GREEN FINANCE, GREEN TECHNOLOGY INNOVATION AND AGRICULTURAL CARBON EMISSIONS IN CHINA

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Abstract. Extensive agricultural development in China has given rise to a range of environmental issues that pose a significant hurdle to the country's "dual-carbon" goal. In order to tackle this challenge effectively, it becomes crucial to tap into the potential of green financial developments as means of reducing carbon emissions. To shed light on this matter, this study collates data from a total of 30 provinces in China from 2007 to 2019. And A two-way fixed-effects model was employed to examine the extent to which the advancement of green finance (GF) in China has effectively contributed to the decrease of carbon emissions in the agricultural sector. Furthermore, our research endeavors encompass the investigation of the specific mechanisms via which green finance has its influence on carbon emissions within the agricultural sector. The findings indicate that the implementation of green finance plays a crucial role in facilitating the reduction of carbon emissions within the agricultural sector in China. Technological advancements emerge as the primary mechanism through which green finance facilitates agricultural carbon emission reduction. Nevertheless, the impact of modernizing the regional industrial structure has been detrimental in this regard.
Keywords: *technological progress, industrial structure, impact mechanisms, agricultural sector, climate change*

Introduction

China, as the leading global emitter of greenhouse gases, has encountered significant pressure to uphold ecosystems and safeguard the environment (Nogrady, 2021; Zheng et al., 2021). The agricultural sector emerged as a notable contributor to emissions, as evidenced by many studies (Liang et al., 2021; Shi et al., 2023; Yang et al., 2022; Zhuang et al., 2019). Within this sector, emissions were primarily attributed to agricultural activities such as animal production, rice cultivation, and biomass burning. The issue of carbon emissions in China has had a detrimental influence on global climate change, posing a significant risk to both food security and the sustainable development of agriculture (Chen et al., 2021; Koondhar et al., 2021; Pata, 2021). Considering China's standing as one of the largest agricultural producers globally, finding a balance between agricultural sustainable development and greenhouse gas reduction is a significant challenge (Xu et al., 2020; Zhang et al., 2020). Committed to its responsibilities under the Paris Agreement, China aims to be carbon peak and carbon neutral by 2030 and 2060, respectively (Zhao et al., 2022). Thus, to attain the crucial objective of reducing carbon emissions, the Chinese government has undertaken substantial efforts across various sectors, including agriculture (Dong et al., 2019). Furthermore, the launch of a series of policies and

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initiatives aimed at achieving carbon emission reductions demonstrates the determination of the Chinese government to implement its commitment to combating climate change (Liu et al., 2022).

The urgency of climate change has brought attention to the need for innovative financial mechanisms that can support investments in climate-resilient practices (Gunningham, 2020; Irfan et al., 2022; Zhou et al., 2019). The Government of China similarly recognizes the importance of incorporating sustainable financial measures. It also noted the importance of green financial measures to support low-carbon agricultural practices (Li et al., 2023a). Green finance encompasses a range of financial goods and services that are designed to support sustainable development and foster environmentally friendly practices (Zhang et al., 2021b). By utilizing financial mechanisms such as credit, insurance, and carbon markets, green finance aims to incentivize and support various practices that reduce carbon emissions (Ran and Zhang, 2023). Remarkably, China has made substantial strides in developing green finance policies to tackle carbon emissions within its agricultural sector (Zhang et al., 2021b). The government has introduced various financial incentives, such as preferential loans and subsidies, to encourage farmers and agribusinesses to adopt low-carbon production techniques (Du et al., 2023; Zhang et al., 2023b). And the development of carbon markets has provided new opportunities for green agriculture to monetize emission reductions (Cui et al., 2021).

Green finance applies to the broader field of sustainable finance, which aims to enable financial flows aligned with sustainable development goals (Muganyi et al., 2021; Qin et al., 2022). While green finance has gained considerable attention in areas like renewable energy, its potential application in the agricultural sector remains relatively limited (Li et al., 2021; Sampene et al., 2023). The unique characteristics of the agricultural sector, including diverse stakeholders, complex supply chains, and vulnerability to climate change, present both opportunities and challenges for the green finance initiatives (Havemann et al., 2022; Muganyi et al., 2021). Addressing carbon emissions from agriculture may therefore require a multifaceted approach that combines, for example, green finance with industrial structural optimization and technological progress (Dong et al., 2020; Sampene et al., 2023). Previous research has demonstrated that green finance has the potential to offer the requisite financial backing for sustainable endeavors, including the enhancement of regional industrial structures and the promotion of green technical advancements (Irfan et al., 2022; Zhang et al., 2021a). The ongoing optimization of the regional industrial structure, in conjunction with the continual enhancement of green technology innovation capability, has successfully resulted in a reduction in the overall quantity of agricultural carbon emissions (Muganyi et al., 2021; Zhang et al., 2021a).

The application and effectiveness of green finance in China’s agricultural sector continue to fall behind, despite its significant potential in mitigating carbon emissions associated with agriculture. Hence, an endeavor is made to address this disparity by investigating the association between the wider agricultural producing industry and the advancement of green finance in China. Moreover, the primary objective of this study is to identify the precise mechanism that impact green finance in order to facilitate the reduction of carbon emissions in the agricultural sector. The findings not only provide valuable insights with green finance for mitigating agricultural carbon emissions, but also shed light on the challenges and opportunities China faces in meeting its climate commitments. By identifying effective strategies and financing mechanisms, the

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Chinese government, financial institutions, and agricultural stakeholders can collaborate in meeting China's climate commitments, all while ensuring the long-term profitability and resilience of the agricultural sector.

Research hypotheses

Green finance and agricultural carbon emissions

The influence of China's green financial advancement on agricultural carbon emissions can be observed in two key areas. Firstly, green finance provides financial backing for sustainable agricultural practices through banks and other financial institutions (Tolliver et al., 2021). This facilitates the allocation of social capital towards eco-friendly agricultural production, leading to expanded financing options and reduced financial pressures on green agriculture (Veelen van, 2021). The swift development of sustainable agricultural production models has resulted in increased efficiency and significant strides in decreasing agricultural pollutant emissions, thereby establishing a foundation for transitioning to more environmentally-friendly agricultural practices (Deng and Gibson, 2019; Shen et al., 2020). Secondly, green finance not only widens the funding sources for low-carbon agricultural production but also restricts financing options for highly polluting agricultural production methods (Yang et al., 2021). Guided by the green finance policy, funds for highly polluting agricultural activities are subject to strict control, imposing regulations and raising the cost of pollution control (Muganyi et al., 2021). According to Chen and Chen (2020), the rise in pollution expenses serves as a catalyst for a transition in agricultural practices towards less environmentally harmful ways. This shift aligns with the objective of attaining carbon reduction goals. It is noteworthy that green finance serves as a means to mitigate the financial limitations encountered by green agriculture. However, it is imperative to acknowledge that this approach may potentially induce farmers to expand their production scale and augment the consume of production factors, thereby resulting in a subsequent elevation of carbon emissions originating from agricultural activities (Zhang et al., 2023a). Additionally, China is currently undergoing a transition towards agricultural greening, where traditional crude agricultural production methods are gradually being transformed into low-carbon modern agricultural practices with the support of green finance (Li et al., 2023a, 2022a). According to Zhang et al. (2023), the influence of China's green finance on agricultural carbon emissions is anticipated to remain over an extended duration. However, it is projected that the overall outcome will be predominantly beneficial, surpassing any negative consequences. Based on the aforementioned analysis, we have formed study hypothesis 1:

H1: *Green finance promotes the greening of the agricultural transition by easing financing constraints for sustainable agricultural development and limiting financing options for highly polluting agriculture. Although green finance may also have some negative impacts in promoting green agriculture, it maintains a significant positive effect on the overall reduction of carbon emissions from China's agricultural sector.*

Influential mechanism

The longstanding crude approach to development in China has exacerbated the problem of environmental contamination (Zhao et al., 2021). Upgrading the industrial structure stands as a crucial task in economic structure reform, offering an avenue to

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establish a greener and more sustainable development model, and fostering an environmentally friendly society (Li and Lin, 2017; Wang and Wang, 2021; Wu et al., 2021). To attain this objective, the Chinese Government has implemented a range of policies aimed at fostering environmentally sustainable growth. These policies primarily concentrate on facilitating the advancement of green industries through financial mechanisms and facilitating the enhancement of regional industrial structures (Gu et al., 2021; Wang and Wang, 2021). Green finance plays an essential part in the optimization of the regional industrial structure, as highlighted by Hu and Zhang (2023) and Wang and Wang (2021). Firstly, green finance facilitates the formation and flow of capital (Li et al., 2022b). It fosters innovation in financial instruments, thus enhancing savings and expediting the conversion of savings into investments (Soundarrajan and Vivek, 2016). Moreover, green finance directs capital flows towards environmentally friendly industries, while increasing the borrowing costs for high-pollution industries (Muganyi et al., 2021). Consequently, it promotes the transformation of industrial structure towards more advanced levels. Secondly, green finance facilitates industrial integration. It encourages green industries to pursue vertical and horizontal integration in order to enhance their competitiveness and reduce costs. The continuous agglomeration of production factors within the green industry has produced a strong spatial agglomeration effect (Hou et al., 2023; Wu, 2022). The achievement of enhancing the regional industrial structure has been successfully accomplished through the aforementioned primary paths.

Enhancing the industrial structure represents a significant avenue for attaining carbon emission reduction within the agricultural sector. Nevertheless, the developmental approach adopted by China, which prioritizes economic growth but disregards the environmental consequences, hampers the potential benefits of regional industrial restructuring in mitigating carbon emissions in the agricultural sector (Zhao et al., 2021). Moreover, that the China's historical approach of giving precedence to the advancement of secondary and tertiary sectors has had a detrimental effect on the progress of the primary sector, hence limiting its capacity to make a substantial impact on the reduction of carbon emissions (Dong et al., 2020). The aforementioned policy inclination is similarly evident in the green finance. The allocation of funding from green finance predominantly favored the secondary and tertiary sectors during the process of upgrading the regional industrial structure. The primary industry continues to face the challenge of budgetary limitations during the course of implementing sustainable practices. The process of upgrading regional industrial structure, although initially relieving the burden of agricultural carbon emissions, inadvertently creates a negative transmission mechanism within the realm of green finance that impacts agricultural carbon emissions. Thus, we propose Hypothesis 2:

H2: *China's long-standing policy tendency to prioritize the development of secondary and tertiary industries has hindered the allocation of green finance to the primary sector. Thus, while regional industrial structure optimization is an effective way to drive carbon reduction in China's agricultural sector. However, in the process of green finance influencing carbon emission reduction in China's agricultural sector, regional industrial structure optimization has become a negative transmission mechanism.*

The primary contributor to environmental pollution is the overconsumption of factors of production, as stated by Bian et al. (2019). The primary objective of green technology innovation is to mitigate factor consumption and enhance resource efficiency (Du et al., 2019). The implementation of green technological innovation has

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the potential to facilitate the attainment of a balanced and sustainable relationship between the economy and the environment. However, the successful adoption of such innovations necessitates both external financial support and appropriate governmental direction (Du et al., 2021; Yu et al., 2021). On one hand, green projects face challenges such as high financing costs, low financing efficiency, and difficulties in securing financing due to long investment cycles and unstable returns (Rasoulinezhad and Taghizadeh-Hesary, 2022). However, investment and financing signals from green finance can help reduce investors' search costs, improve investment efficiency and scale, and provide crucial financial backing for green technological innovation (Yu et al., 2021). On the other hand, green financial policies provide tax advantages and financial subsidies to promote environmentally friendly initiatives, so motivating businesses to enhance their environmental practices through the adoption of green technological advancements (Zeng et al., 2023). But heavily polluting enterprises face constraints as they experience a decline in their debt financing levels due to financing penalties. As a result, these financial constraints hinder their ability to engage in green technological innovation, thus impeding progress in this area to some extent.

The green technology innovation plays a crucial position in facilitating the mitigation of carbon emissions within the agricultural sector (Guo and Zhang, 2023). Firstly, it integrates various production factors required in agricultural production, optimizes resource consumption, and reduces pollutant emissions (Li et al., 2023a). Secondly, it enhances the green production efficiency of farmers, effectively converting green technological innovation into economic benefits, and reduces pollution emissions while maintaining existing agricultural outputs (Mehmood et al., 2024). In essence, green finance mitigates financial constraints associated with green technological innovation, provides policy guidance, and facilitates its application in agricultural practices. As a result, there is a significant decrease in carbon emissions within the agricultural sector. Building upon the aforementioned analysis, we propose Hypothesis 3 for the present study:

H3: *The introduction of environmentally friendly technologies in agricultural production can help reduce greenhouse gas emissions and achieve the goal of sustainable development. However, the creation and diffusion of technologies cannot be achieved without external financial support and appropriate guidance from the government. The tax incentives and financial subsidies brought by green finance alleviate the financing constraints of green technology innovation and strongly support its positive role in promoting agricultural carbon emission reduction.*

Data and methodology

Data

The study encompasses a sample scope consisting of 30 provinces in China, spanning the period from 2007 to 2019. The total number of valid observations amounts to 390. The data pertaining to green credit (GC), green investment (GI), green support (GS), independent variables, and control variables were mostly sourced from the China Statistical Yearbook spanning the years 2008 to 2020. The data pertaining to agricultural energy in the measurement of agricultural carbon emissions is sourced from the China Energy Statistics Yearbook. The data pertaining to green insurance (GIN) in the field of green finance is sourced from the China Insurance Yearbook. The data regarding the quantity of green patents that have been granted is sourced from the China Research Data Service Platform (CNRDS). In order to accommodate for individual missing values, a

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linear interpolation technique was employed. Furthermore, in order to enhance the smoothness of the data, we applied a logarithmic transformation to the three variables: total agricultural carbon emissions, farmers' income, and agricultural mechanization level.

Variables

Dependent variable

Various types of greenhouse gases are generated during agricultural production activities such as farming, animal breeding and biomass burning (Huang et al., 2019; Yun et al., 2014). The production activities serve as the foundation for quantifying the aggregate carbon emissions originating from China's agriculture sector. First and foremost, agricultural cultivation encompasses the practice of cultivating rice, engaging in land ploughing, and utilizing agricultural materials. For example, the production of rice results in the emission of methane gas. In order to accommodate the disparities in the growth cycle of rice across various provinces and cities, we choose to utilize a median value of 130 days. And ploughing the land during agricultural cultivation also leads to nitrous oxide emissions. Additionally, the use of agricultural films, pesticides, fertilizers, and various types of agricultural energy during cultivation also contribute to carbon emissions. Secondly, animal farming is responsible for generating greenhouse gases, primarily methane produced through animal intestinal fermentation, as well as methane and nitrous oxide from animal feces. The emission factors for methane from enteric fermentation are based on the average farming cycles of animals. The emission factors for methane and nitrous oxide from animal feces are derived from the six major administrative regions in China. The end-of-year population numbers of each type of livestock and poultry are used for measurement. Lastly, biomass burning, mainly straw, also adds to carbon emissions and is gradually becoming the second largest source of carbon emissions from China's agricultural sector. In our specific measurements, we focus on the straw burning of the six main straw crops (Huang et al., 2019). The formula that has been derived for calculating the total agricultural carbon emissions in China is as follows:

$$Carbon = \sum Carbon_k = \sum \alpha_k T_k \qquad \text{(Eq.1)}$$

Where *Carbon* represents the aggregate quantity of carbon emissions from agricultural activities, $Carbon_k$ represents the amount of carbon emissions specifically attributed to the kth category of agricultural carbon sources, T_k represents the total quantity of carb-on sources falling under the kth category, and α_k represents the emission coefficients as-sociated with the kth category of carbon sources. The specific agricultural carbon emission coefficients can be found in *Table 1*.

Independent variable

A comprehensive assessment framework for green finance in China was developed, taking into account the existing data and prior research conducted by Lv et al. (2021) and Zhou et al. (2020). The evaluation approach has four primary variables, namely green credit, green investment, green insurance, and green support (*Table 2*). The entropy approach is employed to assess the green finance index for every province and city within China. Firstly, the availability of data on green credit from China's five major banks remains confined to the national level, making it impossible to conduct an in-depth analysis at the provincial or municipal level. In order to overcome this constraint, we

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propose the utilization of the interest expense ratio of industries with high energy consumption as a proxy indicator for the assessment of green credit. It is notable that a higher interest expense ratio observed in China's industries with high energy consumption indicates a lower level of green credit in the country. Secondly, green investment and green support play a key role in green project financing and are the main manifestation of financial support for green technological innovation and a reliable indicator of government support for energy conservation and environmental protection. Considering their significance, these factors are duly incorporated within the evaluation system proposed in this paper. In this context, green investment is the share of regional environmental pollution investment in Gross Domestic Product (GDP), while green support is the share of fiscal environmental protection expenditure in total fiscal expenditure. Thirdly, green insurance in China predominantly refers to environmental pollution liability insurance. However, given its relatively recent introduction in 2013, this type of insurance faces challenges such as a limited sample period, low participation rates, and insufficient official data. As an alternative measure, we utilizing the payout rate of agricultural insurance as a substitute for the payout rate of environmental pollution liability insurance.

Table 1. *Agricultural carbon emission coefficients*

Carbon source	Emission coefficients	Emission factor sources
Rice cultivation	3.136 g/m^2·day	Matthews et al. (1991)
Land ploughing	312.600 kg/km^2	Institute of Agronomy and Biotechnology, China Agricultural University (IABCAU)
Agricultural film	5.180 kg/kg	Institute of Resource, Ecosystem and Environment of Agriculture, Nanjing Agricultural University (IREEA)
Pesticide usage Fertilizer usage	4.934 kg/kg 0.896 kg/kg	Oak Ridge National Laboratory (ORNL)
Coal Diesel Petrol	0.756 kg/kg 0.593 kg/kg 0.554 kg/kg	Intergovernmental Panel on Climate Change (IPCC)
Cow Camel Horse Donkey/mule Goat Sheep Pigs Poultry	2136.939 kg/(head·year) 1101.891 kg/(head·year) 509.061 kg/(head·year) 281.547 kg/(head·year) 205.191 kg/(head·year) 201.201 kg/(head·year) 152.355 kg/(head·year) 3.528 kg/(head·year)	Collated from the Guidelines for the Preparation of Provincial Greenhouse Gas Inventories
Rapeseed Rice Corn Wheat Soy beans Cotton	0.220 kg/kg 0.180 kg/kg 0.170 kg/kg 0.160 kg/kg 0.150 kg/kg 0.130 kg/kg	Huang et al. (2019)

In the greenhouse effect, 1 ton of methane is equivalent to 21 tons of carbon dioxide, while 1 ton of nitrous oxide is equivalent to 310 tons of carbon dioxide

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Table 2. *China green finance indicator system*

Secondary indicators	Tertiary indicators	Indicator direction
Green credit	Interest expenses of energy-intensive industries	-
Green investment	Environmental protection investment	+
Green insurance	Agricultural Insurance Payout	+
Green support	Public expenditure on environmental protection	+

Control variables

Based on pertinent research, a number of crucial variables have been identified as control factors (Li et al., 2023b; Yun et al., 2014; Zhang et al., 2019). Firstly, farmers' income. Increased income levels of farmers can help to alleviate the financial constraints on the adoption of green production technologies. Secondly, urbanization rate. As urbanization rates increase, a large number of people move out of the agricultural sector, which increases pressure on the supply of agricultural products. It is likely to result in a shift towards higher inputs and emissions in agricultural production. Thirdly, financial support for agriculture. The proliferation of green production technology can be attributed to the augmented financial assistance provided by the government to the agricultural. Fourthly, we consider the agricultural industrial structure. The large contribution of agricultural carbon emissions via farming and animal husbandry is widely acknowledged. Therefore, any increase in the proportion of these activities within the agricultural production structure will inevitably result in higher carbon emissions. Fifthly, science and education expenditure (SEE). Investment in science and technology by local governments is an essential foundation for promoting regional technological innovation. Similarly, rational resources to education empowers farmers to adopt sustainable production technologies while enhancing their overall knowledge and awareness. It is noteworthy that strengthening environmental protection campaigns and cultivating farmers' awareness of green practices are also of utmost importance. Sixthly, the level of agricultural mechanization. The increasing mechanization of agriculture has transformed traditional practices and ushered in a more modernized sector. Nevertheless, the consequent rise in energy use has also resulted in elevated agricultural carbon emissions. Seventhly, the effective irrigation rate of agricultural land. Precision irrigation is a critical component of precision agriculture technology and an embodiment of the modernization and greening of agricultural practices. Lastly, we consider the level of transport infrastructure. Enhancements in transportation infrastructure have facilitated the establishment of large-scale agricultural production models. Nevertheless, the augmented influx of production materials linked to these models has led to elevated levels of carbon emissions in the agriculture sector.

Mediating variables

In order to elucidate the correlation between green finance and agricultural carbon emissions, our research dives into the underlying mechanism. Drawing from the theoretical analyses outlined in the previous section, we establish regional industrial structure (RIS) and technological progress (TP) as the mediating variables. In order to accurately assess the regional industrial structure, we utilize the ratio between the output of the tertiary industry and the output of the secondary industry. In addition, we used the number of green patents granted per year in each province and city to assess

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technological progress. It is worth noting that the number of green patents granted is in 10,000 units. For green technology and green technology patents, they are defined in the Green Technology Patent Classification System published by the State Intellectual Property Office of China. Compared with traditional technologies, green technologies refer to emerging technologies that can reduce pollution, minimize consumption and achieve sustainable development. And green technology patents are patents with green technology as the subject of invention, which is the direct embodiment of green technology. The names, abbreviations and descriptions of all the study variables are shown in *Table 3*.

Table 3. *Variables description*

Variables	Sign	Description
Dependent variable		
Agricultural carbon emissions	Carbon	Calculated from equation 1
Independent variable		
Green finance	GF	Entropy method yields
Control variables		
Farmers' income	Income	Natural logarithm of net farm income
Urbanization	Urban	Urban population/total population
Financial support for agriculture	Support	Agricultural expenditure/total fiscal expenditure
Agricultural industry structure	Structure	Gross value of agricultural and livestock production/gross value of agricultural, forestry, livestock and fisheries production
Science and education expenditure	SEE	Financial expenditure on science, technology and education/GDP
Agricultural mechanization	Machine	The natural logarithm of the total power of agricultural machines
Effective irrigation of agricultural land	Irrigation	Effective irrigated area/sown area
Transport infrastructure	Road	Road length per capita
Mediating variables		
Regional Industrial structure	RIS	Tertiary sector output/secondary sector output
Technological progress	TP	The quantity of green patents granted

Models

Baseline regression model

This study employs a panel data model to examine the effectiveness of green finance in achieving carbon emission reduction in China's agricultural sector:

$$Carbon_{it}=\alpha_0+\beta_0 GF_{it}+\beta_n \sum Z_{it}+\delta_i+\varphi_t+\varepsilon_{it} \quad \text{(Eq.2)}$$

In the model, the constant term α_0 represents the intercept, while the coefficients of each variable β represent their respective impacts. The i is used to denote the province, whereas the t is used to represent the year. The dependent variable, denoted as $Carbon_{it}$,

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signifies the agricultural carbon emissions of the ith province (city) in year t. On the other hand, the core independent variable, denoted as GF_{it}, represents the green financial development index of the ith province (city) in year t. Additionally, a control variable $\beta_n \sum Z_{it}$ is included. The province fixed effect is shown by the symbol δ_i, the time fixed effect is expressed by φ_t, and the random error term is represented by ε_{it}.

Mediated effects model

To further explore potential mechanisms, we have used the research ideas proposed by Persico et al. (2004). Thus, we have introduced two mediating variables into the baseline regression to further analyze the mechanisms and direction of transmission. By observing the changes in the estimated coefficients of green finance, we can determine the presence of these mechanisms and their effect. If the coefficient on green finance decreases when a mediating variable is introduced into the baseline regression, it indicates that the mediating variable is a positive mechanism. *Figure 1* illustrates that one of the mediating variables (M), referred to as M, acts as a positive transmission mechanism in two scenarios: when green finance positively (or negatively) influences M, and when M positively (or negatively) affects agricultural carbon emissions. Hence, by establishing the positive nature of M as a transmission mechanism and its consequential impact on agricultural carbon emissions, it can be inferred that green finance similarly yields a positive influence on M. On the contrary, if the incorporation of a mediating variable in the baseline regression analysis leads to an augmentation in the coefficient for green finance, then suggests that the mediating variable operates as a negative mechanism. *Figure 1* demonstrates that the mediating variable M serves as a negative transmission mechanism in two cases: when green finance positively (or negatively) influences M, but M negatively (or positively) affects agricultural carbon emissions. Therefore, if it is established that M functions as a negative transmission mechanism and exerts an adverse impact on carbon emissions in the agricultural sector, it may be inferred that green finance yields a beneficial outcome for M.

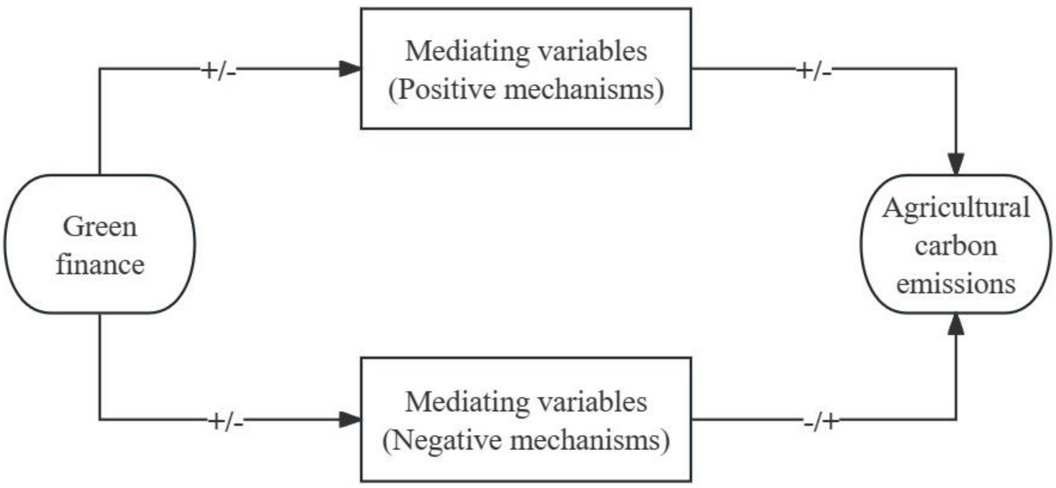

Figure 1. *Transmission mechanism*

Based on this analysis, we have constructed the following panel mediation effects model:

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$$Carbon_{it}=\omega_0+\mu_0 GF_{it}+\mu_1 M_{it}+\mu_n \sum Z_{it}+\delta_i+\varphi_t+\varepsilon_{it} \quad \text{(Eq.3)}$$

$$M_{it}=\sigma_0+\theta_0 GF_{it}+\theta_n \sum Z_{it}+\delta_i+\varphi_t+\varepsilon_{it} \quad \text{(Eq.4)}$$

In the mediated effects model, we have constant terms represented by ω_0 and σ_0. The coefficients of each variable are denoted by μ and θ, while M_{it} is the mediating variable. The remaining settings are held constant, consistent with the baseline regression model.

Empirical results and discussion

Econometric model selection

Before the regression analysis, it is prominent to ascertain the appropriate choice between the mixed Ordinary Least Squares (OLS) and the variable coefficient model. And the test results are shown in *Table 4*. The outcome of the Breusch-Pagan (B-P) test yielded significant. Consequently, the original hypothesis of employing the mixed OLS regression must be dismissed, favoring the adoption of the variable coefficient model. Once the selection of the variable coefficient model is determined, the subsequent step involves deciding between the random effects model and the fixed effects model. This determination is accomplished through the application of the Hausman test, which measures the disparity between the two models. The Hausman test presented a chi-square value of 153.33, signifying significance at the 1% level. Consequently, the hypothesis of employing a random effects model necessitates rejection in favor of choosing a fixed effects model for the regression analysis.

Table 4. *B-P test and Hausmann test results*

Variables	B-P	Fe	Re	Difference	S.E.
GF		-1.484	-1.524	0.040	0.020
Income		-0.041	-0.207	0.166	0.031
Urban		1.023	0.759	0.264	0.033
Support		-0.125	-0.219	0.094	0.013
Structure		0.520	0.443	0.077	0.025
SEE		1.597	1.498	0.098	0.067
Machine		0.149	0.198	-0.049	0.004
Irrigation		-0.407	-0.459	0.052	0.010
Road		0.010	0.007	0.003	0.000
Carbon	0.982 (0.991)				
E	0.002 (0.040)				
U	0.110 (0.332)				
Chibar2	1697.60***				
Chi2				153.33***	

The standard error is in parentheses; * p < 0.1, ** p < 0.05, *** p < 0.01

Baseline regression

Based on the inclusion of province fixed effects, we further considers the potential influence of time fixed effects. The results of the baseline regression analysis are

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displayed in *Table 5*. Model (1) solely controls the main explanatory variables, while model (2) includes additional control variables. Models (3) and (4) encompass both the main explanatory variables and all control variables. The distinction between models (3) and (4) lies in the fact that model (4) also controls for time fixed effects. The results indicate that green finance exerts a statistically significant negative impact across models (1) to (4). Furthermore, compared to model (3), the goodness of fit of model (4) improves after accounting for time fixed effects, thereby confirming the necessity of utilizing a two-way fixed effects model. Specifically, green finance mitigates the financing burden of transitioning to agricultural greening and promotes the advancement of agricultural green production methods (Guo et al., 2022). Consequently, green finance is effective in reducing the overall carbon emissions originating from the agriculture sector, thus validating Hypothesis 1.

Table 5. *Baseline regression results*

Variable	**Carbon**			
	(1)	**(2)**	**(3)**	**(4)**
GF	-2.673*** (0.355)	-1.906*** (0.368)	-1.454*** (0.215)	-1.484*** (0.219)
Income		0.235 (0.256)	0.031 (0.065)	-0.041 (0.163)
Urban		0.881 (0.631)	0.894** (0.369)	1.023** (0.419)
Support		-0.307 (0.460)	-0.021 (0.252)	-0.125 (0.347)
Structure		0.760** (0.354)	0.521** (0.251)	0.520** (0.236)
SEE			1.942*** (0.653)	1.597** (0.752)
Machine			0.147*** (0.030)	0.149*** (0.032)
Irrigation			-0.434*** (0.088)	-0.407*** (0.093)
Road			0.008** (0.003)	0.010** (0.004)
Cons	14.553*** (0.039)	11.477 (2.025)	12.286*** (0.393)	12.810*** (1.359)
Province	YES	YES	YES	YES
Year	YES	YES	YES	YES
R^2	0.704	0.753	0.834	0.845
N	390	390	390	390

The standard error is in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The regression outcomes for the control variables closely consistent with previous studies, and this paper provides a brief analysis of the estimation results obtained from model 4 (Shi and Chang, 2023; Xiong et al., 2020; Yun et al., 2014). The coefficients pertaining to the urbanization rate, agricultural industrial structure, expenditure on science and education, level of transport infrastructure and level of agricultural

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mechanization are all significantly higher than zero and statistically significant. Conversely, the coefficient for the effective irrigation rate of agricultural land exhibits a negative value and demonstrates statistical significance. It is noteworthy that the expansion of expenditure on science and education has not produced the expected results of reducing carbon emissions, possibly due to the shortage of awareness among farmers to protect the environment.

Robustness test

We employ three different methodologies to validate the baseline regression results. The initial approach entails employing the instrumental variable method, where the instrumental variable is represented by the first-order lagged term of green finance. The second method restricts agriculture to plantation and recalculates the total agricultural carbon emission as a proxy variable. The third method involves rerunning the regression using the system generalized method of moments (SGMM).

The study faces two potential endogeneity problems. Firstly, although this paper controls for the main variables affecting agricultural carbon emissions, there may still be omitted variables that could bias the regression results. Secondly, it is plausible that a reverse causation relationship exists between green finance and carbon emissions within agricultural sector. As a result, it is necessary to employ the two stage least square (2SLS) for regression estimation. The endogeneity test of the instrument variables yields a p-value of 0.049, suggesting that green finance is indeed endogenous and that the baseline regression results may be biased. To overcome this bias, the instrumental variables method must be employed. Finally, the F-value obtained for the one-stage estimation is 713.75, surpassing the critical value threshold of 10. This result provides strong evidence in support of the selection of instrumental variables. Upon analyzing the outcomes of the second-stage estimation, it is evident that green finance maintains a consistently negative and statistically significant effect. This finding further reinforces the reliability and validity of the baseline regression results.

Column (3) of *Table 6* shows the results of rerunning the regression estimation with replaced explanatory variables. The regression coefficient for green finance remains negative and significant, again demonstrating its ability to drive carbon reduction in agriculture. Furthermore, taking into consideration the possibility that current agricultural carbon emissions may be impacted by the previous period, column (4) employs the SGMM for the regression analysis. The Arellano-Bond (AR) test value of AR(1) is significant at 5 per cent level while the value of AR(2) fails the test of significance. Therefore, the original hypothesis is accepted and the selected lagged term of one period for agricultural carbon emissions is considered valid. The regression analysis employing the SGMM reveals that green finance exhibits a consistent positive influence on the mitigation of overall carbon emissions within agricultural sector. In summary, it may be inferred that the baseline regression findings exhibit robustness.

Heterogeneity analysis

In order to examine the disparate impacts of green finance on agricultural carbon emissions across regions of China, the sample data was categorized into three segments according to the established regional split of Chinese provinces. And the estimation method employed was the same as the baseline regression. The findings of

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the analysis can be found in *Table 7*, with Models (1)-(3) representing the estimation results for eastern, central, and western China, respectively. The coefficient of green finance in Eastern China is notable negative, and lower than the baseline regression findings. The unique location advantage of eastern China, along with its high degree of marketization, facilitates access to all types of development resources. This lends substantial support for the greening transformation of regional agriculture. In contrast, the influence of green finance in the central region is found to be insignificant. One plausible reason for this phenomenon could be attributed to the inadequate functioning of the market mechanism at the regional level, which hinders the efficient allocation and distribution of green finance resources. The obstruction of capital flow is a significant challenge to the effective implementation of green finance in achieving the desired outcomes of reducing carbon emissions in the agriculture sector. In the western region, the coefficient of green finance exhibited a notably negative. But in comparison to the eastern region, its influence and significance are relatively stronger. The rationale behind this is that the advancement of green finance in the western region is currently at an early stage, and its greater marginal impact allows for the swift promotion of agricultural carbon emission reduction in the near future. In brief, the implementation of green finance has shown to be a significant contributor to the mitigation of overall agricultural carbon emissions in both the eastern and western areas of China. However, the impact in the central region is not yet obvious and deserves further study.

Table 6. *Robustness test results*

Variable	**2SLS**		**Plantation**	**SGMM**
	(1)	**(2)**	**(3)**	**(4)**
GF		-1.631^{***} (0.144)	-1.094^{***} (0.337)	-0.325^{***} (0.113)
L. GF	0.936^{***} (0.024)			
L. Carbon				1.013^{***} (0.191)
Control variables	YES	YES	YES	YES
Cons	0.192 (0.145)	12.520 (0.804)	1.112^{**} (2.268)	0.306 (0.265)
F value	713.75			
AR(1)				-2.213^{**}
AR(2)				0.641
Province	YES	YES	YES	YES
Year	YES	YES	YES	YES
N	360	360	390	330

L. N is the first order lag term of the variable N. The standard error is in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Furthermore, our aim is to investigate the potential variations in the effects of the individual sub-indicators that comprise green finance on carbon emissions within agricultural sector. Among these indicators, it is observed that the impact of green credit

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is contrary to expectations, although this impact is not statistically significant. And green investment becomes a major contributor of carbon reduction in agriculture. This indicator functions as for measuring the annual investment intensity in environmental pollution control within each province of China. It not only reflects local financial expenditure but also encompasses the leveraging of social funds for environmental control. Data on green investment from 35 developed and emerging countries show that. As the 1990s progressed, the leadership of green investment gradually shifted from Europe and the United States to China. Even during the financial crisis, green investment in Asia continued to soar, with China taking the lion's share. By 2010, China's green investment had surpassed that of the entire European region (Eyraud et al., 2013). Similarly, the effects of green insurance are in line with expectations, even though they are not statistically significant. The limited coverage of China's environmental pollution liability insurance, introduced in 2013, may be identified as the primary factors contributing to this situation. And green support displays a significant negative affect on carbon emissions within agricultural sector. Green support represents the government's attention and support for environmental protection, acting as a driving force for advancing the transformation towards greener agricultural practices. In summary, our findings highlight the differences in the impact of various green financial instruments on agricultural carbon emissions.

Table 7. *Regional differences, and heterogeneous outcomes in green finance*

Variable	**Region**			**GF**			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
GF	-1.003** (0.384)	0.331 (0.234)	-2.741*** (0.811)				
GC				0.082 (0.087)			
GI					-5.522* (2.743)		
GS						-0.846 (1.324)	
GIN							-0.048*** (0.008)
Control variables	YES	YES	YES	YES	YES	YES	YES
Cons	10.496*** (3.041)	14.381*** (1.019)	12.201*** (3.539)	11.771*** (1.808)	11.617*** (1.720)	11.720*** (1.783)	11.740*** (1.467)
Province	YES	YES	YES	YES	YES	YES	YES
Year	YES	YES	YES	YES	YES	YES	YES
N	143	130	117	390	390	390	390

The standard error is in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Mechanisms of influence

The findings of the mechanism analysis are displayed in *Table 8*. And the regression findings can be summarized as follows. Firstly, upon considering pertinent variables, the statistical significance of the coefficients on industrial structure and technological progress becomes evident, as seen in Columns (3) and (5). The coefficient of industrial

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structure has a statistically significant negative influence, suggesting that optimizing the regional industrial structure is an effective means of reducing agricultural carbon emissions. And the coefficient of technological progress is positively significant, suggesting that technological advancements lead to an enhance in agricultural carbon emissions, possibly due to an expansion in production scale and intensified factor consumption. Hence, the influence of industrial structure and technical progress on carbon emissions in the agriculture sector is substantiated. Secondly, when comparing Column (1) to Columns (3) and (5), it becomes evident that the coefficients of green finance show a remarkable increase when the industrial structure variable is included in the baseline model, while a significant decrease is observed when the technological progress variable is included. By combining Column (2) and Column (4), it becomes evident that industrial structure acts as a negative mechanism for the affect of green finance on carbon emissions in the agriculture sector, while technological progress acts as a positive mechanism. This signifies that optimizing the regional industrial structure through green finance dose not improve carbon emissions within agriculture sector, while technological progress can help achieve a reduction. Therefore, research hypotheses 2 and 3 are supported.

Table 8. *Mechanism analysis results*

Variable	**Carbon**	**RIS**	**Carbon**	**TP**	**Carbon**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
GF	-1.484^{***} (0.219)	0.806^{**} (0.383)	-1.435^{***} (0.121)	6.289^{***} (2.219)	-1.801^{***} (0.205)
RIS			-0.060^{***} (0.017)		
TP					0.050^{**} (0.022)
Control variables	YES	YES	YES	YES	YES
Cons	14.553^{***} (0.039)	3.215 (2.192)	13.003^{***} (0.690)	16.157^{**} (6.038)	11.995^{***} (1.289)
Province	YES	YES	YES	YES	YES
Year	YES	YES	YES	YES	YES
N	390	390	390	390	390

The standard error is in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

In column (3), the coefficient for green finance exhibits an increase of 0.049 units when compared to the column (1). This shows that the negative mechanism explains 3.3% of the affect of green finance on carbon emissions in agriculture. Additionally, the estimated coefficient of technological progress in column (5) decreased to -1.801, which is 21.36% lower than the baseline regression value. This indicates that technological progress, as a positive mechanism of green finance affecting carbon emissions in agriculture, has a mediating effect of 21.36%. Overall, it can be observed that the mediating effect of the positive mechanism, at 21.36%, is significantly larger than the mediating effect of the negative mechanism, at 3.3%. This suggests that the implementation of green finance continues to have a inhibitory influence on carbon emissions in the agricultural sector as a whole.

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Conclusions and policy recommendations

"Clear waters and green mountains are as good as mountains of gold and silver." It is imperative to prioritize environmental quality over economic development. Given this perspective, the current study aims to examine the impact of China's green finance on agricultural carbon emissions. The results can be succinctly summarized into three primary points. Firstly, the promotion of green finance in China effectively diminishes the overall agricultural carbon emissions. This outcome remains highly credible even after conducting thorough robustness tests. Secondly, the implementation of green finance has been found to have a substantial inhibitory affect on agricultural carbon emissions in both the eastern and western areas of China, with a particularly notable impact observed in the western region. Moreover, the green investment is a key contributor in facilitating the mitigation of carbon emissions within the agricultural sector. Lastly, in the context of green finance facilitating the reduction of agricultural carbon emissions, the industrial structure serves as a disincentive, while technical innovation functions as a catalyst. Significantly, the positive impact of technical advancement surpasses the negative affect of industrial organization. Hence, the fundamental assertion that green finance has a major role in mitigating carbon emissions in the agricultural sector of China remains unaltered.

In response to the aforementioned findings, our aim is to propose targeted policy recommendations. Firstly, it is imperative to enhance the structure of the green financial system. On one hand, the establishment of a trading platform specifically for agricultural carbon emissions becomes necessary. This platform will play a pivotal role in guiding China's agriculture towards adopting more sustainable practices through the pricing and trading of agricultural carbon emission rights (Abdul et al., 2019). On the other hand, the establishment of a green agricultural credit rating system holds significant importance. The ratings of agricultural enterprises would then serve as a significant determinant in borrowing and lending decisions, thereby incentivizing them to prioritize environmental conservation. Secondly, it is of utmost importance to develop regionally differentiated carbon emission reduction policies (Chen and Groenewold, 2015). The eastern region, for instance, should actively introduce advanced low-carbon technologies from an international perspective to enhance the efficiency of agricultural carbon emission reduction through technological advancements. Similarly, the central region should leverage its geographic advantage by actively acquiring advanced low-carbon agricultural technology and management expertise from the eastern region. As for the western region, expedited efforts should be made to popularize and construct green finance, thereby facilitating the growth of financial science and technology in order to effectively support low-carbon agricultural technologies. Finally, green financial development is used to promote the application of green technologies. Compared with the world's major technology innovation countries and regions, China's green technology growth is far ahead of the rest and ranks first. However, China's green development still relies heavily on factors of production rather than improving productivity through the application of green technologies to promote economic growth (Wang et al., 2019). In particular, there is a large gap between China and Organization for Economic Co-operation and Development (OECD) and Group of 20 (G20) members in terms of environmentally adjusted multifactor productivity (Rodríguez et al., 2016). Therefore, to solve the problem of China's long-term low application rate of green technology, we should focus on the use of green finance to break the financing constraints and thus promote the widespread application of green

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technology. Only through such a comprehensive approach can China fully fulfil its commitment to address climate change and maintain the long-term stability of the global ecosystem and environment.

This study aims to reconstruct and assess the overall agricultural carbon emissions in China, taking into consideration previous research findings. While related studies mostly concentrated on the plantation sector, this paper extends its scope to include animal breeding and biomass burning when measuring agricultural carbon emissions. In order to derive accurate measurement coefficients, authoritative documents published by the Chinese government serve as the basis. Nevertheless, the constraints in research data may result in discrepancies between the estimated outcomes of China's overall agricultural carbon emissions and the true amount. Despite this, the credibility of the research results remains unaffected, and future research should strive for further improvement in this area. The relationship between green finance development and agricultural carbon emissions is intricate and multifaceted. Therefore, subsequent researchers should explore additional mechanisms to develop a better understanding of this relationship in the Chinese context.

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