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Exploring the Impact of Digital Inclusive Finance on Agricultural Carbon Emissions

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Abstract

Digital inclusive finance, a deep integration of traditional financial services and information technology, has injected strong momentum into the nation's path towards green and low-carbon development through a carefully crafted online financial service system and precise adjustments to corporate financing structures, displaying significant positive impacts. The article employs a fixed effects model to empirically test the impact of digital inclusive finance on agricultural carbon emissions using panel data from 31 provinces and cities from 2011 to 2021. The study finds that digital inclusive finance significantly reduces agricultural carbon emissions, and these results hold true after a series of robustness tests. Heterogeneity analysis reveals that the impact of digital inclusive finance on agricultural carbon emissions varies by region, with the most significant suppression in the eastern regions, followed by central and then western regions. Furthermore, compared to non-major grain-producing areas, the development of digital inclusive finance in major grain-producing areas has a more significant impact on reducing agricultural carbon emissions. To achieve the goals of reducing agricultural carbon emissions and sustainable agricultural development, it is necessary to rely on digital technology and the digital economy, actively develop digital inclusive finance, promote agricultural technological innovation and dissemination, and expand the geographic boundaries of financial services to reduce the cost of capital flows between different regions, thereby promoting agricultural carbon reduction and environmentally friendly agricultural development.

Keywords

Heterogeneity Analysis; Digital Inclusive Finance; Agricultural Carbon Emissions.

1. Introduction

1.1. Background

Global climate change concerns necessitate reducing agricultural carbon emissions, a key greenhouse gas. China has set ambitious "dual carbon" targets to peak carbon emissions and reach carbon neutrality in response to global climate governance. Agriculture, the backbone of the economy, is essential to attaining these goals (Wang,2024). Innovative digital inclusive finance combines financial technology and inclusive financial services to reduce agricultural carbon emissions. Digital inclusive finance uses the internet, big data, and mobile communications to provide convenient, affordable, high-quality financial services. Advances in information and financial technology make financial services for farmers and agricultural firms more accessible and efficient, enabling industry upgrades and sustainable development (Carmela Annosi,2020).

The Chinese government has promoted digital inclusive finance in agriculture through many policy documents. Regions and agencies have made tremendous progress since the State Council's 2023 proposals for high-quality inclusive financing implementation (Mindzaeva,2023). These policies promote orderly digital inclusive financing in the digital

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economy, boosting rural development. Digital inclusive finance helps marginalized farmers access quality financial services, enabling rural economic development and industry transformation (Jin, S., 2024). It also fosters agricultural technical innovation, production process changes, and energy and pollution reduction. Digital inclusive financing minimizes agricultural carbon emissions by lending and insuring modern agricultural technologies and equipment. It also offers sustainable energy loans and favourable policies to promote solar and wind energy, lowering fossil fuel use.

1.2. Research Objective

In the context of climate change, studying how digital inclusive financing affects agricultural carbon emissions is crucial. This work builds models and uses statistical data to investigate the relationship between digital inclusive finance and agricultural carbon emissions using econometric methodologies. It shows how digital inclusive financing affects agricultural carbon emissions and how it might reduce them (Chang, 2022). The study also helps policymakers understand how digital inclusive finance promotes green agriculture and carbon reduction. This allows policymakers tailor policies to agricultural sectors at different phases of growth in different areas, optimizing digital inclusive finance's contribution in lowering agricultural carbon emissions.

This research also advances green economic growth and sustainable agriculture. Agriculture, a pillar of the national economy, must reduce its carbon emissions for sustained green economic development. Digital inclusive finance may optimize resource allocation, increases production efficiency, and lowers production costs in agriculture, promoting sustainable development (Wang,2024). The influence of digital inclusive finance on agricultural carbon emissions must be studied to identify underlying links, provide policy frameworks, and promote economic development. This research promotes China's financial system reforms and green agriculture and economic development.

2. Literature Review

2.1. Factors Influencing Agricultural Carbon Emissions

In the journey towards sustainable agricultural production, several studies have focused on different aspects influencing carbon emissions. Guan, N.,(2023) demonstrated that increased agricultural mechanization helps control carbon emissions from production. Concurrently, Althoey (2023) explored the effects of agricultural technological advancement on emissions from energy use in agriculture, highlighting that such advancements significantly mitigate emission intensity. Technological efficiency not only reduces emissions locally but also has a beneficial spillover effect on neighboring regions. Moreover, Wang(2021) and his team observed that agricultural land transactions contribute to lowering emission intensity, economic development and mechanization as intertwined drivers affecting emissions levels.

Further detailing the factors affecting carbon emissions, the role of soil management and inputs in cultivated lands of Northeast China (Li, H., 2024). Demographic and skill-related characteristics of farmers impact emissions. And agricultural emissions to ongoing economic development within the sector. However,Enhancing production efficiency, optimizing the agricultural structure, and reducing the rural population are key to reducing emissions, it also need structural optimization to curb emission growth. Tran(2021) further linked emissions from livestock farming to the income of rural residents, uncovering a significant dynamic interplay between the two variables. These studies collectively underline the multifaceted approach needed to tackle agricultural carbon emissions effectively.

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2.2. Impact of Digital Inclusive Finance on Agricultural Carbon Emissions

While extensive literature has explored the general impact of digital inclusive finance on carbon emissions, specific studies concerning its influence on agricultural carbon emissions are still in their infancy. There is a positive effect of digital inclusive finance in reducing the intensity of agricultural carbon emissions. Digital inclusive finance supports low-carbon agricultural practices by facilitating efficient land use transitions, thereby fostering low-carbon development in the agricultural sector(Streimikiene, D., 2024). Additionally, the development level of digital inclusive finance across various provinces has been shown to have a dual-threshold effect on reducing agricultural carbon emissions, indicating significant variability based on regional development stages (Xu, X., 2021). Further examination using a spatial Durbin model revealed that the impact of digital inclusive finance on agricultural carbon emissions varies across different regions, presenting a misaligned spatial overlay pattern (Charfeddine, 2023). A nonlinear relationship between digital inclusive finance and green agriculture, suggesting that as digital finance matures, it increasingly supports sustainable agricultural practices. Zheng, G.(2023) concluded that digital inclusive finance not only mitigates the intensity of agricultural carbon emissions but also bolsters the level of socialized agricultural services and deepens industry integration, significantly aiding the green transformation and high-quality development of agriculture. Despite these advances, the research is not yet comprehensive, highlighting the need for more focused studies that consider regional disparities in economic development, agricultural structures, and digital finance levels to formulate precise and effective policies.

3. Methodology

To examine the impact of the development of digital inclusive finance on agricultural carbon emissions and account for differences among provinces, a fixed effects model is used to analyze the relationship. The model is designed as follows to eliminate the effects of heteroscedasticity by incorporating the logarithmic forms of control variables:

$$lnEC_{i,t} = \beta_0 + \beta_1 lnDF_{i,t} + \gamma lncontrol_{i,t} + \mu_i + \varepsilon_t + e_{i,t} \quad (1)$$

$EC_{i,t}$ represents the agricultural carbon emissions of the i th province in the t th year. $DF_{i,t}$ represents the level of development of digital inclusive finance of the ith province in the tth year.; $control_{i,t}$ represents a series of control variables including the level of economic development (ED), the level of urbanization (UR), the level of agricultural modernization (AM), and the level of government support for agriculture (FS); β_0 is the constant term, β_1 is the coefficient of the main explanatory variable,

γ represents the coefficients of control variables, μ denotes the fixed effects for regions, ε denotes the time fixed effects, and e is the random error term in the model.

3.1. Dependent Variable

This paper uses the carbon emission coefficient method, commonly referenced in existing literature, to calculate agricultural carbon emissions. There are two approaches to measuring agricultural carbon emissions: narrow and broad. The primary sources of carbon defined here include diesel used in agriculture, fertilizers, pesticides, agricultural plastic film, irrigation area, and tilled area.

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Table 1. Agricultural Carbon Emissions

Carbon Source	Carbon Emission Coefficient (kg/m2)	Reference Source
Diesel	0.59	IPCC
Fertilizers	0.89	Oak Ridge National Laboratory, USA
Pesticides	4.93	Oak Ridge National Laboratory, USA
Agricultural Plastic Film	5.18	Nanjing Agricultural University Institute of Agricultural Resources and Environmental Sciences
Irrigation Area	25	Dubey
Tilled Area	3.1260	China Agricultural University College of Biology and Technology

$$CE = \sum Carbon_i = \rho_i \times \theta_i$$

CE is the total carbon emissions, $Carbon_i$ represents the individual carbon emission factors, $\rho_i$represents the quantity of each carbon-emitting element, θ_i represents the carbon emission coefficient for each element.

3.2. Core Explanatory Variable

The Peking University Digital Finance Research Center's 2011–2021 provincial-level Total Digital Inclusive Finance Index is used to measure digital inclusive finance development in this paper. The development level of digital inclusive finance can be assessed by indexes for breadth of coverage (COV), depth of use (DEP), and degree of digitalization (DIG). This index's scientific measurement method accurately and reasonably assesses province-wide digital inclusive finance development. This measure is greater in digital inclusive finance-developed regions.

3.3. Manage Variables

Monetary GDP growth measures this. The Environmental Kuznets Curve (EKC) theoretical paradigm, which links economic growth to environmental damage, drove the choice. The EKC theory suggests that early GDP development may increase environmental damage, notably agricultural carbon emissions. Technology, environmental restrictions, and public awareness reduce pollution after an economic turning point.

Urban population as a percentage of total population. Urbanization affects agricultural productivity and carbon emissions as people shift from rural to urban locations. Migration to cities boosts agriculture. As rural labor decreases, agriculture becomes more intensive and large-scale, improving productivity and lowering resource use per unit. Population shift and agricultural scaling can be hazardous if agricultural scale-up practices are not advanced. Scaled production may increase agricultural carbon emissions if inefficient production methods waste resources and degrade the environment.

The horsepower of agricultural tractors in kilowatts measures the Agricultural Modernization Level (AM). Farm mechanization and chemical processes boost yield and efficiency as agriculture modernizes. Modernization harms the environment. Mechanized and chemical production employing fossil fuels, fertilizers, and pesticides increases agricultural carbon emissions. This rise is largely from fossil fuel burning and field chemical synthesis and degradation.

Water, forestry, and agriculture as a percentage of the budget. The government's investment in agricultural growth affects agricultural carbon emissions. Government funding increases agricultural infrastructure, technology R&D, and environmental protection. The investments increase agricultural production, productivity, and sustainability. Increased government support may indirectly affect agricultural carbon emissions. For instance, agricultural

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infrastructure that uses too much fossil fuel or R&D that ignores environmental considerations may increase carbon emissions.

3.4. Data Information

This study examined panel data from 2011 to 2021 for 31 Chinese provinces excluding Hong Kong, Macau, and Taiwan. The "China Rural Statistical Yearbook." provided pesticides, fertilizers, diesel, agricultural film, tilled area, and irrigated area for measuring agricultural carbon emissions. The Peking University Digital Finance Research Center provided the digital inclusive finance index. The "China Statistical Yearbook," province statistics yearbooks, and Guotai'an database provided further data. Interpolation imputed missing data for data continuity. The descriptive statistics for each variable are in Table 2.

Table 2. Descriptive Statistics of Variables

Variable Name	Meaning	Sample Size	Mean	Standard Deviation	Minimum	Maximum
lnCE	Log of Agricultural Carbon Emissions	341	5.370	1.120	2.660	6.900
lnDF	Log of Digital Inclusive Finance Index	341	5.280	0.680	2.790	6.130
lnCOV	Log of Coverage Breadth	341	5.130	0.840	0.670	6.070
lnDEP	Log of Usage Depth	341	5.260	0.640	1.910	6.240
lnDIG	Log of Digitalization Level	341	5.560	0.580	2.030	6.140
lnED	Log of Economic Development Level	341	10.82	0.450	9.680	12.14
lnUR	Log of Urbanization Rate	341	4.050	0.230	3.120	4.500
lnAM	Log of Total Agricultural Machinery Power	341	7.640	1.130	4.540	9.500
lnFS	Log of Government Support for Agriculture	341	2.400	0.330	1.410	3.010
lnTF	Log of Transportation Infrastructure Level	341	11.77	0.793	9.437	12.91

4. Empirical Results and Analysis

(1) Baseline Regression

Table 3. Baseline Regression

	(1)	(2)	(3)	(4)	(5)
	lnCE	lnCE	lnCE	lnCE	lnCE
lnDF	-0.270***	-0.282***	-0.131**	-0.0977**	-0.100**
	(0.0912)	(0.0970)	(0.0582)	(0.0466)	(0.0399)
lnED		-0.0763	-0.265	-0.338**	-0.381**
		(0.156)	(0.209)	(0.136)	(0.1403)
lnUR			0.868*	0.731**	0.731**
			(0.440)	(0.307)	(0.305)
lnAM				0.244**	0.294**
				(0.0912)	(0.0920)
lnFS					-0.0160
					(0.0629)
_cons	4.412***	5.113***	4.477**	3.832***	3.891***
	(0.3218)	(1.5205)	(1.6449)	(1.2987)	(1.4056)
N	341	341	341	341	341
R^2	0.472	0.374	0.543	0.663	0.663
year	Yes	Yes	Yes	Yes	Yes
province	Yes	Yes	Yes	Yes	Yes

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(2) Robustness Test

The baseline regression results clearly demonstrate that digital inclusive finance has a significant inhibitory effect on the intensity of agricultural carbon emissions. To verify the robustness of this conclusion, this paper further implements two strategies for in-depth robustness testing, aimed at ensuring the study's broad applicability and reliability.

Table 4. Robustness Test outcome

	(1) Baseline Regression	(2) Excluding Municipalities Directly Under the Central Government	(1) Adding Control Variables
lnDF	-0.100**	-0.113**	-0.101**
	(0.0399)	(0.072)	(0.039)
lnED	-0.341**	-0.0790	-0.355**
	(0.1303)	(0.136)	(0.141)
lnUR	0.631**	-0.185	0.683**
	(0.305)	(0.263)	(0.306)
lnAM	0.244**	0.107**	0.241**
	(0.092)	(0.081)	(0.091)
lnFS	-0.0160	0.113*	-0.0202
	(0.0629)	(0.058)	(0.063)
lnTF			0.0742
			(0.092)
_cons	3.891**	5.613***	3.279**
	(1.306)	(0.798)	(1.567)
N	341	297	341
R^2	0.663	0.598	0.665
year	Yes	Yes	Yes
province	Yes	Yes	Yes

To avoid bias, this study excluded samples from municipalities directly under the central government to accurately estimate digital inclusive finance's impact. After removing Beijing, Tianjin, Shanghai, and Chongqing, Model (2) in Table 4 shows that the key explanatory variable's regression coefficient is significant at 5%. Even without these unique municipal samples, digital inclusive finance has a considerable and robust impact on farm carbon emissions. This finding improves our understanding of digital inclusive finance processes and makes policy analysis and design more accurate.

Digital inclusive finance's impact on agricultural carbon emissions is better examined by adding transportation infrastructure level as a control variable. The model fit is great and the R^2 value has increased, adding to its explanatory power. Model (3) shows that the digital inclusive finance index regression coefficient remains negative. Even when controlling for transportation infrastructure, digital inclusive finance reduces agriculture carbon emissions significantly. A 1% increase in the digital inclusive finance index reduces agricultural carbon emissions by 0.101%. This data shows how digital inclusive finance reduces agricultural emissions and promotes sustainable agricultural development.

(3) Endogeneity Test

After controlling for a series of key factors that could affect agricultural carbon emissions, such as economic development, urbanization level, and agricultural modernization, no direct significant correlation was found between the prevalence of the internet and agricultural

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carbon emissions. This indicates that while the internet penetration rate, as an instrumental variable, is correlated with the main explanatory variable—the development of digital inclusive finance.

Table 5. Endogeneity Test Outcome

	First step lnDF	Second step lnCE
IV	1.645***	
	(0.232)	
lnDF		-0.215**
		(0.087)
Control variables	Yes	Yes
N	341	341
R^2		0.674
Kleibergen-Paap rk LM		19.577(p=0.0000)
Cragg-Donald Wald F		111.908

Table 5 shows that the instrumental variable, internet penetration rate, is significantly positively correlated with the core explanatory variable, the digital inclusive finance index, at the 1% level. During the weak instrument variable test, the Wald statistic obtained is significantly greater than the critical value at the 10% level. This result validates that the chosen instrumental variable is appropriate and has good explanatory power for the digital inclusive finance index.

(4) Heterogeneity Analysis

Given the considerable differences in agricultural production conditions across regions, as well as disparities in the allocation of various resource factors, and significant variations in agricultural technology and labor levels, it follows that the inhibitory effect of digital inclusive finance on agricultural carbon emission intensity will also vary by region.

Table 6. Heterogeneity Analysis

	(1) Eastern	(2) Central	(3) Western
lnDF	-0.172**	-0.169*	-0.0717
	(0.0965)	(0.0907)	(0.0470)
lnED	-0.213	-0.286***	-0.326***
	(0.134)	(0.0655)	(0.0962)
lnUR	1.265***	-0.215	-0.257
	(0.215)	(0.212)	(0.157)
lnAM	0.426***	0.0544	0.242***
	(0.0564)	(0.0184)	(0.0476)
lnFS	-0.159**	0.140***	0.0311
	(0.0629)	(0.0211)	(0.0525)
_cons	5.993***	8.622***	6.245***
	(1.031)	(0.355)	(0.459)
N	121	88	132
R^2	0.813	0.706	0.451
year	Yes	Yes	Yes
province	Yes	Yes	Yes

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(5) Comparison Between Major Grain-Producing Areas and Non-Grain-Producing Areas

Three provinces were selected as major grain-producing areas, and eighteen provinces and cities were selected as non-grain-producing areas.

Table 7. Heterogeneity Analysis: Comparison Between Major Grain-Producing Areas and Non-Grain-Producing Areas

	(1) Major Grain-Producing Areas	(2) Non-Grain-Producing Areas
lnDF	-0.279***	-0.0485
	(0.0579)	(0.0442)
lnED	0.0419	-0.455***
	(0.0755)	(0.101)
lnUR	-0.681***	0.965
	(0.184)	(0.155)
lnAM	0.152***	0.236***
	(0.0289)	(0.0362)
lnFS	0.261***	-0.179***
	(0.041)	(0.050)
_cons	6.119***	4.055***
	(0.745)	(0.894)
N	143	198
R^2	0.689	0.690
year	Yes	Yes
province	Yes	Yes

At the 1% confidence level, the digital inclusive finance index adversely correlates with agricultural carbon emissions in major grain-producing regions. This shows that digital inclusive finance reduces agricultural carbon emissions in these places. These are China's main grain production regions, with intense farming and substantial carbon emissions. Digital inclusive financing improves agricultural production technology and efficiency, lowering carbon emissions. Improved access to finance, information, and digital payment and loan platforms help farmers invest in more efficient and low-carbon agricultural technologies, optimize farming practices, and optimize agricultural supply chains and resource allocation efficiency.

5. Conclusion and Recommendations

Research shows digital inclusive finance dramatically reduces farm carbon emissions. Mobile payments, internet loans, and other digital technologies can help farmers fund low-carbon agricultural equipment. Agricultural carbon emissions fall. Digital inclusive finance helps farmers improve productivity, resource utilization, and waste reduction with market knowledge and scientific farming. Digital inclusive farm financing is promoted by rural financial reforms, agricultural technology subsidies, and infrastructural development. China's "Internet+ Agriculture" policy aids farmers financially and technically on digital platforms. These initiatives modernize and minimize carbon emissions in agriculture. Digital inclusive finance improves financial accessibility, optimizes production information, and supports sustainable agriculture and carbon reduction with government backing.

Different places reduce agricultural carbon emissions using digital inclusive funding. Eastern dropped most, then Central and Western. The Eastern region's established economy and

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substantial digital infrastructure encourage farmers to employ digital inclusive finance, lowering agricultural carbon emissions. The Central region has less economic development and digital infrastructure than the East, while government promotion slows progress. Western farmers rarely use digital inclusive funding due to inadequate economic development and digital infrastructure, reducing agricultural carbon emissions. Additionally, major grain- and non-grain-producing areas differ. High carbon emissions from intensive agriculture are decreased via digital inclusive funding in major grain-producing areas. Digital inclusive financing gives farmers credit for innovative agriculture technologies and low-carbon output, cutting carbon emissions. Digital inclusive financing barely lowers non-grain-producing agriculture carbon emissions. These places have reduced agricultural production and lower carbon emissions, and non-agricultural sectors use digital inclusive funding more.

6. Recommendations

Digital economy and technology-based inclusive funding is essential to encourage agricultural technology innovation, sustainable development, carbon reduction, and environmental friendliness(Goel, R. K.,2022). Improve environmental service platforms and provide new financial incentives to reduce agricultural carbon emissions. Digital inclusive finance training and promotion in rural regions could help farmers use digital financing. Rural and distant farmers should receive financial education from governments and relevant departments to use digital financial services (Pazarbasioglu, C.,2020). Local governments and businesses should invest social capital in rural revival and sustainable development, supporting online agricultural carbon reduction. Develop digital inclusive finance through technology and the digital economy to reduce agricultural carbon emissions and improve sustainability.

The government should fund low-carbon, energy-efficient, and high-efficiency farm technology R&D (Albino, V.,2014). Agricultural research institutions and schools receive funds to study precision agriculture, water-saving irrigation, renewable energy, and carbon capture and storage. A structured technological innovation framework demands interdepartmental cooperation. Through integrated technical innovation platforms, business, academia, and research can speed agricultural technology development. Farmers get new technologies quickly and efficiently through comprehensive agricultural technology distribution. On-site agricultural technology demonstration zones, promotion centers, and farmer training bases can teach farmers new technologies (Mgendi, G., 2021). IT solutions including agricultural technology applications, online training, and remote technical guidance platforms expedite technology distribution, reduce promotion costs, and boost efficiency. These changes will reduce carbon emissions and improve sustainability in agriculture.

Today's fast-growing financial business requires globally diverse financial services to fulfill regional and group needs. This reduces interregional capital flow costs. Financial network optimisation reduces transaction costs, increasing capital flow and economic and social development. Also important is reducing East-West, urban-rural, and city-level information exchange barriers. Internet, big data, and AI combine with traditional information sharing platforms to create efficient and easy networks. This accelerates and shares information, promoting regional cooperation.

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