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The Impact of Digital Inclusive Finance on Agricultural Carbon Emission Reduction

——Analysis Based on Panel Data of 54 Prefecture-Level City

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Abstract: Based on the national ranking of the total agricultural output value, this paper selects Shandong, Henan, and Sichuan, which are in the top three, as the representatives of large agricultural provinces, and utilizing panel data from 54 prefecture-level cities throughout the three provinces for the years 2011 to 2020, this study thoroughly applies the fixed effect model, mediating effect model, and moderating effect model to examine the influence of digital inclusive finance on agricultural carbon emission reduction. The findings demonstrate that inclusive digital finance reduces agricultural carbon emissions favorably; the three sub-dimensions of the breadth of coverage, the depth of use, and the degree of digitization all have significant promoting effects on agricultural carbon emissions reduction, of which the breath of coverage has the most obvious effect; compared to the primary regions that produce grains, In non-primary grain-producing zones, the promotion effect of digital inclusive finance on agricultural carbon emission reduction is particularly significant. From the perspective of the mediating effect, agricultural decreases in carbon emissions can benefit from increased regional innovation thanks to digital inclusive funding; from the perspective of the moderating effect, the amount of urbanization is taken advantage of by digital inclusive finance to control the effects of crop reductions in carbon emissions.

Keywords: agricultural carbon emissions, the emission reduction effect, digital inclusive finance

1. Introduction

Humans continue to emit carbon dioxide in agricultural production, industrial manufacturing, service industry operations, and other activities, resulting in frequent occurrence of extreme weather in recent years, the rate of glacier melting has increased, the global sea level is rising, and the continued high carbon emissions will certainly hurt the human society, restricting and affecting the sustainable development of human beings, so controlling and reducing greenhouse gas emissions is particularly important and urgent in promoting green development and high-quality development of the economy. In September 2020, China put forward the "dual-carbon" goal of achieving a carbon peak by 2030 and carbon neutrality by 2060, this is extremely important strategically for China and even the 2021 climate issue, At the COP26 climate meeting, the Food & Agricultural Organization of the United

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Nations, or FAO, published the information below. According to data, China's agri-food industry would produce 14% of the nation's overall carbon dioxide emissions in 2019. how to lessen carbon emissions from farming, promote the effect of carbon emission reduction in agriculture, and encourage agriculture's green development are extremely important from a strategic standpoint in realizing the goal of "double carbon".

Finance is an important support for reduction of agricultural carbon emissions, through guiding the investment of funds to support rural green development, low-carbon and energy-saving development, and so on. Digital inclusive financing has more accessibility, a broader reach, and cheaper prices than traditional finance. Its effect on reducing agricultural carbon emissions should not be understated. On the one hand, the service object of digital inclusive finance is mainly targeted at the "long-tail" groups, and the "three rural areas", as the most representative part of the "long-tail", can obtain financial support through a low threshold, which can be applied to green, low-carbon and energy-saving development. As the most representative part of the "long tail", the "three rural" can obtain financial support through a low threshold and apply it to the environmentally friendly and low-carbon methods of producing food, thereby realizing the transformation of traditional agriculture into green agriculture. On the other hand, digital financial inclusion empowered by digitization is conducive to innovative inputs in the agricultural sector, increases the productivity of agriculture, and further reduces agricultural carbon emissions, which have both economic and environmental benefits. Therefore, this thesis adopts a combination of qualitative and quantitative methods to thoroughly study the effect of inclusive digital financing on agricultural CO2 emissions, intending to advance the growth of digital inclusive financing in order to increase agricultural reductions in carbon efficiency.

2. Literature Review

Relevant studies on carbon emissions. The three industrial activities are important ways and carriers of carbon emissions, and from the FAO, as can be observed, more than one-third of all anthropogenic greenhouse gas (GHG) emissions are produced by activities related to agriculture and food production. China produces a lot of agriculture, hence its overall carbon footprint from agriculture are high and concentrated in large agricultural provinces, and the intensity of agricultural carbon emissions is higher in the eastern coastal areas, central agricultural provinces, and economically developed cities [1]. Consequently, if agricultural carbon emissions are decreased, especially promoting carbon emission reduction in large agricultural provinces, is extremely important for China to achieve the "double carbon" objective. Li (2010) and other research using the LMDI model found that Economic expansion and changes in energy consumption make agricultural carbon emissions worse, and Increasing energy efficiency will help cut carbon emissions associated with agriculture [2]. In addition to this, variables like the expansion of the agriculture economy, agriculture and industrial building [3], and fertilizer input intensity [4] all have an impact on agricultural emissions of carbon dioxide, while others, such as the amount of funding provided to agriculture, the cost of labor, and the degree of rural economic growth, have an inhibitory impact. [5]. Wu Xianrong (2015), on the other hand, from a spatial perspective, using the Durbin model analysis, found that the level of decrease in crop atmospheric carbon is not only affected by the province in which it is located but also has a correlation with neighboring provinces [6]. In the face of complex and diverse influencing factors, scholars have begun to explore the relevant paths to reduce agricultural carbon emissions. Protecting plant diversity and soil carbon sequestration [7], increasing non-farm employment of farm households [8], shifting agricultural trade from net export to net import status [9], developing agricultural insurance [10], and promoting agro-ecological engineering construction [11] are all able to effectively curb the rapid increase in agricultural carbon emissions' rapid increase.

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Relevant research on digital inclusive finance. At present, domestic scholars have gradually shifted their focus from conventional finance to inclusive digital finance, mainly focusing on the levels of poverty reduction effect, industrial structure upgrading, and environmental effect. At the level of poverty reduction effect and industrial structure upgrading, using the analysis of the inner transfer system, Hui Xianbo (2020) discovered that the effect is stronger the closer the service population of digital inclusive finance is to the long-tail population at the bottom of the industry, i.e. it can effectively improve the economic level of the poverty-stricken areas [12]; Tang Wenjin (2019) and others analyzed the data of 283 prefectural-level cities and above, and a conclusion that digital inclusive finance can support the modernization of the manufacturing system in backward areas [13]; Du Jinmin (2020) and others obtained that organizations using digital inclusive finance promotes the optimization of China's industrial structure through its effect on factors such as income distribution optimization, capital accumulation, technology, and innovation [14]. At the level of environmental effects, digital inclusive finance can create conditions for the transformation of traditional agriculture to green agriculture and digital agriculture, and support the rural green industry [15]; and it can have a notable improvement in the emerald entire factor productivity of agriculture by promoting the advancement of agricultural technology, and hence have a considerable beneficial effect on agriculture's sustainable entire factor output [16,17]; at the same time, the knowledge spillover effect on the main body of the business helps to enhance the residents' awareness of green environmental protection [17].

Related studies on digital inclusive finance and carbon emissions. He Maobin (2021) and others found that digital inclusive finance can achieve the effect of enhancing total factor productivity by reducing regional carbon emissions, and this effect is mainly realized through the reduction of carbon emissions in the tertiary industry [18]. Guo Guixia (2022) and others discovered that digital inclusive financing lowers overall greenhouse gas emissions through assisting sectors with digital empowerment [19]. Some scholars take urban carbon emissions as the research object and find that digital inclusive finance is an important influence on the effect of urban carbon emissions [20], which shows regional heterogeneity due to the influence of geographic location and socioeconomic characteristics [21]. In addition, through implications on economic development, industrial structure modernization, and technological innovation, digital inclusive finance influences carbon emissions. [22]. Based on the implementation of the rural revitalization strategy and the "dual carbon" target, a small number of scholars have begun to conduct research on the association between digital inclusive finance and agricultural carbon emissions in recent years. Cheng Wangqiu (2022) and others believe that farm greenhouse gases are seriously affected by digital inclusive finance. [23]; By lowering the intensity of farming's emissions of carbon dioxide, digital inclusive financing can support the growth of farming in a way that is environmentally friendly, low-carbon, and of high quality [24]. Ding Fanlin (2022) proposed for the study of carbon intensity that digital inclusive finance can realize the win-win situation of digital inclusive financial development and comprehensive carbon peaks by guiding residents' low-carbon consumption preference and encouraging low-carbon technological innovation [25].

There is a dearth of investigation on farm reductions in carbon dioxide, with the majority of studies focusing on digital financial inclusion and carbon emissions. Aiming to provide a theoretical foundation and empirical support for assisting the environmentally friendly development in agriculture and promoting the implementation of the rural revitalization strategy, this paper aims to explore the impact of digital inclusive finance on farming reductions in carbon emissions from the perspectives of fixed effect, intermediary effect, regulating effect, etc.

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3. Analysis of the Mechanisms

3.1. Direct Mechanisms for Digital Financial Inclusion to Influence Carbon Emission Reduction in Agriculture

As a modern financial instrument under digital empowerment, digital inclusive finance integrates technologies such as the Internet, big data, cloud computing, and artificial intelligence based on traditional financial services, with advantages such as low cost, convenience, and efficiency, and is conducive to improving green economic benefits and promoting agricultural carbon emission reduction by extending the service tentacles to green agriculture.

3.1.1. Digital Inclusive Finance Contributes to the Development of Agricultural Modernization

Digital inclusive finance directly contributes to the reduction of carbon emissions from agriculture by helping to modernize agriculture. Digital inclusive finance promotes the modernization of agriculture and rural areas by driving the development of agriculture and rural economy, increasing the volume of crop production, increasing the effectiveness of the use of resources from agriculture, and creating an agricultural operation mode based on data and information, etc., to directly reduce carbon emissions [26].

3.1.2. Financial Support for Digital Inclusive Finance

Digital inclusive finance guides the long-tail people to shift to low-energy consumption and low-pollution areas by providing financial support, reducing agricultural carbon dioxide output, and enhancing carbon emission reduction efficiency. There are a lot of tiny and micro businesses in rural areas, and the problem of capital shortage is more prominent, It forces them to produce and refine agricultural commodities using some cheap, high-pollution raw materials, as well as adopting an unstandardized way of disposing of the remaining residues, which leads to pollution of agricultural land and other environmental problems. From the perspective of the service group, digital inclusive finance aims to provide funds for long-tail people who have difficulty obtaining financial support. Farmers, who have no way to consider their credit, few collateralizable assets, and a single source of income, are among the long-tail people who need to be focused on. Digital inclusive finance can help farmers alleviate their financial difficulties and provide them with the possibility of purchasing non-polluting fertilizers and adopting new agricultural technologies, which can help to directly reduce agricultural pollution and lower agricultural carbon emissions.

Accordingly, Hypothesis 1: It is suggested that farming decrease in carbon emissions has a major beneficial effect on digital financial inclusion.

3.2. Digital Financial Inclusion's Indirect Consequences on Agriculture's Carbon Dioxide Emissions Decrease

3.2.1. Regional Innovation Effect of Digital Financial Inclusion

The 20th Congress's report highlights that The first force behind achieving sustained growth in economy is innovation, and the innovation-driven development strategy should be implemented in depth. Digital inclusive finance is a crucial component of the creativity ecosystem, this has the potential to greatly raise the standard of local innovation and have a secondary effect agricultural carbon emission reduction by strengthening infrastructure construction and upgrading human capital [27]. For enterprises, information asymmetry can limit their access to financial support for technological innovation, thus hindering the enhancement of regional innovation efficiency, in order to increase the scope of information mining using massive amounts of data, cloud computing, and

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additional technologies, digital inclusive finance to safeguard the innovative activities of enterprises. It has been shown that agricultural technological innovation can be quite effective at reducing carbon dioxide emissions from agriculture by improving the technological literacy of workers and creating green labor materials [28]. Additionally, digital inclusive finance may make use of the advantages of internet empowerment to reinvent the farming business model and boost harvesting efficiency, which would have the result of lowering the intensity of carbon emissions associated with agriculture.

Accordingly, hypothesis 2 is proposed: By raising the standard on regional innovation, digital inclusive financing influences the effect of agricultural reductions in carbon dioxide emissions.

3.2.2. The Moderating Role of the Level of Urbanization

New-type urbanization and integrated urban-rural development are key tasks explicitly deployed in the Fourteenth Five-Year Plan. Urbanization is the result of productivity improvement and economic development, and it is also the inevitable process of the country's transition to modernization [29]. It has been proved that urbanization affects emissions of carbon from farming, but urbanization alongside growth levels is different in different geographic regions, and there are some differences in the specific performance [30]. Some scholars believe that the extent of urbanism rising causes a reduction in the rural labor force, prompting the scale and intensification of agricultural production [31], fuelling the countryside's economy's growth simultaneously as playing a positive role in the technology and knowledge literacy of farmers, which in turn positively affects the decrease in farming carbon dioxide emissions. Moreover, the speed of urbanization rising is conducive to upgrading rural infrastructure, narrowing the disparity in income amongst urban and rural areas and setting up the framework for the growth of inclusive financial technology. Shi Changliang (2016), on the other hand, it was proposed that urbanization inevitably brings rural population aging, and to mitigate the negative impact on agriculture, agricultural producers will be increasing the use of nutrients, insecticides, and additional production techniques will result in higher carbon dioxide emissions from agriculture [32]. At the same time, the aging of the rural population will exacerbate income inequality, hence impeding the creation of equitable digital finance. In summary, the study contends that as electronic inclusion funding influences rural emission reductions, the degree in urbanization exerts a certain moderating effect., but there is uncertainty about the direction of the moderating effect.

Accordingly, hypothesis 3 is proposed: the influence of digital inclusive financing upon the effect of farming-related decreases in carbon emissions is moderated by the level of urbanization.

4. Design of Empirical Studies

4.1. Modeling

4.1.1. Benchmark Model

This paper intends to use a model with fixed effects to explore the direct method enabling monetary inclusion using the web affecting carbon emission reduction in agriculture. To eliminate heteroskedasticity and make the data smoother, some variables are logarithmically processed, and what follows describes how the model is built:

$$\ln ACE_{i,t} = \alpha_0 + \alpha_1 \ln DFI_{i,t} + \alpha_2 Control_{i,t} + \mu_i + \varepsilon_{i,t} \quad (1)$$

In Equation (1), i stands for towns, t for time, $ACE_{i,t}$ is the agricultural carbon emission, $DFI_{i,t}$ is the digital financial inclusion index, $control_{i,t}$ is the control variable, which covers the organization associated with the agriculture sector (ISTRU), the transportation infrastructure (TRAN), the planting structure (PSTRU), and the extent to which farming receives financial assistance

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(FINAN), etc.; μ_i is a unique, constant impact that remains unchanged throughout period; $\varepsilon_{i,t}$ is a random disturbance term that follows a normal distribution with mean 0, i.e., $\varepsilon_{i,t}$~(0,σ2)。

4.1.2. Mediating Effect Model

To evaluate how the expansion of electronic finance may have an indirect impact on agricultural decreases in carbon emissions, in order to further investigate the influence of the regional innovation impact that digital financial inclusion upon agricultural emission reductions, Wen Zhonglin and Ye Baojuan's (2014) [33] mediating effect model is cited. What follows is how the mediating effect model is built:

$$\ln ACE_{i,t} = \alpha_0 + \alpha_1 \ln DFI_{i,t} + \alpha_2 Control_{i,t} + \mu_i + \varepsilon_{i,t} \quad (2)$$

$$INNO_{i,t} = \beta_0 + \beta_1 \ln DFI_{i,t} + \beta_2 Control_{i,t} + \mu_i + \varphi_{i,t} \quad (3)$$

$$\ln ACE_{i,t} = \gamma_0 + \gamma_1 \ln DFI_{i,t} + \gamma_2 INNO_{i,t} + \gamma_3 Control_{i,t} + \mu_i + \delta_{i,t} \quad (4)$$

In equations (2)-(4), INNO is the mediator variable, which represents the regional innovation effect; The logistic regression variables are α, β, and γ, and $\varepsilon_{i,t}$、$\varphi_{i,t}$、and $\delta_{i,t}$ are the random perturbation terms. Firstly, we regress equation (2) to get the overall impact of financial inclusion in the online environment upon farming greenhouse gases (α_1); secondly, we regress equation (3) to determine how the amount about regional innovation is impacted by digital financial inclusion. (β_1); finally, we regress equation (4) to test the immediate result of digital financial inclusion upon carbon footprints from farming (γ_1) and the mediating effect of regional innovation level (γ_2). Under the precondition thatα_1 is significant, if β_1 and γ_2 are meaningful, the mediation effect appears to be noteworthy. Accordingly, while γ_1 is significant, it denotes an incomplete mediation benefit; otherwise, if γ_1 fails to be essential, then denotes a full mediation result.

4.1.3. Moderating Effect Model

The framework is constructed into it to validate the moderating impact by urbanization level on farmland emission reductions via technologically inclusive financing.

$$\ln ACE_{i,t} = \lambda_0 + \lambda_1 \ln DFI_{i,t} + \lambda_2 Control_{i,t} + \lambda_3 \ln CITY_{i,t} + \lambda_4 \left(\ln DFI_{i,t} * \ln CITY_{i,t}\right) + \mu_i + \theta_{i,t} \quad (5)$$

In equation (5), $CITY_{i,t}$ stands for the degree of urbanization, and $\ln DFI_{i,t} * \ln CITY_{i,t}$ denotes the relationship among the pace of urbanization and financial inclusion via the internet. Due to the high covariance between the interaction term and the explanatory and moderating variables, which will cause the estimation bias of the model, in order to alleviate the high covariance, the model is centered in this paper:

$$\ln ACE_{i,t} = \lambda_0 + \lambda_1 \ln DFI_{i,t} + \lambda_2 Control_{i,t} + \lambda_3 \ln CITY_{i,t} + \lambda_4 \left(\ln DFI_{i,t} - \overline{\ln DFI_{i,t}}\right) * \left(\ln CITY_{i,t} - \overline{\ln CITY_{i,t}}\right) + \mu_i + \theta_{i,t} \quad (6)$$

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4.2. Variable Selection

4.2.1. Explained Variable: Agricultural Carbon Emissions (ACE)

Given that there are more ways to influence releases of carbon from farming. This essay makes use of relevant studies at home and abroad. Drawing on the research of Li Bo (2011), this paper selects six indicators, namely, chemical fertilizer, pesticide, agricultural film, agricultural diesel fuel, agricultural sown area, and agricultural irrigated area, for analysis, consider it primarily from the standpoint of efficiency in agriculture [34]. According to the basic method of carbon accounting recommended by IPCC (2006), this equation is used to estimate carbon emissions:

$$\mathrm{ACE} = \sum(E_i * \theta_i) \tag{7}$$

In Equation (7), i denotes the emission source category, carbon dioxide emissions in each sort of crop producing activity are known as ACE, E_i is the number of each type of emission source, the pollution proportion associated with every emission source is θ_i. These particular details appear within Table 1.

Table 1: Carbon source emission factor for agricultural carbon emissions.

Major sources of carbon emissions from agriculture	Emission factor	reference source
Chemical fertilizer	0.8956Kg/Kg	Oak Ridge National Laboratory, USA
Pesticides	4.9341Kg/Kg	Oak Ridge National Laboratory, USA
Plastic film	5.1800Kg/Kg	Institute of Resource, Ecosystem and Environment of Agriculture, Nanjing Agricultural University
Agricultural diesel	0.5927Kg/Kg	IPCC(2006)
Agricultural sown area	3.1260Kg/hm^2	College of Agronomy and Biotechnology, China Agricultural University.
Irrigated agricultural area	25.0000Kg/hm^2	Dubey(2009)

Source: Study by Li Bo. (2011).

4.2.2. Explanatory Variables: Digital Financial Inclusion Index (DFI)

In this paper, for assessing the progress on digital financial inclusion in each prefecture-level city, the Center for Digital Inclusion Finance from Beijing University's Index (2011–2020) is used as an indicator [35].

4.2.3. Mediating Variable: Regional Innovation Level (INNO)

Referring to the studies of scholars such as Zhang Ke (2019) and Xu Ziyao (2020) [36,37], this paper reflects the regional innovation level considering the viewpoint that innovation's ultimate result. Invention patent authorization is considered to be a high standard, substantial, and breakthrough innovation output, which can reflect the regional innovation level more realistically [37]. Therefore, the investigation uses the authorization rate for inventive licenses per 100 folks as an indicator of regional innovation level and takes logarithmic treatment.

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4.2.4. Moderating Variable: Urbanization Level (CITY)

In order to indicate the degree of urbanization in prefecture-level cities, this study uses the pace of urbanization as an indicator. The pace of urbanization is calculated as the ratio of urban dwellers with the general population.

4.2.5. Control Variables

These control factors are chosen for this article, which draws on prior literature research: (1) Financial assistance for agriculture (FINAN), calculated as a percentage about the overall budget spending that goes toward financing farming, forestry, and irrigation concerns. (2) Agriculture's share of the overall production that includes crops, forests, livestock breeding, and fishery is known as the agricultural industry structure (ISTRU). (3) The percentage of total road miles to regional area, or transportation infrastructure (TRAN). (4) Cultivation structure (PSTRU), which is calculated as the proportion of food-sown land to all crop-sown land.

4.3. Data Sources

The National Bureau of Information' statistics reveals that in 2021, Shandong Province's overall production value for farming, forestry, livestock husbandry, and aquaculture would reach 1146.801 trillion yuan. Given this, the article chooses 54 prefecture-level counties from the main agricultural provinces of Lu, Henan, and Sichuan from 2011 to 2020 to be the study's focus. The statistics calendars for every region in 2011 to 2020, as well as the China statistics Yearbook, China Rural Statistical Yearbook, China Urban Statistical Yearbook, etc., provided the bulk of the data for this study. The data gaps were filled in using linear interpolation. Table 2 displays the statistical information of relevant factors.

Table 2: Descriptive statistics of variables.

Variable	Obs	Mean	SD	Min	Max
agricultural carbon emissions (lnACE)	540	0.566	3.955	-6.931	4.742
digital financial inclusion index (lnDFI)	540	5.022	0.529	3.173	5.705
breadth of coverage (lnBREATH)	540	4.932	0.603	1.502	5.747
Depth of use (lnDEPTH)	540	5.015	0.499	3.236	5.642
Degree of digitization (lnDIG)	540	5.231	0.564	2.891	5.787
regional innovation level (INNO)	540	0.053	0.080	0.000	0.581
urbanization level (CITY)	540	0.442	0.237	-0.629	0.788
Agricultural industry structure (lnISTRU)	540	-0.655	0.224	-1.769	-0.204
Transportation infrastructure (lnTRAN)	540	4.865	0.603	2.528	5.570
industry structure (lnPSTRU)	540	-0.356	0.110	-0.900	-0.105
financial support for agriculture (FINAN)	540	0.127	0.037	0.008	0.335

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5. Empirical Results and Correlation Tests

5.1. Benchmark Regression

Firstly, the fixed-effects model (FE) had been employed to investigate the connection among digital financial inclusion and farm greenhouse gas emissions after the Hausman test on the regression model resulted in a P-value of 0.00 rejecting the null hypothesis. According to benchmark model, the panel data of 54 prefecture-level cities in Shandong, Henan, and Sichuan from 2011 to 2020 are regressed and The prefecture-level cities are where typical mistakes are concentrated, and Table 3 displays the outcomes of the analysis. Among them, the coefficient analysis in column (1), which was obtained without including of any control variables, shows that the main explanatory factor, digital financial inclusion, strongly adversely impacts agricultural greenhouse gases below the 1% range. The regression results are still negative at the 1% statistical level when control factors like the agricultural industrial structure, transportation infrastructure, planting structure, and monetary assistance for farming are added in Column 2. This indicates that digital inclusive finance may substantially minimize agricultural carbon emissions and has an impact upon farming carbon emission reduction, demonstrating the validity of Hypothesis 1.

Table 3: Benchmark regression results.

Variables	(1)	(2)
	lnACE	lnACE
lnDFI	-0.072*** (0.014)	-0.071*** (0.014)
lnISTRU		0.009 (0.095)
lnTRAN		-0.108* (0.054)
lnPSTRU		-0.231 (0.179)
FINAN		1.161*** (0.364)
_cons	0.929*** (0.068)	1.220*** (0.270)
Control	NO	YES
City	YES	YES
R^2	0.184	0.293
N	540	540

Note: Cluster robust standard errors in parentheses; *, **, and *** indicate significant at the 10%, 5%, and 1% levels, respectively. Same below.

5.2. Robustness Check

5.2.1. Replacement of Explanatory Variables

This study utilizes the primary lag term (L.lnDFI) and the second-order lag term (L2.lnDFI) of the digital financial inclusion index to replace the variables that provide explanation sequentially because the effect of digital financial inclusion upon agricultural decreases in carbon emissions may have a time lag. The regression results after replacement demonstrate that it continues to be a robust downward association among the agricultural carbon emissions in lags one and two and the digital

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financial inclusion index, as well as a reduction in agricultural carbon emissions, as a result of digital financial inclusion.

5.2.2. Shorten the Period

Milestones in the advancement in inclusive finance can be seen in the State Council's Plan for Promoting the Development of Inclusive Finance (2016-2020), the G20 Summit's G20 Principles for Digital Inclusive Finance, and other relevant documents. Therefore, this study utilizes the method for shortening time and eliminating the data from 2011 to 2015 in order to confirm the reliability of the benchmark regression results. It views 2016 as a crucial turning point within the emergence for digital inclusive finance in China. Table 4's findings demonstrate that regression analysis findings still hold after shortening the period, demonstrating the importance of the consequences of inclusive digital financing on agricultural carbon emission reduction.

5.2.3. Excluding Some Prefecture-Level City Samples

The Digital Inclusive Finance Index shows that provincial capitals and several first- and second-tier cities with more developed economies have much greater levels of development of digital inclusive finance versus other prefecture-level areas. In contrast to typical prefecture-level towns, the speed of development is greater in rural areas of first- and second-tier cities with strong economies. The results of this study's robustness test, which do not include the selections from first- and second-tier cities, reveal that the growth for digital inclusive finance significantly reduces farming greenhouse gas emissions (Table 4).

Table 4: Robustness test.

Variables	(1)	(2)	(3)	(4)
	Substitution of explanatory variables(L.lnDFI) lnACE	Substitution of explanatory variables (L2. lnDFI)lnACE	shorten the period lnACE	Excluding some prefecture-level city samples. lnACE
L.lnDFI	-0.067*** (0.019)			
L2.lnDFI		-0.078*** (0.018)		
lnDFI			-0.501*** (0.065)	-0.068*** (0.016)
lnISTRU	0.018 (0.095)	0.027 (0.091)	0.026 (0.071)	0.014 (0.103)
lnTRAN	-0.208* (0.114)	-0.174 (0.104)	-0.100** (0.043)	-0.111* (0.057)
lnPSTRU	-0.270 (0.201)	-0.283 (0.238)	-0.165 (0.327)	-0.216 (0.198)
FINAN	1.009*** (0.316)	0.866*** (0.273)	0.298 (0.397)	1.079*** (0.374)
_cons	1.695*** (0.510)	1.589*** (0.467)	3.644*** (0.344)	0.971*** (0.287)
Control	YES	YES	YES	YES
City	YES	YES	YES	YES
R^2	0.345	0.387	0.569	0.272
N	486	432	270	480

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5.3. Endogeneity Test

This study employs the instrumental variable (IV) approach and chooses the digital financial inclusion index with one lag and two lags as the instrumental variables for endogeneity testing, respectively, in order to overcome endogeneity issues brought on by causal inference and missing variables. There is no over-identification issue, and all of the instrumental factors pass the weak instrumental variable, under-identification test. When lags one and two about the variables that explain the result are employed to be instrumental variables, the results of the regression in Table 5 demonstrate the correlation parameters of digital financial inclusion tend to be negative, which validates the finding about the standard regression and demonstrates the robustness of the study's findings.

Table 5: Endogeneity test results.

Variables	(1)	(2)
	(L.lnDFI) lnACE	(L2.lnDFI) lnACE
lnDFI	-0.104*** (0.029)	-0.175*** (0.038)
lnISTRU	0.016 (0.092)	0.022 (0.088)
lnTRAN	-0.190 (0.117)	-0.123 (0.108)
lnPSTRU	-0.268 (0.203)	-0.275 (0.242)
FINAN	0.961*** (0.311)	0.761*** (0.270)
_cons	1.819*** (0.481)	1.892*** (0.415)
Control	YES	YES
City	YES	YES
R^2	0.3691	0.4262
N	486	432

5.4. Heterogeneity Analysis

5.4.1. Regional Diversity Between Food and Non-Food-Producing Regions

Due to the differences between regional geographic locations, the agricultural development level of each prefecture-level city is different, and there is a significant difference between the agricultural planting area and grain production capacity. Therefore, this paper selects the grain cultivation area as a reference indicator, calculates the average value of grain cultivation area of each prefecture-level city from 2011 to 2020, and sorts them in order from high to low, dividing the 54 prefecture-level cities into grain and non-grain producing areas, to determine whether there is heterogeneity between grain and non-grain producing areas in the effect on inclusive digital finance upon agricultural greenhouse gas emissions.

The regression outcomes in Table 6 indicate digital inclusive finance can both encourage agricultural carbon emission reduction and has a major adverse effect overall agricultural carbon emissions across grain- and non-grain-producing areas. The promotion of carbon emission reduction that digital inclusive finance has on non-food-producing places is more pronounced than it is on the

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major food-producing areas. The reason is: the major of food-producing regions have a wide planting area, many inputs, including insecticides and agriculture fertilizers, and low utilization of funds, resulting in low efficiency of inputs and outputs. Therefore, the importance of inclusive digital finance for decreasing greenhouse gas emissions within the major food-producing regions is diminished, resulting in differences in the impact effect. In summary, based on the objective differences in food cultivation, scale of agricultural development, and climate environment among prefecture-level cities, local governments should formulate policies and measures to encourage local efforts to decrease farmland greenhouse gas emissions, etc., to increase the efficiency with which agricultural funds are used and to accomplish the reduction of agricultural carbon emissions.

Table 6: Heterogeneity results between food and non-food producing regions.

Variables	(1)	(2)
	food-producing areas lnACE	non-food-producing areas lnACE
lnDFI	-0.076** (0.029)	-0.052*** (0.014)
lnISTRU	-0.062 (0.128)	0.100 (0.118)
lnTRAN	-0.057** (0.026)	-0.387*** (0.099)
lnPSTRU	0.065 (0.438)	-0.392*** (0.110)
FINAN	1.623*** (0.503)	0.651 (0.520)
_cons	2.681*** (0.220)	0.844 (0.496)
Control	YES	YES
City	YES	YES
R^2	0.279	0.400
N	270	270

5.4.2. Dimensional Heterogeneity

To examine the effects of various aspects of digital inclusive finance upon reducing agricultural carbon emissions, regression analysis was conducted from the three dimensions of breadth of coverage, depth of use, and degree of digitization, respectively, to verify whether there is any heterogeneity in the impact among the three. Table 6's findings show that the three dimensions all reduce agricultural carbon emissions, i.e., agriculture decreases carbon emissions that has a major impact in all three aspects. However, the influence of intensity of usage exists the most significant in terms of the absolute value of the coefficients, and there is less of a difference between the degree of digitization and range on covering. Height of application can enhance the sinking of financial services, offer greater financial support for rural sustainable and carbon-neutral growth, and make the biggest impact on the reduction of agricultural carbon emissions. The scope of the issue and the level of digitisation are inextricably linked to regional infrastructure construction, indicating that China's regional and agricultural systems is still to be improved and requires greater investment, which is particularly important for low-carbon development.

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Table 7: Results of dimensional heterogeneity.

Variables	(1)	(2)	(3)
	lnACE	lnACE	lnACE
lnBREATH	-0.056*** (0.016)		
lnDEPTH		-0.075*** (0.016)	
lnDIG			-0.057*** (0.013)
_cons	0.922*** (0.321)	0.991*** (0.274)	1.009*** (0.321)
Control	YES	YES	YES
City	YES	YES	YES
R^2	0.253	0.283	0.248
N	480	480	480

5.5. Analysis of Intermediation Effects

To further explore the influence mechanism and test whether the regional innovation level serves as a mediator throughout the procedure of digital financial inclusion's influence on the agricultural carbon emission reduction effect, stepwise regression is conducted according to the mediation effect model of equations (2)-(4) and analyzed more precisely by the Sobel test, and the outcomes are displayed in Table 8. Digital financial inclusion has a favorable impact upon the impact for carbon emission reduction from farming, as evidenced by the absolute value for the indicator on digital financial inclusion at column (1), which is 0.071 that surpasses the 1% significance limit.The effect of digital inclusive finance on the regional innovation level in column (2) is statistically significant above the 1% straight, demonstrating that a favorable effect on the level for regional innovation is bigger based on the degree of digital inclusive finance development. Column (3) tests the impact relationship between the three, The level during regional innovation in the process of digital financial inclusion affects how much farming reductions in carbon dioxide serves an element of the facilitating position, while the mediating effect for the overall impact about the proportion in 15.23%, Hypothesis 2 can be verified because the effect of digital financial inclusion and regional innovation stage upon agricultural carbon emissions is equally significantly adverse at the 1% degree. Comprehensive research results demonstrate that inclusive digital finance reduces the threshold of access to capital, improves the financial difficulties faced by the "three rural regions", encourages the allocation about regional resource allocation, provides an adequate platform of capital and resources for the advancement of agriculture technology, increased environmental literacy improves the degree of agricultural specialization and promotes the development of agricultural production and scale, this assists in cutting down on agricultural carbon emissions. It has improved agricultural degrees' specialization while promoting efficient agricultural production and large-scale development, the following encourages the effect of farm carbon emission reduction and is favorable to lowering agricultural carbon emissions.

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Table 8: Results of the analysis of intermediary effects.

Variables	(1)	(2)	(3)
	lnACE	INNO	lnACE
lnDFI	-0.071*** (0.014)	0.025*** (0.009)	-0.072*** (0.027)
INNO			-0.517*** (0.181)
_cons	1.220*** (0.270)	-0.606** (0.299)	1.141** (0.556)
Control	YES	YES	YES
City	YES	YES	YES
Sobel	-0.0130***(Z=-3.729)		
Intermediary effect ratio	0.1523		
R^2	0.293	0.189	0.374
N	540	507	507

5.6. Analysis of Moderating Effects

Theoretical investigation demonstrates that its effect in digital financial inclusion on agricultural carbon emission reduction depends on the degree of urbanization. Using equations (5)–(6), we investigate the moderating effects of digital financial inclusion with urbanization level on the effect of agricultural carbon emission reduction. In this work, we establish the relationship factor along the index of digital financial inclusion with the level of urbanization.

The findings within column (1) about Table 9 demonstrate that the explanatory variable digital financial inclusion has a negative coefficient, and the interaction term (lnDFI*CITY) among the level of urbanization alongside digital financial inclusion also has a negative coefficient, both of which are noteworthy above the 1% degree, which proves that the level of urbanization promotes the influence of digital financial inclusion exerts a beneficial mitigation function on the impact of agricultural carbon emission reduction. Based on the division of the primary food-producing areas and non-food-producing areas, Columns (2) as well as (3) discover the geographic variation of the moderating effect about the degree of urbanization. Conclusions illustrate that the interaction terms during digital financial inclusion and known as level about urbanization are both detrimental and substantial below the 1% degree, which shows that moderating effect of urbanization degreesturns out to be significant. Comparing the difference between the two coefficients, it is found that the moderating effect is more visible in locations that do not produce food than in areas that do. The reason may be that, for the main food-producing areas, urbanization compresses agricultural land inputs, shifts agricultural employment, and affects agricultural activities, resulting in lower agricultural carbon emissions; considering the majority of regions that don't produce food, urbanization improves rural infrastructure, expands the breadth of the coverage of digital inclusive finance and improves the financial literacy of impoverished labor, both of which are beneficial to the carbon-free and environmentally friendly development of agribusiness.

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Table 9: Moderated effects test results.

Variables	(1)	(2)	(3)
	lnACE	food-producing regions lnACE	non-food-producing regions lnACE
lnDFI	-0.064*** (0.017)	-0.079** (0.034)	-0.040** (0.016)
CITY	-0.151*** (0.036)	-0.117*** (0.039)	-0.175*** (0.057)
lnDFI*CITY	-0.219*** (0.044)	-0.174*** (0.035)	-0.265*** (0.081)
_cons	1.296*** (0.255)	2.833*** (0.219)	0.786 (0.538)
Control	YES	YES	YES
City	YES	YES	YES
R^2	0.348	0.320	0.460
N	540	270	270

6. Conclusions of the Study and Related Recommendations

6.1. Conclusions of the Paper

In order to investigate the mechanism by which digital financial inclusion affects the impact of agricultural emissions reductions, this study chooses panel data from 54 prefecture-level cities at the three agricultural provinces of Shandong, Henan, and Sichuan from 2011 to 2020. It also uses the digital financial inclusion index from Peking University and decides on the fixed effect model, the mediating effect model, and the moderating effect model.

It is discovered which the creation of digital inclusive finance greatly decreases agricultural carbon emissions, indicating that digital inclusive finance has an optimistic promotion regarding the reduction of agricultural carbon emissions. The findings are still significant after durability examinations, which include substituting explanation variables and shortening a time frame. (2) Digital financial inclusion has a major beneficial effect on agricultural carbon emission reduction in both food- and non-food-producing regions, with the importance level being larger in the latter. (3) In terms of the three aspects of width of coverage, extent of use, as well as intensity of digitalization, digital inclusive finance has a positive influence on agricultural carbon emission reduction, with width of covering having an especially prominent role. (4) By boosting regional innovation, digital inclusive financing can lower agricultural carbon emissions. This will have a favorable impact on the reduction of agricultural carbon emissions. (5) Urbanization degrees have a beneficial moderating impact on the process, and this effect is more prominent in non-food-producing areas.

6.2. Relevant Recommendations

First, broaden the scope of digital financial inclusion and its penetration. Considering the urgency to promote low-carbon farming, create the necessary infrastructure conditions, promote the process of rural networking, product visualization, and service intelligence, and increase the sinking of digital inclusive finance empowered by digital technology; guide rural financial institutions to innovate green digital inclusive financial products, and create a digital inclusive financial model that integrates digitization, low-carbonization, and high efficiency. Through digital channel innovation, they will lower the threshold of access, improve the controllability of risk, enhance the availability of loans,

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expand the scope of inclusive digital financing, focus their services on low-carbon agriculture, and direct their capital investment to green agriculture, thus helping to realize the "double-carbon" goal.

Secondly, we should promote the synergistic and innovative regional growth in financial inclusion using digital technology. Given regional differences in the level of development between the primary grain-producing areas and those that are not, climate environment, supporting facilities, location advantages, and other aspects, rural financial institutions should adopt policies according to local conditions and make efforts according to needs. Based on maintaining the existing support and relevant measures for non-food producing regions, they should increase the inclination of policies, funds, and supporting facilities for food-producing regions, accelerate the construction of the digital inclusive financial system in food-producing regions, build a mechanism for the integration of advantages and resource sharing between food-producing regions and non-food producing regions, promote inter-regional synergistic and innovative development, and drive the carbon emission reduction and promotion effect of digital inclusive finance in non-food producing regions to narrow the regional development differences.

Thirdly, digital and intelligent financial means should be used to support green technological innovation and enhance the level of regional innovation. Agricultural provinces should introduce corresponding tax relief and other incentive mechanisms, take advantage of the digitalization and intelligentization of inclusive finance, and guide rural financial institutions to increase capital investment in green and low-carbon agriculture; formulate incentive policies for low-carbon and high-efficiency agricultural production, and encourage green technological innovation and transformation of achievements by farmers and rural enterprises in the field of agriculture; build a digital and intelligent resource platform to create conditions for the development of agricultural technology plus an increase in farmers' knowledge of green finance. It will also build a digital resource platform to create conditions for the advancement of agricultural technology and the improvement of farmers' green financial literacy. We will take multiple measures to enhance the regional innovation level of large agricultural provinces, thereby promoting the agricultural sector's ability to reduce carbon emissions.

Fourthly, urbanization degrees should be raised and its regulatory effect enhanced. Rural financial institutions should increase their investment in the urbanization of rural areas, Promote the urbanization of farmers while accelerating urbanization through a resurgence of rural industry. With the help of continuously broadening the coverage of inclusive finance, they should cultivate farmers' green financial literacy and enhance their awareness of carbon emission reduction. Given the reality that agricultural land is being compressed in the process of urbanization in the main grain-producing areas, rural financial institutions should guide them to rationally plan the layout of agricultural industries utilizing digital financial means, to enhance the level of urbanization and empower the carbon emission reduction effect of digital inclusive finance, and to effectively play its regulating role.

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