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Original Research

Green Finance: An Emerging Driving Force for Low-Carbon Transformation of China's Energy Structure

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Abstract

Energy is the driving force behind economic development. The low-carbon transformation of the energy structure (the following may be referred to as LCT) contributes to balancing development and emission reduction. Green finance serves as a significant financial tool for LCT, yet relevant academic research in this area remains scarce. Based on panel data from 30 provinces in China spanning from 2007 to 2021, this paper analyzes the impact of green finance on LCT. The study draws the following conclusions: Green finance has significantly promoted LCT. Using green finance and green innovation as threshold variables, the impact of green finance on LCT exhibits a single threshold effect. Beyond the threshold value, green finance significantly enhances its role in improving LCT. Moreover, green finance exhibits spatial spillover effects on LCT, concurrently improving local and other regions' LCT. Lastly, the study provides corresponding policy recommendations focusing on vigorously developing green finance, continuously enhancing green innovation capabilities, and leveraging the regional spillover effects of green finance.

Keywords: green finance, energy structure, low-carbon transformation, threshold effect, spatial effect

Introduction

Climate change has become a pivotal factor influencing global sustainable development, with carbon dioxide and other greenhouse gases emitted from human economic production and daily activities being the primary contributors to global warming. In December 2015, 178 parties worldwide collectively signed the Paris Agreement, aiming to limit the average global temperature increase to below 2 degrees Celsius this century. Around 2004, China overtook the US to become the world's biggest carbon emitter. By 2022, China's total carbon emissions reached 11.4 billion tons. The reduction of carbon emissions in China holds significant importance for mitigating the rise in global temperatures. The Chinese government has placed a high priority on addressing climate change, setting forth the "dual carbon" goals for 2020. These targets outline China's ambition to reach a peak in carbon dioxide emissions before 2030 and to achieve carbon neutrality by 2060. The primary sources of carbon dioxide emissions stem from the use of traditional high-carbon fossil fuels such as coal and oil. To achieve the "dual carbon" target, it is imperative to diminish the use of these high-carbon fossil fuels.

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Simultaneously, economic growth is inextricably linked to energy use. Therefore, it is necessary to increase the use of clean energy to help transform the energy structure to become low-carbon. The low-carbon transformation of the energy structure is characterized by slow progress, a lengthy cycle, and a low rate of return. These characteristics make it exceptionally challenging for LCT to secure support from traditional financial channels [1].

Green finance, as an innovative financial instrument, is regarded as a key driver in promoting the development of clean energy and green technologies [2]. The Chinese government attaches great importance to the role of green finance in green development, introducing a range of policies and measures such as the "Guidance on Green Finance Development". These measures encourage financial enterprises to increase their investment in green activities [3]. However, there is a lack of of scholarly exploration on whether green finance has facilitated the low-carbon transformation of China's energy structure. Therefore, assessing the impact of green finance in China on promoting LCT is not only crucial for China in achieving the dual objectives of development and emissions reduction but also holds significant reference value for other nations striving for balanced economic and social development and a reduction of carbon dioxide emissions.

The potential contributions of this paper include: First, it incorporates the concepts of green finance and LCT into a unified analytical framework, concluding that green finance can promote LCT. This expands the research on the green effects of green finance and enriches the understanding of the factors influencing LCT. Second, the paper discusses the linear relationship and spatial effects between green finance and LCT. It posits that green finance not only propels the local LCT but also has spatial spillover effects, which can foster LCT in other regions. This provides a multi-faceted clarification of the relationship between green finance and LCT. Third, the paper examines the threshold effects of green finance on LCT. It is found that when green finance and green innovation are used as threshold variables, a single threshold effect exists between them. Once green finance and green innovation surpass the threshold value, the enhancing effect of green finance on LCT can be significantly improved. The findings offer theoretical insights for the formulation of differentiated policies across various regions.

The remainder of this paper is structured as follows: Section 2 is a review of the relevant literature. Section 3 shows the mechanism of green finance for LCT. Section 4 reports the research design, including the empirical model, variables, and date. Section 5 introduces the empirical results of linear relationships, threshold effects, and spatial effects. Section 6 shows conclusions and further research.

Literature Review

Green finance is a financial approach that emphatically prioritizes environmental protection and resource conservation. Utilizing specific financial instruments, green finance facilitates the simultaneous achievement of economic development and environmental conservation [4, 5]. In academia, research on green finance predominantly centers around its green effects. Building upon assessments of the level of green finance development, scholars have conducted extensive investigations into the impact of green finance. There is a general consensus that green finance exhibits positive green and economic effects. Relevant studies primarily encompass the following aspects:

The first aspect concerns the impact of green finance on the environment. Zhou et al. [6] indicated that green finance in China not only enhances the environment but also promotes economic growth. Khan et al. [7] and Wu et al. [8] demonstrated that green finance has improved the environment in both Asian countries and G7 nations. In G7 countries, a 1% increase in the level of green finance development results in a 0.375% improvement in the environment. Huang and Chen [9] investigated the influence of China's green finance development on environmental quality, suggesting that green finance can improve the environment. However, as the economic development level increases, the environmental improvement effect of green finance diminishes.

The second aspect analyzes the effect of green finance on green innovation. Muhammad Irfan et al. [10] conducted an analysis based on Chinese data, concluding that green finance significantly drives China's green innovation. The mechanisms involved in this effect include optimizing industrial structure, increasing research and development (R&D) investment, and driving economic development. The relationship between green finance and green innovation shows regional heterogeneity; notably, in green finance innovation and reform pilot areas, green finance exerts a stronger driving effect on green innovation compared to other regions. Huang et al. [11], also using Chinese data, further analyzed the spatial impact of green finance on green innovation. They argue that Chinese green finance exhibits spatial spillover effects, enhancing local green innovation levels while also elevating green innovation levels in other regions. Zhou et al. [12] further demonstrated, at the micro-level, that green finance facilitates enterprise green innovation by mitigating financing constraints, reducing information asymmetry, and employing similar mechanisms.

The third aspect explores the impact of green finance on carbon emission reduction. Jin et al. [13] validate the carbon emissions reduction effect of green finance, demonstrating that its development facilitates increased consumption of non-fossil energy, thereby reducing carbon emission intensity. Zhang et al. [14] indicated that green finance has reduced carbon emissions in China, with environmental regulations playing a positive regulatory role in enhancing the carbon emissions reduction effect of green finance. Bai et al. [15] further indicated that regions with higher levels of economic development and industrial structure display a more pronounced carbon emissions reduction effect of green finance.

The fourth aspect investigates the impact of green innovation on high-quality development. Yang et al. [16]

analyzed the influence of green finance on China's high-quality economic development, contending that green finance enhances economic growth quality by improving the ecology, enhancing economic efficiency, and optimizing industrial structure. Wang et al. [17] studied the impact of green finance on China's high-quality energy development, suggesting that green finance promotes high-quality energy development and exhibits significant spatial spillover effects in their relationship. Xu et al. [18] further demonstrated that the higher the level of development of green finance, the greater the improvement it will provide for the high-quality development of energy. Liu and Wang [19] showed that companies that obtain green finance will hire more labor, especially highly skilled labor.

Energy constitutes the most fundamental input factor in industrial production, and the development of modern economies and societies is intrinsically linked to energy. China's long-term energy consumption has predominantly relied on fossil fuels such as coal and oil, leading to high levels of pollution. To mitigate environmental pollution, balance the 'dual carbon' strategy, and promote economic development, China must undergo a transformation in its energy structure. There is a limited amount of research in the academic community on LCT, whereas there is a greater volume of studies on energy structure. The research closely related to this paper predominantly concentrates on the influencing factors of energy structural transformation. According to existing research, numerous factors can influence the energy structure.

At the macro level, the energy structure is primarily affected by factors such as resource endowment, level of economic development, energy prices, and urbanization. Yang et al. [20] observed that the agglomeration of population and capital in the eastern region of China leads to a cleaner energy structure. Hafner et al. [21] found that as the level of economic development increases, the energy structure is likely to improve. Llop [22] identified that rising energy prices can result in a reduction in the consumption of conventional energy sources. Lv et al. [23] discovered that an increase in the level of urbanization can lead to a decrease in the consumption of traditional energy sources.

At the meso level, factors such as industrial structure, foreign trade, and the development of the new energy industry can influence the energy structure. Luan et al. [24] discovered that the optimization of industrial structures can lead to a reduction in energy intensity. Shahzad et al. [25] found that diversification of export products can promote the development of renewable energy sources. Hou et al. [26] identified that an increase in investment in the renewable energy sector contributes to the advancement of clean energy development.

At the micro level, factors including environmental regulations, innovation capability, and operational efficiency can impact the energy structure. Liu et al. [27] found that an increase in the number of green patents contributes to the improvement of the energy structure. Lee and Lee [28] discovered that enhancements in total factor productivity are beneficial for the amelioration of the energy structure.

In summary, there are numerous factors that can influence the energy structure. However, the literature on the relationship between green finance and the energy structure is limited. There is also limited scholarly literature addressing the issue of LCT. Although Sun and Chen [29] and Gu et al. [30] discussed the linear relationship between green finance and the energy structure, they concluded that green finance contributes to improving the energy structure through mechanisms such as optimizing industrial structure and promoting green innovation and acknowledged the regional heterogeneity in the relationship between green finance and the energy structure. There is a deficiency in research concerning nonlinear relationships, as well as a gap in the exploration of the relationship between green finance and LCT. Green finance, as a financial service, may exert nonlinear effects [31]. Simultaneously, green development and the 'dual carbon' goals have become crucial developmental objectives for major global economies and are also integral to China's national strategy. Therefore, a successful case of combining economic growth and carbon reduction through the development of green finance in one region is likely to attract attention from other regions. The relevant technologies and experiences may spill over to other areas, generating positive impacts. In other words, the improvement of LCT through green finance in one region may diffuse to other regions, giving rise to spatial effects. Therefore, building upon the discussion of the linear relationship between green finance and LCT, this study analyzes the nonlinear relationship and spatial effects between the two.

Theoretical Analysis

Green finance can exert both direct and indirect influences on LCT. In terms of direct impact, green finance can provide financial services and financial support for the development of clean energy, thereby easing the financial constraints on the further development of clean energy. This support helps expedite the resolution of technical challenges encountered during the development and widespread adoption of clean energy, facilitating a more stable and low cost supply. Consequently, under the premise of ensuring energy security, clean energy steadily replaces traditional energy sources, thereby improving LCT. In terms of indirect impact, green finance can promote LCT by fostering green innovation. LCT cannot do without the support of green innovation. However, green innovation, characterized by high investment, long cycles, low returns, and high risks, faces challenges in obtaining support from traditional financial institutions. However, green innovation is a primary beneficiary of green finance [32]. On one hand, green finance can provide financial support and services for green innovation, alleviating its financing constraints [33]. On the other hand, the support of green finance for green innovation can also create a signaling effect, attracting more funds to green innovation projects [34], thereby enabling more green innovation projects to receive financial support and promoting LCT. In summary, this study proposes Hypothesis 1.

H1: Green finance can improve LCT.

According to data from the People's Bank of China, the credit balance of green finance accounts for less than 10% of the total loans in commercial banks. Despite the small scale, there is a substantial demand for green finance for various green projects. Moreover, the long-standing mismatch between supply and demand in China's financial system may hinder green finance from reaching enterprises or projects that require financial support the most. Many small and medium-sized enterprises also struggle to access green finance due to their limited financial strength and lower creditworthiness. Therefore, when the scale is small, the effect of green finance on LCT is relatively small. As the scale of green finance continues to expand, more green financial resources will spill over to small and medium-sized enterprises and sectors in urgent need of green financial support. The impact of green finance on LCT will significantly increase [35]. Additionally, the effect of green finance on LCT might be influenced by the level of green innovation. LCT depends on green innovation. When the level of green innovation is low, the effect of green finance on LCT is relatively small. Conversely, a higher level of green innovation may significantly enhance the influence of green finance on LCT. In summary, this study proposes the following research hypotheses:

H2a: When green finance is used as a threshold variable, the effect of green finance on LCT exhibits a threshold effect. Beyond the threshold value, green finance significantly enhances its role in improving LCT.

H2b: When green innovation is used as a threshold variable, the effect of green finance on LCT exhibits a threshold effect. Beyond the threshold value, green finance significantly enhances its role in improving LCT.

The influence of green finance on LCT is not confined to local regions but can also spill over to other areas. Firstly, green low-carbon development is a national strategic priority in China. Green finance's positive impact on improving LCT serves as a demonstration effect. Successful cases in one region can spread to others, encouraging them to adopt similar strategies by vigorously developing green finance to promote local LCT [36]. Secondly, after elevating the local green technology level, the presence of technological diffusion effects enables rapid improvements in green technology levels in other regions, thereby aiding in promoting their LCT. Furthermore, the development of green finance helps grow the local low-carbon energy market. As the low-carbon energy market expands, the low-carbon energy supply chain and infrastructure will spread to other regions, leading to the spatial expansion of low-carbon energy supply and availability, thereby promoting LCT in other regions. In summary, this study proposes Hypothesis 3.

H3: Green finance's improvement effect on LCT exhibits spatial effects, spilling over to other regions and promoting LCT in those areas.

Methods and Material

Model Construction

We focus on investigating the impact of green finance on LCT. Therefore, we consider LCT as the dependent variable, with green finance as the core independent variable. The linear relationship model is established as follows:

$$lct_{it} = \alpha_0 + \alpha_1 gf_{it} + \alpha_2 CV_{it} + \varepsilon_{it} \tag{1}$$

In this context, where i represents provinces and t denotes years, lct represents the low-carbonization degree of the energy structure, gf signifies green finance, CV denotes a series of control variables, and e represents the random error term. If the coefficient a_1 for green finance is significant, it shows that the development of digital finance can influence the low-carbonization degree of energy structure. Drawing from existing research, marketization level (*mar*), level of financial development (*fin*), degree of openness to international trade (*open*), environmental regulation (*er*), and industrial structure (*tps*) have been selected as control variables in this study.

This study employs threshold models to examine the nonlinear impact of green finance on LCT. Taking a single threshold effect model as an example, the model is specified as follows:

$$\begin{aligned} lct_{it} &= \alpha_0 + \alpha_1 gf_{it} \times I(TV_{it} \leq \pi) \\ &+ \alpha_2 gf_{it} \times I(TV_{it} > \pi) + \theta_c CV_{it} + \varepsilon_{it} \end{aligned} \tag{2}$$

Where TV represents the threshold variable, π is the threshold value, and I (•) is an indicator function, taking values of 1 or 0. It equals 1 if the condition within the parentheses holds true and 0 otherwise.

We further employ a spatial effect model to investigate the spatial spillover effects of green finance on LCT. Given the scope of our research, the spatial model is specified as follows:

$$\begin{aligned} lct_{it} &= \alpha_1 gf_{it} + \alpha_2 CV_{it} + \theta_1 W * gf_{it} \\ &+ \theta_\gamma W * CV_{it} + \rho W * lct_{it} + \varepsilon_{it} \end{aligned} \tag{3}$$

Where W represents the spatial weight matrix and the coefficient ρ signifies the spatial autoregressive parameter. The significance and sign of ρ are used to assess the presence of spatial spillover effects on LCT. In employing spatial econometric models, it is crucial to determine the spatial weight matrix. We simultaneously choose a geographic adjacency matrix, a geographic distance matrix, and an economic distance matrix for our research.

Variable Selection

1. Dependent Variable: The low-carbonization degree of energy structure (*lct*). We introduce the low-carbonization degree of energy structure (*lct*) as the dependent variable. The calculation method is as follows:

Various energy consumption quantities across provinces were converted into standardized coal units using conversion coefficients. Let α, β, and γ represent the proportions of coal, oil and gas, and other energy consumption in each province, respectively.

$$\cos(\theta_1) = \frac{\alpha}{\alpha^2 + \beta^2 + \gamma^2} \tag{4}$$

$$\cos(\theta_2) = \frac{\beta}{\alpha^2 + \beta^2 + \gamma^2} \tag{5}$$

$$\cos(\theta_3) = \frac{\gamma}{\alpha^2 + \beta^2 + \gamma^2} \tag{6}$$

Therefore, the low carbonization in the energy structure, denoted as *lct*, can be expressed as:

$$lct = \arccos[\cos(\theta_1)]^3 + \arccos[\cos(\theta_2)]^2 + \arccos[\cos(\theta_3)] \tag{7}$$

A higher *lct* value indicates a higher degree of low-carbonization in the energy consumption structure.

2. Core Explanatory Variable: Green Finance (*gf*). Various methods are commonly employed to measure green finance, including single indicators [37] and indicator systems. Among these, an indicator system has the advantage of incorporating more information. In 2016, the Ministry of Environmental Protection (China) (referred to as MEP) introduced the "Guidance on Building a Green Financial System," which defined green finance from multiple perspectives, such as green credit, green bonds, green stock indices, green development funds, green insurance, and carbon finance. Drawing on MEP's definition and existing literature [38, 39] and considering data availability, this study selected indicators from four dimensions: green credit, green insurance, government support, and green investments, to establish an indicator system (Table 1). Subsequently, the entropy weight method was applied to calculate the Composite Green Finance Development Index. This index was used to assess the overall development of green finance.

3. Threshold Variables. In this study, the threshold variables encompass green finance (*gf*) and the level of green innovation (*pat*). Green finance is calculated using the method described in the previous section, while the level of green innovation is represented by the number of authorized green patents. During the empirical process, a logarithmic transformation was applied. Data for these variables were sourced from the China Research Data Services Platform (CNRDS).

4. Controlling Variables. ① Marketization level (*mar*). It is represented by the marketization index proposed by Wang et al. [40]. This index is constructed based on indicators related to the relationship between the government and the market, the development of non-state-owned economies, the degree of development in product markets, the degree of development in factor markets, and the development of intermediary organizations in the market, as well as the legal system environment. In the

Table 1. Green Finance Index system

Dimension	Indicators	Indicator description	Indicator attribute
Green credit	Proportion of high energy consumption industry interest expenditure	Interest expenditure of six high energy-consuming industrial industries/Total industrial interest expenditure	-
Green insurance	Depth of agricultural insurance	Agricultural insurance income/Gross agricultural output value	+
Government support	Proportion of environmental protection expenditure	Environmental protection expenditure/ General budget expenditure	+
Green investment	Proportion of environmental pollution control investment in GDP	Environmental pollution control investment /GDP	+

Table 2. Descriptive Statistics of Variables

Variables	Obs	Mean	SD	Min	Max
lct	450	5.563	0.386	4.975	6.956
gf	450	0.149	0.094	0.041	0.763
pat	450	541.736	1000.803	1	6936
mar	450	1.581	1.134	0.041	7.014
fin	450	3.043	1.139	1.290	8.153
open	450	0.286	0.334	0.014	1.709
er	450	1.346	0.658	0.301	4.240
tps	450	1.196	0.651	0.527	5.234

empirical process, the index is divided by 100. ② Level of Financial Development (*fin*). It is represented by the ratio of the sum of deposits and loans to GDP. ③ Degree of Openness to International Trade (*open*). It is represented by the ratio of total import and export trade volume to GDP. ④ Environmental Regulation (*er*). It is represented by the ratio of investment in environmental pollution control to GDP, multiplied by 100 due to the small scale of this indicator in empirical analysis. ⑤ Industrial Structure (*tps*). It is represented by the degree of industrial sophistication, calculated as the ratio of value added in the tertiary sector to that in the secondary sector.

The panel data used in this study cover 30 provinces in China from 2007 to 2021, excluding Hong Kong, Macau, Taiwan, and Tibet. The data were primarily sourced from publications such as the "China Statistical Yearbook", the "China Energy Statistical Yearbook", and the official websites of the National Bureau of Statistics and various provincial statistical bulletins. The descriptive statistics for each of the variables are presented in Table 2.

Results and Discussion

Linear Analysis Results

Table 3 presents the benchmark regression results for the linear relationship in Column (1), while Columns (2)-(4) display the results of the robustness check conducted to ensure the reliability of the outcomes. Specifically, Column (2) exhibits the results obtained by substituting the proportion of coal consumption for LCT. Column (3) shows the outcomes after excluding the four municipalities directly under the central government from the sample. Column (4) displays the results derived from two-stage least squares (2SLS) estimation, employing the average of green finance in the three provinces with GDP sizes closest to the instrumental variables. Across these different specifications, the coefficient of green finance remains consistently significant. This indicates that green finance plays a crucial role in the process of low-carbon transformation of energy structures. Thus, Hypothesis H1 is confirmed. Green development and achieving the "dual carbon" goals are vital national strategies in China. Under the guidance of these strategies, green financial resources continue to flow into the energy sector, which has lower emissions and pollution, consequently improving LCT and promoting high-quality green development.

The results for the control variables across different models are largely consistent. Based on the results of the baseline regression, the marketization coefficient is significantly positive, indicating that a higher level of marketization is conducive to promoting LCT. The significance of the financial development level is relatively weak, suggesting that the impact of financial development on LCT is not strong. This may be due to the traditional financial system's greater emphasis on returns, whereas LCT has a long cycle and the returns are subject to uncertainty. The coefficient for the level of openness to foreign trade is significantly positive, indicating that

Table 3. Linear regression results

Variables	(1) Benchmark regression	(2) Coal consumption	(3) Drop 4 cities	(4) 2SLS
gf	0.614*** (6.81)	-0.577*** (-6.95)	0.673*** (7.69)	0.106*** (4.21)
mar	0.484*** (3.39)	-0.428*** (-4.82)	0.328*** (4.10)	0.473** (2.08)
fin	0.008 (1.23)	-0.023* (-1.81)	0.006* (1.82)	0.014** (2.00)
open	0.074*** (3.68)	-0.128*** (-6.71)	0.059** (2.08)	0.124* (1.84)
er	0.003** (2.09)	-0.002** (-2.10)	0.007*** (4.16)	0.017** (2.06)
tps	0.005** (2.16)	-0.036* (-1.85)	0.005 (1.16)	0.024*** (4.31)
Constant	3.823*** (10.77)	0.824*** (7.14)	4.089*** (8.26)	5.176*** (8.93)
Province FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
Kleibergen-Paap rk LM statistic				52.317 [0.00]
Kleibergen-Paap rk Wald F statistic				69.423 {15.24}
Observations	450	450	390	450
R^2	0.534	0.481	0.506	0.428

Note: *** p <0 .01, ** p <0 .05, * p <0.1; t-statistics in parentheses a higher level of openness is beneficial for promoting LCT, which implies that China focuses on the quality of its openness to the outside world. The coefficient for environmental regulation is significantly positive, suggesting that increased investment in environmental protection is beneficial for LCT. The coefficient for industrial structure is significantly positive, indicating that the higher the degree of industrial sophistication, the more it is conducive to LCT.

Threshold Effect Results

Table 4 displays the threshold effect test results when green finance serves as the threshold variable. It can be seen that the effect of the single threshold passed the test of significance, while the effect of the double threshold did not pass the test of significance. The results indicate that when green finance is used as the threshold variable, the impact of green finance on the LCT exhibits a single threshold effect, with a threshold value of 0.067.

Table 4. Test results of threshold effect when the threshold variable is gf

Model	Threshold	F-statisti	Prob	10%	5%	1%
Single	0.067***	42.76	0.0200	21.8910	24.4627	39.5819
Double	0.138	7.07	0.7000	22.0723	27.9518	31.7923

Note: *** p <0 .01, ** p <0 .05, * p <0 .1

The results of the estimation of the threshold effect using green finance as the threshold variable are presented in Table 5. It can be seen that when below the threshold value of 0.067, the coefficient for green finance is 0.481 and is statistically significant at the 1% level. This signifies that green finance significantly improves the LCT; for every 1% increase in the level of green finance, the LCT improves by 0.481%. After exceeding the threshold value of 0.067, the coefficient for green finance becomes 1.113 and is statistically significant at the 1% level. This indicates that even after surpassing the threshold, green finance continues to significantly enhance the LCT; for every 1% increase in the level of green finance, the LCT improves by 1.113%. By comparing the magnitudes of these coefficients, it is evident that the improvement in the LCT due to green finance significantly increases when green finance surpasses the threshold. Thus, the previously stated research hypothesis H2a has been validated.

Table 5. Estimation results when the threshold variable is gf

Variables	(gf≤0.067)	(gf>0.067)
gf	0.481*** (6.93)	1.113*** (7.57)
mar	0.501*** (8.08)	
fin	0.011* (1.82)	
open	0.105*** (4.15)	
er	0.008* (1.88)	
tps	0.019*** (4.15)	
Constant	3.838*** (15.76)	
Observations	450	
R^2	0.615	

Note: *** p <0 .01, ** p < 0.05, * p <0 .1; t-statistics in parentheses

Table 6 presents the threshold effect test results when green innovation serves as the threshold variable. According to the results, the effect of the single threshold passed the test of significance, while the effect of the double threshold did not pass the test of significance. This indicates that when the threshold variable is green innovation, the impact of green finance on LCT exhibits a single threshold effect, with a threshold value of 7.547.

Table 6. Test results of threshold effect when the threshold variable is lnpat

Model	Threshold	F-statisti	Prob	10%	5%	1%
Single	7.547**	28.51	0.0200	21.0476	26.7315	30.2391
Double	9.468	8.43	0.4700	21.496	28.3174	43.6382

Note: *** p <0 .01, ** p <0 .05, * p <0 .1

Table 7 displays the threshold effect estimation results when green innovation serves as the threshold variable. It can be observed that when green innovation is below the threshold value of 7.547, the coefficient of green finance is 0.310 and is statistically significant at the 5% level. This indicates that green finance significantly improves the LCT; for every 1% increase in the level of green finance, the LCT improves by 0.310%. When green innovation exceeds the threshold value of 7.547, the coefficient for green finance becomes 0.890 and is statistically significant at the 1% level. This suggests that

Table 7. Estimation results of the threshold model when the threshold variable is lnpat

Variables	(lnpat≤7.547)	(lnpat>7.547)
gf	0.310** (2.07)	0.890*** (5.07)
mar	0.383*** (5.46)	
fin	0.012* (1.78)	
open	0.130*** (4.79)	
er	0.004 (0.89)	
tps	0.023* (1.76)	
Constant	3.821*** (15.80)	
Observations	450	
R^2	0.603	

Note: *** p < 0.01, ** p < 0.05, * p < 0.1; t-statistics in parentheses even after green innovation surpasses the threshold, green finance continues to significantly enhance the LCT; for every 1% increase in the level of green finance, the LCT improves by 0.890%. By comparing the magnitudes of these coefficients, it is evident that the improvement in LCT due to green finance significantly increases when green innovation surpasses the threshold. Thus, the previously stated research hypothesis of H2b has been validated.

Spatial Effect Results

Calculation of Moran's Index

First, the global Moran's Index was calculated to determine the existence of spatial correlation. The Moran's Index results using three types of weight matrices are presented in Table 8. It can be observed that during the sample period, the Moran's index for both green finance and LCT is statistically significant at the 5% level or higher. This indicates a strong spatial correlation between green finance and LCT during the observation period. Therefore, employing spatial econometric models in this study is justified.

Spatial Model Results

The results of LM, LR, and Hausman tests indicate that our data is better suited for a spatial Durbin model with both time and space bidirectional fixed effects. Hence, the subsequent regression analysis in this paper employs the Spatial Durbin Model (SDM). Table 9 presents the regression results of the SDM. According to Table 9, the spatial autoregressive coefficient (ρ) is significant for all three matrix regressions, indicating the presence of spatial autocorrelation effects. Across different models, the general regression coefficient (gf) for green finance is consistently significant and positive, suggesting that the development of green finance can improve the LCT. Additionally, the spatial regression coefficient (W*gf) is also consistently significant and positive. This implies that green finance exhibits spatial spillover effects on the LCT, indicating that green finance from other regions can also enhance the local LCT. Thus, our earlier research hypothesis H3 has been validated.

The Spatial Durbin Model can be further decomposed to obtain the direct, indirect, and total effects of green finance on LCT. The direct effect represents the influence of local green finance on the local LCT. The indirect effect represents the impact of green finance from other regions on the local LCT. The total effect is the sum of the direct and indirect effects, indicating the combined influence of local and external green finance on the local LCT.

The decomposition results are presented in Table 10. It can be observed that in the regression results using three different weight matrices, the regression coefficients for the three types of effects of green finance are all significantly positive. This indicates that the development of both local and external green finance can improve the local LCT. By comparing the magnitudes of these coefficients, it can be concluded that, overall, the improvement in LCT due to local green finance is greater than that due to external sources. In terms of specific impact magnitudes, within the geographical adjacency matrix, a 1% increase in the level of local green finance

Table 8. Global Moran Index for Green Finance and LCT

Year	Green finance			LCT		
	W_1	W_2	W_3	W_1	W_2	W_3
2007	0.075***	0.019***	0.089***	0.009***	0.057***	0.069**
2008	0.071**	0.018***	0.090***	0.011***	0.049***	0.062***
2009	0.061***	0.021**	0.095***	0.025***	0.032***	0.041***
2010	0.052**	0.020***	0.100***	0.011**	0.039***	0.059**
2011	0.058***	0.018***	0.098***	0.056***	0.039***	0.072***
2012	0.069***	0.023***	0.094***	0.049***	0.042***	0.077***
2013	0.077***	0.026***	0.095***	0.060***	0.038***	0.162***
2014	0.073**	0.021**	0.094**	0.036**	0.045***	0.157***
2015	0.068***	0.019***	0.091***	0.058***	0.047**	0.158***
2016	0.064***	0.022**	0.090***	0.079***	0.045***	0.085**
2017	0.073**	0.021*	0.096***	0.077***	0.041***	0.096***
2018	0.075*	0.023***	0.097***	0.084***	0.039**	0.095***
2019	0.078**	0.018**	0.102***	0.120**	0.041***	0.103***
2020	0.079***	0.020***	0.103***	0.098***	0.043***	0.107***
2021	0.077***	0.021***	0.108***	0.102***	0.046***	0.109***

Note: W_1 represents Geographical Adjacency Spatial Weight Matrix; W_2 represents Geographical Distance Spatial Weight Matrix; W_3 represents Economic Distance Spatial Weight Matrix; the same below; *** p <0 .01, ** p < 0.05, * p < 0.1

Table 9. Spatial Durbin Model regression results

Variables	(1)W_1	(2)W_2	(3)W_3
gf	0.635*** (7.19)	0.707*** (7.95)	0.563*** (5.98)
mar	0.496*** (3.50)	0.449*** (3.20)	0.379*** (2.64)
fin	0.006* (1.81)	0.005 (0.64)	0.003 (1.39)
open	0.074*** (4.78)	0.111*** (4.08)	0.070*** (2.93)
er	0.001** (2.11)	0.001 (0.70)	0.004* (1.87)
tps	0.003* (1.81)	0.014* (1.79)	0.192** (2.17)
W*gf	0.256** (2.03)	0.639*** (2.96)	0.085** (2.09)
W*mar	0.269* (1.84)	0.231** (2.00)	0.012*** (3.75)
W*fin	0.004 (1.19)	0.009 (1.14)	0.024 (0.98)
W* open	0.001* (1.82)	0.341* (1.83)	0.002* (1.79)
W* er	0.140 (1.36)	0.022 (0.69)	0.030** (2.10)
W* tps	0.051** (1.98)	0.254* (1.83)	0.055 (1.16)
W* lct	0.170** (2.35)	0.323*** (5.86)	0.113** (2.06)
Province FE	YES	YES	YES
Year FE	YES	YES	YES
Observations	450	450	450
R^2	0.582	0.535	0.481

Note: *** p <0 .01, ** p < 0.05, * p < 0.1; t-statistics in parentheses

leads to a 0.655% improvement in the local LCT. Among this improvement, 0.527% is attributed to the influence of local green finance, while 0.128% is from external green finance. Within the geographical distance matrix, a 1% increase in local green finance results in a 1.188% enhancement in the local LCT. Of this improvement, 0.763% is due to local green finance, and 0.425% is due to external green finance. Within the economic distance matrix, a 1% rise in local green finance leads to a 0.658% enhancement in the local LCT. Within this enhancement, 0.459% is influenced by local green finance, and 0.199% is influenced by external green finance.

Conclusions

Conclusion and Inspiration

By furnishing financial support, green finance constitutes a pivotal driving force in the low-carbon transition of China's energy structure. Building upon theoretical analysis of the relationship between green finance and LCT, we conducted empirical testing using panel data from 30 provinces in China for the period spanning from 2007 to 2021. The primary conclusions drawn from these analyses are as follows: Firstly, the linear analysis results indicate that green finance has significantly enhanced China's LCT. Secondly, the threshold effect results indicate that using green finance and green innovation levels as threshold variables, green finance exhibits a single threshold effect on LCT. Beyond the threshold values, the positive impact of green finance on LCT improvement significantly intensifies. Thirdly, the spatial effect results indicate that green finance's positive influence on LCT improvement demonstrates spatial effects, extending its benefits to other regions. The implications of the conclusions drawn in this study are highly significant and evident.

Firstly, the development of green finance should be continuously promoted. The government should enact relevant policies to guide financial institutions in directing capital towards sustainable sectors, including green industries and environmental projects. Financial institutions should innovate financial products and provide more financing channels for green projects. Enhancing green finance regulation is crucial to fortifying investor confidence and mitigating investment risks. Furthermore, there is an imperative to intensify talent development in the field of green finance to provide additional intellectual support for the progression of green finance.

Secondly, the green innovation capabilities should be significantly enhanced. Both the government and enterprises should increase investment in the research and development (R&D) of green technologies, overcome key technological challenges, and promote the application of green technologies. Collaboration between enterprises, universities, and research institutions needs to be strengthened, fostering an integrated approach to industry, academia, and research, jointly advancing the R&D and innovation of green technologies. It is essential to establish and refine a green standards system, elevating the levels of standardization and normalization of green technologies, thereby facilitating the dissemination and application of green technologies. Simultaneously, efforts

Table 10. Decomposition results of spillover effects in Spatial Durbin Model

Spatial weight matrix	Variables	Direct effects	Indirect effects	Total effects
W_1	gf	0.527(6.99)***	0.128(3.98)***	0.655(4.13)***
W_2	gf	0.763(7.42)***	0.425(1.82)*	1.188(3.56)***
W_3	gf	0.459(2.15)**	0.199(2.08)**	0.658(5.77)***

Note: *** p < 0.01, ** p < 0.05, * p < 0.1; t-statistics in parentheses should be made to strengthen the protection of intellectual property rights in the field of green technologies in order to have a stimulating effect on innovation.

Thirdly, the spillover effects of green finance should be fully leveraged. Governments, financial institutions, and enterprises can achieve this by establishing collaborative green finance projects or participating in joint green investment funds. Strengthening cooperation and communication among regions regarding green finance is essential to facilitate the rational allocation and flow of green finance resources across regions. Standardizing green finance regulations and standards is crucial to reducing barriers to cross-regional investments and project collaborations.

Limitations and Further Research

As an empirical study, this paper has the following limitations: Firstly, considering the accessibility of data, this study chose panel data from 30 provinces in China as the research sample. However, within the same province, disparities in green finance and LCT exist among different cities, which could potentially affect the relationship between green finance and LCT. Due to constraints related to data completeness and availability, this study was unable to obtain city-level data as extensively as desired. Consequently, provincial-level data were chosen as a sample. If more data at the city level or even more detailed county-level data become available in the future, it would be necessary to conduct further research focusing on these city-level or county-level data.

Secondly, using China's data as the sample, this study examined the relationship between green finance and LCT. However, numerous emerging economies worldwide heavily rely on fossil fuels such as coal and oil as their primary energy sources. While research focused on China provides valuable insights into these countries, conducting direct studies on these nations in the future would be highly intriguing. Such research endeavors would enhance the generalizability of the conclusions drawn in this paper.

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Conflict of Interest

The authors declare no conflict of interest.

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