The Impact of Green Finance on Carbon Emissions: An Empirical Study Based on Spatial Metrology

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Abstract: Green finance plays a crucial role in driving industrial transformation and upgrading, crucial for China's dual carbon goals. This study constructs comprehensive green finance indicators from market and policy perspectives using the entropy method. Panel data from 30 Chinese provinces (2007-2020) is analyzed via spatial Durbin model to assess the impact of green finance policies on carbon emissions, considering driving mechanisms and geographical heterogeneity. Findings show a steady increase in green finance development across Chinese provinces, with the east leading. Local green finance significantly correlates with carbon reduction, especially in the east and central regions. Policy recommendations are derived from these insights. The final policy recommendations come from these insights.

Keywords: Green finance development; Carbon emission intensity; Carbon neutralization; Spatial spillover effect

1. Introduction

President Xi Jinping announced at the 75th United Nations General Assembly China's specific timetable for reaching peak carbon emissions and achieving carbon neutrality, making a significant contribution to global emission reduction efforts, and showcasing China's grand vision and sense of responsibility (Zhang et al., 2022). China attaches great importance to climate change and has implemented policies to promote energy conservation and emissions reduction. Green development has become an urgent imperative. Under a market-oriented system, financial institutions play a crucial role in the development of the green economy. They enhance the efficiency of fund allocation and resource distribution through resource integration, while also significantly promoting environmental protection and urban ecological construction (Gu and He, 2012). Green finance promotes high-quality economic development by guiding resources from high-pollution and high-energy-consuming industries to more resource-efficient, technological, and eco-friendly sectors. It encourages enterprises to adopt more proactive green production methods and enhances consumer awareness of green consumption. Importantly, it emphasizes simultaneous progress in financial activities, environmental protection, and ecological balance (Wang et al., 2021). Against this backdrop, detailed research into the impact of green finance on carbon emissions reduction is essential.

2. Literature review

Based on existing literature, China's green finance system is still in early stages of development, with limited data disclosure prompting scholars to rely on qualitative analysis (Yan et al., 2016; Zhu et al., 2018; Zhang and Chen, 2021). As the system matures, more scholars are using indicators and empirical methods to assess policy effectiveness. However, data constraints hinder precise measurements of green finance development. Research on green finance's impact on carbon emissions varies: qualitative analyses explore financial development's link to CO2 emissions, lacking quantitative studies on spatial spillover effects. Empirical studies mostly focus on green

credit (Lu et al., 2021; Zhang et al., 2022), with little analysis on how different green finance tools affect carbon emissions and spatial dynamics (Sun and Deng, 2002).

3. Driving mechanism

China's green finance relies on two main mechanisms to drive carbon emissions: direct effects and spatial effects. In terms of direct effects, there are three transmission pathways: signaling effects, technological progress effects, and entrepreneurial responsibility effects. Spatial econometric researchers argue that economic units often exhibit geographic correlations, leading to spatial autocorrelation, which indicates mutual economic activity influences among neighboring units. Therefore, considering spatial effects is crucial. Scholars such as Li Yunyan et al. (2023), Mao Yanjun et al. (2022), and Feng et al. (2022) have identified spatial spillover effects of green finance on carbon emissions. This study emphasizes two primary pathways for these effects. Firstly, spatial signaling occurs when policy signals influence carbon emissions in related areas through demonstration effects. Simultaneously, high punitive interest loans serve as a warning to high-polluting industries, prompting innovation in green production technologies and enhancing energy efficiency. Secondly, technology spillover effects promote the diffusion of innovative green environmental technologies between regions, driving the expansion and transformation of green industries and stimulating innovation among competitive enterprises, thereby enhancing efforts to reduce carbon emissions.

4. Research Design

4.1 Variables and Data

4.1.1 Dependent variable

Per capita carbon emissions (C). This article selects per capita carbon emissions (CO_2/total resident population) as the dependent variable. The carbon dioxide emission data is sourced from the China Carbon Accounting Database (CEADS).

Table1. Evaluation System for the Development Level of Green Finance

Evaluation dimension	Secondary indicators	Third level indicators	Third level indicators
Market dimension	Green credit	The proportion of interest expenses in high energy consuming industries	Six high energy consuming industrial industry interest expenses/total industrial industry interest expenses
	Green Securities	Market value proportion of environmental protection enterprises	Market value of environmental protection enterprises/total market value of A-shares
		Market value proportion of high energy consuming industries	The total market value of the six high energy consuming industries/A-share total market value
	Green insurance	The proportion of agricultural insurance scale	Agricultural insurance expenditure/total insurance expenditure
		Agricultural insurance payout ratio	Agricultural insurance expenditure/agricultural insurance income
Policy dimension	Government investment	The proportion of investment in environmental pollution control	Pollution control investment/GDP
		The proportion of public expenditure on energy conservation and environmental protection	Fiscal expenditure on energy conservation and environmental protection industry/total fiscal expenditure

4.1.2 Core explanatory variable

Green Finance Development Index (Green). This article is based on the construction method of local green finance development index mentioned in the "China Local Green Finance Development Report (2021)" and refers to the measurement method of green finance indicators by Zhang et al. (2022) and Gao et al. (2022) and uses the entropy method to comprehensively construct green finance development level indicators from two aspects: policy effect and market effect (as shown in Table 1). The data mainly comes from the National Bureau of Statistics, the Finance Bureau, the China Insurance Statistical Yearbook, the China Industrial Statistical Yearbook, and the Wind database.

4.1.3 Core explanatory variable

This article refers to Shao Shuai et al. (2019) and selects the level of technological development, openness to the outside world, economic development, energy intensity, urbanization level, and environmental regulations as control factors to alleviate possible endogeneity issues. The specific construction method is as follows: (1) The level of technological development (Tech) uses the per capita number of patent authorizations in each province; (2) The degree of openness to the outside world (Open) is calculated by converting the percentage of foreign direct investment (FDI) to the nominal GDP of the region; (3) The level of economic development (GDP) is calculated using the per capita GDP of each province; (4) Energy intensity (Ei) is represented by the energy consumption per unit of GDP; (5) Urbanization level (Urban) refers to the proportion of urban population to the total population of the region; (6) Environmental regulation (Er) selects the proportion of environmental related vocabulary in provincial government work reports as the measurement standard. The data sources include the National Bureau of Statistics, the China Energy Statistical Yearbook, provincial statistical yearbooks, and government work reports.

4.2 Empirical Model

Before the empirical analysis began, in order to observe the spatial correlation of carbon emissions in each province more intuitively and clearly, this article calculated the global Moran's I based on carbon emission data from 30 provinces in China from 2007 to 2020, and used Geoda to draw a Moran scatter plot. As expected, except for western regions such as Guizhou, Qinghai, and Xinjiang, most provinces are distributed in the first and third quadrants. This indicates that there is a clear spatial positive correlation between carbon emissions in most provinces, that is, carbon emissions generally exhibit high to high clustering and low to low clustering.

Based on Elhorst's (2014) research, this paper conducted diagnostics on spatial econometric models to select an appropriate framework. LM and robust LM tests indicate that, among four spatial weight matrices tested, all except the geographic weight matrix passed, suggesting suitability for the Spatial Durbin Model (SDM). Additionally, Wald and LR test results show that all specifications, except for the economic weight matrix, passed, further validating the robustness and suitability of the SDM. The Hausman test results suggest that, aside from the geographic weight matrix, a fixed effects model is more appropriate, supported by LR tests for spatio-temporal bidirectional fixed effects analysis. Based on these diagnostic results, this study employed the SDM model to empirically investigate the impact of green finance on carbon emissions.

$$y_{it} = \sigma + rwy_{it} + a_1 green_{it} + b_1 wgreen_{it} + a_2 x_{it} + b_2 wx_{it} + u_i + v_t + e_{it}, \quad (1)$$

in eq. (1), i represents the province and t represents the year; y_{it} represents the carbon emission intensity of province i in year t; $green_{it}$ represents the level of green finance development in province i in year t; u_i represents spatial fixed effects; v_t represents a fixed time effect; ε_{it} represents a random perturbation term; w represents the spatial weight matrix, and this article sets four standardized spatial weight matrices: ①Geographical adjacency weight matrix (w_{0-1}); ②Geographic distance weight matrix (w_d); ③Economic distance weight matrix (w_e); ④Geo economic nested spatial weight matrix (w_{ed}). The regression coefficients that this article focuses on

are α_1 and β_1, which refer to the impact of the level of green finance development (green) and its spatial lag term ($w * green$) on carbon dioxide emissions. The expected coefficient is negative, indicating that the deeper the development of local green finance, the stronger the driving effect on carbon dioxide reduction in local and spatially related areas.

5. Empirical analysis

5.1 Benchmark regression results

The benchmark regression results of this article are shown in Table 2. Under the setting conditions of four types of spatial weight matrices, the level of green finance development (green) has a significant negative impact on carbon dioxide emissions, and the spatial lag term of green finance development ($w * green$) has a significant negative spatial spillover effect on carbon dioxide emissions. The development of local green finance can indeed have a significant positive impact on reducing carbon emissions in the local area, and this positive impact can also have a positive impact on carbon reduction in surrounding areas through geographical or economic correlations.

Table 2. Spatial Durbin Model Regression Results of Green Finance on Carbon Emissions

Model	（1）	（2）	（3）	（4）
Spatial weight matrix	W_{0-1}	W_d	W_e	W_{ed}
Green	-1.359***	-1.766***	-0.933***	-1.609***
	(0.335)	(0346)	(0.302)	(0.334)
W*Green	-1.183*	-3.236*	-0.538	-4.372**
	(0.636)	(1.863)	(1.008)	(1.953)
Time fixed effect	control	control	control	control
Spatial fixed effect	control	control	control	control
Sample size	420	420	420	420
R^2	0.589	0.542	0.541	0.610

5.2 Total Effect Decomposition

Green finance's impact on carbon emissions can be divided into direct effects and spatial effects. Under four different spatial weighting matrices, as shown in Table 3, both direct and spatial effects, as well as total effects, demonstrate statistical significance at the 1% level with consistent coefficient directions. This indicates that green finance plays a role in promoting regional carbon reduction through both direct and spatial effects. Possible reasons include direct promotion of carbon reduction through government policy signaling, technological advancement, and enhanced corporate social responsibility. Additionally, it facilitates regional information exchange, green industry clustering, and drives the entire industry chain towards low-carbon transformation through environmental enterprises.

Table 3. Direct effects, spatial effects, and total effects

Effect decomposition	Model	Model 1	Model 2	Model 3	Model 4
	Variable	W_{0-1}	W_d	W_0	W_{ed}
Direct effects	Green	-1.362***	-1.734***	-0.911***	-1.523***
		(0.343)	(0.354)	(0.311)	(0.337)
Spatial effect	W*Green	-1.277**	-2.650	-0.175	-2.595*
		(0.590)	(1.678)	(0.742)	(1.376)
Total effect	Green	-2.639***	-4.384**	-1.086	-4.119***
		(0.709)	(1.808)	(0.778)	(1.470)

5.3 Robustness testing

To ensure robustness, we used CO_2 emissions intensity (CO_2/GDP) instead of total GDP to eliminate economic scale effects. Real GDP at constant 2007 prices was employed to mitigate annual price fluctuations. Results confirm significant negative coefficients for green finance and its spatial lag, validating robust findings. Following Kim (2019), we applied a one-period lag to all variables, including controls, to address the time required for green finance to impact emissions and minimize interference from concurrent factors. Regression across four spatial weighting matrices consistently shows significant negative coefficients for both green finance (green) and its spatial lag (w * green), reinforcing the robustness of our conclusions.

5.4 Heterogeneity analysis

This study classified the development and penetration of green finance in the eastern, central, and western regions, as shown in Fig. 1. Overall, compared to the central region, the eastern region shows superior development, while the western region lags. An analysis was conducted on 30 provinces in China by region, revealing geographical differences in the impact of green finance on carbon emissions. Specifically, significant negative estimates of green finance and its spatial lag have been observed in the eastern and central regions. This indicates that green finance in these regions significantly affects carbon emissions in both time and space, not only reducing local emissions, but also producing significant negative spatial spillover effects on neighboring areas. In contrast, the western region has shown insignificant negative impacts, indicating that due to economic challenges and slow development of green finance measures, the reduction of carbon intensity is less effective.
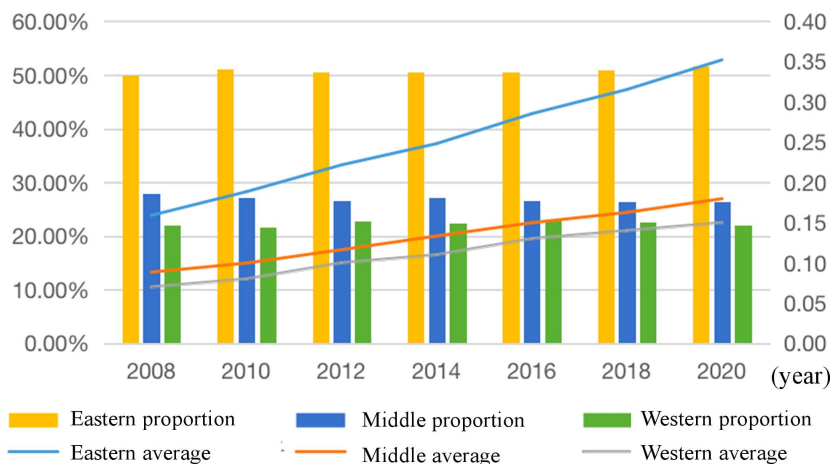

Fig. 1 Trends in the Development of Green Finance in China from 2007 to 2020

6. Conclusion and recommendations

6.1 Research Conclusion

This study used the entropy method to create green finance development indicators for provinces in China from 2007 to 2020. It found that green finance is growing across provinces, led by the eastern region. The research confirmed a causal link between green finance development and carbon dioxide emission reduction. It also highlighted that higher local green finance development levels help achieve carbon reduction goals and benefit nearby regions economically or geographically. However, emission reduction effects vary, being more pronounced in the eastern and central regions compared to the western regions.

6.2 Research recommendations

Based on the current situation and research conclusions in China, this article proposes the following development suggestions: (1) Strengthen the supervision and policy guidance of green finance, establish an evaluation system, and play its role in low-carbon transformation and green development. (2) Developing differentiated green finance policies, eastern provinces can leverage the mature advantages of financial markets to promote industrial structure upgrading; The central and western regions should improve their financial products and services based on their economic positioning and industrial characteristics, and strengthen cooperation with the eastern regions. (3) Promote international green finance cooperation, share successful experiences, and strengthen the coordination of international standards and norms.

Acknowledgements

References

[1] Zhang Zhuoqun, Zhang Tao, Feng Dongfa Research on Regional Differences, Dynamic Evolution, and Convergence of Carbon Emission Intensity in China [J] Quantitative Economics, Technical and Economic Research, 2022, 39 (04): 67-87

[2] Gu Hongmei, He Bin   China Population, Resources and Environment, 2012,22 (08): 22-27

[3] Yan Chengliang, Li Tao, and Lan Wei Financial development, innovation, and carbon dioxide emissions [J] Financial Research, 2016, (01): 14-30

[4] Zhu Dongbo, Ren Li, Liu Yu Inclusive development of China's finance, economic growth, and carbon emissions [J] China Population, Resources and Environment, 2018,28 (02): 66-76

[5] Wang Xiuhua, Liu Jinhua, Zhao Yaxiong Measurement of the effectiveness of green finance reform and innovation pilot zones [J] Research on Quantitative Economy, Technology and Economics, 2021,38 (10): 107-127

[6] Zhang Jianpeng, Chen Shiyi Financial development, environmental regulation, and green economic transformation [J] Financial Research, 2021,47 (11): 78-93

[7] Lu Jing, Yan Yun, Wang Taoxuan A Study on the Micro effects of Green Credit Policy: Based on the Perspective of Technological Innovation and Resource Reallocation [J] China Industrial Economy, 2021, (01): 174-192

[8] Sun Hongqing, Deng Ying Reflection on the Development of Green Finance [J] Economics and Management, 2002, (01): 37-38

[9] Li Yunyan, Zhang Shuo, Zhang Yuze Research on the spatiotemporal evolution and emission reduction of carbon emissions in Chinese provinces from the perspective of green finance [J] Soft Science, 2023, (03): 1-15

[10] Mao Yanjun, Qu Yingbo, Zheng Tian'en Research on the Carbon Emission Effect and Energy Efficiency Mechanism of Green Credit: Analysis Based on Spatial Econometric Models [J] Financial Theory and Practice, 2022, (09): 57-68

[11] Shao Shuai, Zhang Ke, Dou Jianmin The Energy Conservation and Emission Reduction Effect of Economic Agglomeration: Theory and Chinese Experience [J] Managing the World, 2019, 35 (01): 36-60+226

[12] Wang Xiuhua, Liu Jinhua, Zhao Yaxiong Measurement of the effectiveness of green finance reform and innovation pilot zones [J] Research on Quantitative Economy, Technology and Economics, 2021,38 (10): 107-127

[13] Wang Yao, Liu Qian, Li Zheng Green Finance Blue Book: Report on the Development of Local Green Finance in China (2021) [M] Beijing: Social Science Literature Publishing House, 2021

[14] Feng L.G., Shang S., An S.F., et al. The spatial heterogeneity effect of green finance development on carbon emissions[J]. Entropy, 2022, 24(8):1-14.

[15] Zhang A.X., Deng R.R., Wu Y.F. Does the green credit policy reduce the carbon emission intensity of heavily polluting industries?-Evidence from China's industrial sectors[J]. Journal of Environmental Management, 2022, 311(06):1-12.

[16] Gao L.T., Tian Q.B., Meng F. The impact of green finance on industrial reasonability in China:empirical research based on the spatial panel Durbin model[J]. Environmental Science and Pollution Research, 2022, (02):1-17.

[17] Grossman G.M., Krueger A.B. Economic growth and the environment[J]. The Quarterly Journal of Economics, 1995, 110(02):353-377.

[18] Roberts J.T., Grimes P.E. Carbon intensity and economic development 1962–1991:A brief exploration of the environmental Kuznets curve[J]. World Development, 1997, 25(02):191-198.