9 Regression results for moderating effects

Variables	(1) lced	(2) lced	(3) lced
gf	0.216*	0.073	0.207*
	(1.94)	(0.56)	(1.74)
gf*market		1.110***	
		(6.62)	
market		-0.034	
		(-0.82)	
gf*mtech			3.504*
			(2.03)
mtech			-1.181
			(-1.34)
Province FE	YES	YES	YES
Year FE	YES	YES	YES
Control Variables	YES	YES	YES
Number of code	30	30	30
Observations	478	478	478
R-squared	0.669	0.718	0.673

*Notes: *, ** and *** represent significant levels of 10%, 5%, and 1%, respectively.*

6. Conclusions and policy implications

This This paper constructs a comprehensive index of green finance and low carbon economic development in China, which is measured by the entropy weighting method of temporal and spatial extreme differences, and conducts an empirical study based on panel data from 2005 to 2020. The following conclusions are drawn from the study: first, green finance can produce policy incentive effect and institutional incentive effect, which significantly promote the development of low carbon economy; second, green finance can positively influence the development of low carbon economy by promoting industrial structure upgrading, green technology innovation and FDI inflow; third, there is regional heterogeneity in the influence of green finance on the development of low carbon economy, and the promotion effect is more significant in the western region Third, there is regional heterogeneity in the impact of green finance on low-carbon economic development, with the promotion effect being more significant in the western region and the non-Yangtze River Economic Zone region; Fourth, the institutional environment and the level of technology market development can play a positive regulatory role.

Based on the research findings, this paper proposes several policy recommendations to facilitate the ongoing advancement of a low-carbon economy. Firstly, given the current underdevelopment of green finance, it is imperative for the government to actively promote and support green finance across various dimensions. Secondly, there should be a sustained effort to upgrade the industrial structure and increase the share of clean production industries. Thirdly, it is essential to enhance support for green technological innovation, with a particular emphasis on green invention innovation. Fourthly, local governments should actively attract high-quality foreign

direct investment enterprises by offering appropriate preferential policies. Fifthly, the implementation of green finance should be intensified in the central and eastern regions, as well as in the Yangtze River Economic Belt. Lastly, continuous optimization of China's institutional environment and improvement in the development level of the technology market are necessary.

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