

-RESEARCH ARTICLE-

ANALYSING THE IMPACT OF GREEN CREDIT ON AGRICULTURAL CARBON EMISSION REDUCTION AND PRODUCTION EFFICIENCY IN CHINA: A SYNERGY ANALYSIS

Ting Li

School of Business and Economics Universiti Putra Malaysia 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia.

Email: gs65473@student.upm.edu.my

Wei Theng Lau*

School of Business and Economics Universiti Putra Malaysia 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia.

Email: lwtheng@upm.edu.my

Mohamed Hisham Dato Haji Yahya

School of Business and Economics Universiti Putra Malaysia 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia.

Email: mohdhisham@upm.edu.my

—Abstract—

The study investigates the role of green financing, regulatory frameworks, and agricultural efficiency in reducing carbon emissions and promoting sustainability. It explores these critical factors to identify optimal strategies for reducing agricultural emissions and achieving environmental sustainability. Climate, technological advancements, and labour force participation are also analysed to assess their impact on agricultural sustainability. Specifically, the research examines how green credit, production efficiency, and environmental regulations have influenced agricultural carbon emissions in China from 2010 to 2023. The analysis seeks to understand the interplay between green financing, regulatory measures, and production efficiency in fostering sustainable agriculture. The study employs dynamic panel data and regression models, including Random Effects, Fixed Effects, and the Generalised Method of

Citation (APA): Li, T., Lau, W. T., Yahya, M. H. D. H. (2024). Analysing the Impact of Green Credit on Agricultural Carbon Emission Reduction and Production Efficiency in China: A Synergy Analysis. *International Journal of Economics and Finance Studies*, 16(02), 327-354. doi: 10.34109/ijefs.202416216

Moments (GMM), to evaluate the impact of these independent variables on agricultural carbon emissions. Data from Chinese provinces over the period 2010–2023 were used to examine green loan allocations, production efficiency, and environmental policies. The GMM model effectively addressed issues of endogeneity and inter-variable relationships. The results of the Hausman, Sargan, and Serial Correlation tests validated the robustness of the study. Findings reveal that stringent environmental regulations, coupled with green credit, significantly reduce agricultural carbon emissions. Additionally, regions with higher production efficiency exhibit lower carbon emissions. The study recommends financial support, regulatory enforcement, and improvements in production efficiency to mitigate agricultural emissions. A unified policy and financial framework are advocated to enhance sustainability. The findings suggest that governments and private organisations should provide green financing and implement stringent environmental standards to curb agricultural carbon emissions effectively.

Keywords: Green Finance, Agricultural Carbon Emission, Sustainability, Financial Support, Environmental Regulation, China.

INTRODUCTION

Addressing climate change and enhancing sustainability necessitates reducing agricultural carbon emissions. Agriculture plays a crucial role in China's economy but is a significant source of greenhouse gas emissions. Inefficient farming practices, excessive fertiliser use, and deforestation contribute substantially to China's agricultural carbon emissions (Chen & Chen, 2021; Udeagha & Ngepah, 2023). These practices have far-reaching environmental impacts, including global warming and ecosystem degradation. As sustainable development becomes a global priority, reducing the environmental footprint of agriculture is a key concern for both China and the international community. Innovative solutions, such as green credit, advancements in production efficiency, and stringent environmental regulations, are essential for promoting sustainable agricultural practices. Green credit has become increasingly significant as governments and financial institutions encourage farmers to adopt environmentally friendly practices. By supporting sustainable farming methods and technologies, green credit enables farmers to reduce carbon emissions (Fan et al., 2024).

Improving production efficiency is another critical strategy, optimising the use of resources such as water, fertilisers, and energy to minimise agriculture's environmental impact. At the same time, stricter environmental regulations necessitate consistent compliance, which in turn increases the demand for financial incentives and enhanced efficiency. These elements are vital to ensuring both food security and environmental sustainability in agriculture. Understanding the interplay between these factors is fundamental to designing effective carbon-reduction strategies and promoting sustainable farming practices (Azhgaliyeva & Liddle, 2020). Integrating green credit,

production efficiency, and robust regulatory frameworks offers a comprehensive pathway to mitigate agricultural emissions and advance sustainability goals.

Despite the increasing focus on sustainable agriculture, limited research explores how Green Credit, production efficiency, and environmental regulations collectively influence carbon emissions (Fang & Shao, 2022; Ren et al., 2020; Udeagha & Muchapondwa, 2023). Much of the existing literature focuses narrowly on either financial incentives or regulatory frameworks. This fragmented approach neglects the potential synergies between financial mechanisms and regulatory policies within China's agricultural sector. While industrialised nations have extensively studied Green Credit, its application in Chinese agriculture remains underexplored. Research on production efficiency is also insufficient, particularly regarding how varying technological capabilities and resource management practices can optimise agricultural productivity while minimising the carbon footprint. Addressing these gaps is essential to develop comprehensive and effective policies for agricultural sustainability (Lee, 2020).

Without a thorough understanding of the interplay between financial, regulatory, and efficiency factors, policymakers and stakeholders may struggle to design appropriate programmes for reducing agricultural carbon emissions. Efforts to cut emissions risk failure without adequate financial backing and stringent environmental regulations. Green Credit, for instance, can provide farmers with the resources needed to implement sustainable practices, but its impact would be magnified with the enforcement of strict environmental laws. Similarly, while advances in production efficiency offer significant potential for emission reductions, farmers may be reluctant to adopt innovative technologies without the support of financial incentives. The evident research gaps underscore the importance of integrating financial assistance, regulatory measures, and efficiency improvements into a unified strategy for agricultural sustainability (Fang & Shao, 2022; Udeagha & Muchapondwa, 2023).

Holistic approaches are critical to achieving meaningful and lasting reductions in agricultural carbon emissions. Green Credit, production efficiency, and environmental regulation significantly contributed to reducing carbon emissions in Chinese agriculture between 2010 and 2023. This study aims to identify optimal agricultural sustainability strategies by examining the interplay of these parameters. Dynamic panel data analysis, employing Random Effects, Fixed Effects, and GMM models, is utilised to explore these relationships comprehensively. Control variables such as weather, technological advancements, and labour force participation ensure a holistic analysis of agricultural sustainability. The findings are expected to enhance financial, regulatory, and efficiency-based strategies for reducing agricultural carbon emissions (Khan et al., 2022).

This study makes two key contributions. Firstly, it addresses significant research gaps

by analysing the combined effects of Green Credit, production efficiency, and environmental regulation on Chinese agricultural carbon emissions. This comprehensive approach highlights the synergies between these factors, providing valuable insights for improving sustainability, particularly in developing countries. Secondly, the research advocates for a coordinated effort between governments and financial institutions to integrate financial support systems with regulatory frameworks, thereby maximising the impact of green financing on agricultural sustainability. The findings of this study have important implications for agricultural policy. By aligning economic growth with environmental preservation, policymakers can develop strategies that not only foster sustainable agricultural practices but also mitigate the sector's environmental impact. These insights could guide the development of agricultural policies that balance productivity with long-term ecological sustainability.

LITERATURE REVIEW

Recent scholarly attention has increasingly focused on agricultural sustainability, particularly in relation to carbon emission reduction. Numerous studies have investigated the drivers of environmental degradation in agriculture, with an emphasis on reducing its carbon footprint. Inefficient farming practices, excessive fertiliser use, and poor land management significantly contribute to global greenhouse gas emissions (Chen et al., 2024). Research underscores the urgent need for transformative changes in agriculture to align with global climate goals and international treaties. Green Credit has emerged as a critical financial mechanism for supporting sustainable agriculture. It provides funding for precision farming, organic agriculture, and sustainable energy initiatives. A growing body of literature suggests that green finance plays a pivotal role in helping farmers achieve both economic and environmental sustainability. Studies on Green Credit in emerging economies Chien (2024) reveal that it helps farmers and agricultural enterprises overcome the initial costs associated with adopting sustainable technologies.

While these studies highlight the importance of green credit, they often fail to explore its interaction with production efficiency and environmental legislation. This gap in the literature underscores the need for a more integrated analysis of how these factors collectively contribute to reducing agricultural emissions. Research on green credit has primarily centred on its application in the industrial and energy sectors, with limited attention paid to its impact on agriculture. This is particularly evident in rapidly developing nations like China, where agriculture presents both significant sustainability challenges and opportunities (Agrawal et al., 2024). A more comprehensive understanding of how green credit, production efficiency, and environmental regulation interact is essential for designing policies that promote agricultural sustainability while addressing carbon emission concerns effectively.

Another significant area of agricultural sustainability research is total factor

productivity (TFP), or production efficiency. Improved efficiency enables farms to produce more while using fewer resources such as water, energy, and fertilisers, thereby reducing waste and mitigating environmental impact. Numerous studies demonstrate that more efficient farming systems generate lower carbon emissions per unit of output. These findings substantiate claims that resource optimisation through enhanced production efficiency underpins both economic and environmental sustainability in agriculture (Dong et al., 2021; Peng & Zheng, 2021). However, the literature seldom examines the connection between production efficiency and financial mechanisms such as green financing or agricultural regulation. The interplay between efficiency improvements and broader sustainability factors, including funding and regulation, remains underexplored. While environmental legislation, economic considerations, and production efficiency have all been extensively studied as drivers of agricultural sustainability, their interconnectedness has not been adequately addressed. Environmental regulation plays a pivotal role in managing the environmental impact of various industries, including agriculture. Research suggests that stringent environmental policies can compel farmers to adopt sustainable practices by imposing penalties for non-compliance. These policies often target key agricultural sustainability concerns, such as emissions, water use, pesticide application, and land management. Despite the critical role of environmental regulations, much of the existing research focuses on their effectiveness in isolation, without considering how they might interact with financial incentives like green credit or advancements in production efficiency. This research gap hinders a comprehensive understanding of how regulatory frameworks can synergise with financial and technological solutions to enhance agricultural sustainability (Feng et al., 2022; Gao et al., 2022). Bridging this gap is essential for developing holistic approaches to address sustainability challenges in the agricultural sector.

The relationship between financial support, efficiency improvements, and regulatory enforcement in agricultural sustainability remains underexplored. Most studies treat these factors as independent variables influencing sustainability, without adequately examining their potential synergies (Ning et al., 2023; Xiong & Sun, 2023; Yu et al., 2022). For instance, green financing alone may not lead farmers to adopt sustainable technologies in the absence of stringent environmental regulations. Similarly, while production efficiency has the potential to reduce carbon emissions, significant changes in agricultural practices may not occur without financial incentives or regulatory enforcement to ensure compliance. The interaction of financial, regulatory, and technical variables has largely been overlooked in the existing literature. Another significant limitation is the predominant focus on developed economies, which generally possess stronger financial systems, advanced technology, and robust regulatory frameworks. In industrialised nations, the interplay between green credit, production efficiency, and environmental policies has been studied extensively (Feng et al., 2022).

However, there is limited understanding of how these factors operate in developing countries, such as China, where agriculture faces distinct sustainability challenges and resource constraints. Emerging economies, which account for the majority of global agricultural emissions, must be central to climate policy discussions. Understanding the combined effects of financial mechanisms, regulatory frameworks, and production efficiency variability in these contexts is critical (Jian & Afshan, 2023; Liu & Yang, 2021; Mohsin et al., 2023; Zhu et al., 2023). To address these gaps, this study proposes a research framework, as illustrated in Figure 1, which integrates these variables to explore their collective impact on agricultural sustainability in developing nations.

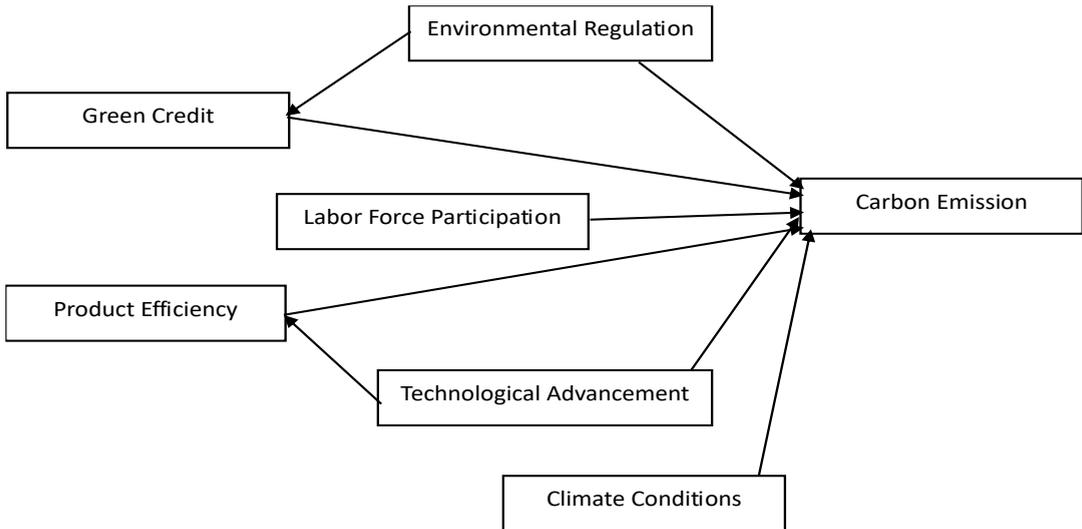


Figure 1: Conceptual Framework of the Study

Empirical research on green financing, production efficiency, and environmental legislation often fails to address the issue of endogeneity. Many regression models overlook the potential feedback loops between these variables, resulting in incomplete analyses (Guo et al., 2022; Tolliver et al., 2021). For instance, if producers who are already efficient receive green credit or are subject to stricter environmental standards, endogeneity may arise. Only a limited number of scholars have employed advanced econometric techniques, such as the GMM, to address this challenge (Guo et al., 2022; Tolliver et al., 2021). Ignoring endogeneity risks distorting estimates, leading to invalid conclusions and creating a critical gap in the literature. This study addresses these limitations by analysing agricultural carbon emissions through the lenses of green credit, production efficiency, and environmental regulation. Unlike previous research, it examines how these factors collectively enhance sustainability in China's agricultural sector.

The study employs Random Effects, Fixed Effects, and GMM models to effectively capture the relationships among variables and address endogeneity concerns. Focusing on China—a rapidly developing nation with unique sustainability challenges and

opportunities—this research aims to bridge the gap in non-Western agricultural sustainability studies. By providing a comprehensive analysis of the components driving agricultural carbon emissions, this study addresses several critical gaps in the literature. It explores the roles of financial support, efficiency improvements, and regulatory enforcement in reducing agricultural emissions (Khan et al., 2022). The findings are expected to offer valuable insights for policymakers and financial institutions in emerging economies, enabling them to develop targeted strategies that enhance agricultural sustainability while reducing carbon emissions. This research contributes to the broader understanding of sustainable agricultural practices in developing nations, offering a framework for addressing global sustainability challenges.

RESEARCH METHODOLOGY

Green credit reduces agricultural carbon emissions and increases production efficiency in China. This study uses the newest econometric methods and literature-based regression models for robust and detailed analysis. A more advanced regression model that blends environmental economics and sustainable finance literature quantifies green finance's effects. A dynamic panel data regression model is utilized to resolve endogeneity, autocorrelation, and heteroscedasticity in panel data analysis, as shown by recent empirical investigations. A critical time in China's agricultural transformation and green financial reforms is 2010–2023. Modelling the gradual effects of green finance and environmental regulations on carbon emissions and industry efficiency requires lagged dependent variables and dynamic adjustments. A dynamic regression model with a GMM estimator was employed to address endogeneity from lagged dependent variables and simultaneity bias. For dynamic linkages between financial assistance, policy actions, and agricultural performance across regions, recent research endorses the GMM model. The main equation for green credit and agricultural carbon emissions is:

$$CE_{it} = a + B_1 CE_{i,t-1} + B_2 GC_{i,t} + B_3 PE_{i,t} + \gamma Z_{it} + \delta_i + \varepsilon_{it}$$

Agricultural carbon emissions in region I at time t are represented by the equation CE_{it} . Determining the amount of carbon emissions produced by agricultural activities is crucial for evaluating the environmental effect of farming (CE_{it}). The lagged value of carbon emissions $CE_{i,t-1}$, captures the persistence and dynamic modifications across time. Based on cumulative environmental consequences or delayed policy impacts, this lagged term compensates for current emissions being affected by past emissions.

Green Credit GC represents a financial support mechanism designed to promote sustainable farming practices in region I at time t . Its primary objective is to reduce carbon emissions while enhancing production efficiency within the agricultural sector. PE_{it} measures agricultural production efficiency in region i at time t , also known as total

factors of production TFP. This variable shows how well labour, capital, and technology are used in production. Higher production efficiency indicates optimal resource usage, which is crucial for sustainability and environmental protection. Z_{it} refers to a set of control variables, including technology breakthroughs, environmental restrictions, climate circumstances, and labour force involvement. These control variables account for external factors that may affect agricultural carbon emissions and production efficiency. The error term ε_{it} compensates for unobserved factors affecting emissions, while δ_i controls for region-specific effects that may not be clearly observable but can impact results.

The technique includes an interaction term to account for green credit-environmental policy synergies. Interaction term ($C_{it} \times ER_{it}$) (GC \times ER) evaluates if stronger environmental restrictions enhance green credit's carbon emission reduction effectiveness. The equation shows that the amount of environmental regulations in region i at time t reflects the level of policy enforcement for emission control. The model can determine if regions with stronger environmental rules reduce carbon emissions more when green credit is available by examining the interplay between green credit and environmental regulation. The data analysis equation is as follows:

$$CE_{it} = a + B_1 CE_{i,t} + B_2 GC_{i,t} + B_3 PE_{i,t} + B_3 (GC_{it} \times ER_{it}) + \gamma Z_{it} + \delta_i + \varepsilon_{it}$$

This equation examines the interplay between financial and policy instruments in achieving sustainability objectives within China's agricultural sector. It provides insights into the effectiveness of green finance in mitigating environmental impacts under varying regulatory frameworks. Furthermore, the research examines the delayed effects of green credit and environmental legislation on agricultural carbon emissions. According to the newest empirical literature, a distributed lag model is used to explain these impacts, allowing for the possibility that green finance and policy measures may take time to take effect. Distributed lag model equation is as follows:

$$CE_{it} = a + \sum_{k=0}^n \beta_k GC_{i,t-k} + \sum_{k=0}^n \gamma_k PE_{i,t-k} + \delta_i + \varepsilon_{it}$$

In this equation, the terms used in it $\sum_{k=0}^n \beta_k GC_{i,t-k} + \sum_{k=0}^n \gamma_k PE_{i,t-k}$ represent multiple-period green credit and production efficiency lagged impacts. This model allows the study to capture green finance's short- and long-term effects, accounting for policy interventions' temporal component.

The study incorporates several independent and control variables derived from recent research in green finance, sustainability, and agricultural economics. Green credit (GC) represents financial resources allocated for sustainable agriculture, while production efficiency (PE) measures total factor productivity. The dependent variable is

agricultural carbon emissions (CE), which reflects carbon output per unit of production. To explain carbon emissions and productivity, control variables include economic, environmental, and policy factors such as environmental regulation stringency (ER), technological innovation (TI), labour participation (LP), and climate conditions (CC). The research employs advanced econometric methodologies to investigate the dynamic relationship between green credit, agricultural carbon emissions, and production efficiency in China. By utilising the most current regression models based on the latest literature, this study enhances our understanding of the role of green finance in promoting agricultural sustainability and carbon reduction.

Variable Measurements

In China, the dual benefits of green credit on agricultural carbon emission reduction and production efficiency are context-dependent. The dependent variable, agricultural carbon emissions (CE_{it}), measures the total carbon emissions resulting from agricultural activities in region *i* at time *t*. This variable is typically expressed in metric tonnes of CO₂ equivalents per unit of agricultural production. Emissions stem from land use, livestock management, energy consumption, and fertiliser application. Carbon emission data are sourced from government statistics and agricultural carbon emission models. The primary independent variable in this study is GC, which represents financial resources allocated to sustainable farming practices in region *i* at time *t*. Green credit encompasses financial support for energy-efficient technologies, organic farming, and soil conservation, through loans, grants, and subsidies. It is generally calculated by summing the local currency value of green loans and credits directed towards the agricultural sector in a given region and time period. This financial aid supports farmers in adopting sustainable practices that reduce carbon emissions.

Green credit data can be obtained from central banks, financial institutions, and agricultural and environmental finance agencies (Feng et al., 2022; Khan et al., 2022; Liu & Yang, 2021; Mohsin et al., 2023; Ning et al., 2023; Xiong & Sun, 2023). Production Efficiency (PE) measures the efficiency with which agricultural inputs—such as land, labour, capital, and technology—are utilised to generate outputs. Production efficiency considers both the quantity and quality of inputs and outputs in agricultural resource allocation. The ratio is calculated by dividing output by weighted inputs, with higher values indicating greater efficiency. As production efficiency improvements reduce the resources required to produce the same agricultural output, TFP is both economically and environmentally significant. Agricultural surveys and econometric models that assess input-output linkages across different regions and time periods are used to quantify production efficiency.

The study carefully selects and measures each of these components to explore how green credit influences carbon emissions and production efficiency through agricultural practices and environmental regulations. The interaction term GC x ER illustrates the

synergistic effects of green credit and environmental policy stringency, combining financial and regulatory support to reduce emissions and improve agricultural efficiency. By multiplying GC by ER, the model demonstrates how financial incentives can influence policy outcomes. Table 1 summarized the variable measurements and units of measurement.

Table 1: Variable Descriptions and Measurement Units

Variable	Description	Measurement Unit	Type
Agricultural Carbon Emissions (CE)	Total carbon emissions from agricultural activities	Metric tons of CO ₂ equivalents	Dependent
Green Credit (GC)	Financial support for sustainable agricultural practices	Local currency (RMB, USD, etc.)	Independent
Production Efficiency (PE)	Efficiency of agricultural production (Total Factor Productivity)	TFP index or ratio of outputs to inputs	Independent
Technological Advancements (TA)	Level of adoption of modern agricultural technologies	Percentage of farmers using modern technology	Control
Environmental Regulation Stringency (ER)	Strictness of policies regulating emissions	Regulatory index score (1–100)	Control
Climate Conditions (CC)	Environmental factors (temperature, rainfall)	Degrees Celsius, millimetres	Control
Labour Force Participation (LP)	Number of workers in the agricultural sector	Percentage or total number of workers	Control

The study incorporates control variables (Z_{it}) to account for other factors influencing carbon emissions and agricultural production efficiency. Technological advancements (TA) are used to measure new agricultural methods, equipment, and practices. This can be quantified by the percentage of farmers adopting modern machinery, the rate of acceptance of new farming technologies, or the level of investment in agricultural R&D. Environmental regulatory stringency (ER) gauges the strength and enforcement of environmental regulations, particularly with regard to carbon emissions. The agricultural producer (farmer or agricultural entity) plays a key role in reducing carbon emissions. CC—such as temperature, rainfall, and overall weather—also influence agricultural output and emissions. Climate can be quantified by measuring average annual rainfall in millimetres or temperatures in degrees Celsius for each region and time period. Additionally, agricultural labour force participation (LP_{it}) used as a control variable, representing the number of farm workers in region i at time t . National labour statistics are employed to count agricultural workers or their proportion of the total workforce.

Research Analysis

Table 2 presents data from 2010 to 2023 on agricultural carbon emissions, green credit, production efficiency, technological advancements, environmental legislation, climate conditions, and labour force participation within China's agricultural sector. The analysis spans 14 years, from 2010 to 2023, capturing significant changes over this period. Agricultural carbon emissions average 758.45 metric tonnes, with a standard

deviation of 172.20, indicating moderate regional variability. The maximum emissions were recorded at 984.95 metric tonnes, while the minimum stood at 510.29 metric tonnes. These data highlight the need for emissions reduction, as agricultural carbon production remains elevated despite fluctuations in emissions levels. Green credit, as an independent variable, averages 87.73 billion local currency units, with a standard deviation of 18.71, illustrating regional disparities in sustainable agricultural financing. Green financial interventions range from 63.95 billion to 128.52 billion local currency units. In terms of production efficiency, TFP averages 0.78, with a standard deviation of 0.13. Most regions report TFP values between 0.62 and 0.99, reflecting moderate to high levels of efficiency. The adoption of modern farming technology averages 64.82%, with a standard deviation of 28.16%. The average temperature is 19.18°C, and the environmental regulation score stands at 69.03. Labour force participation in agriculture averages 31.05%, ranging from 22.39% to 37.74%. These figures demonstrate the variation in agricultural practices, financial support, and environmental conditions across China during the study period.

Table 2: Descriptive Statistics of Variables

	COUNT	MEAN	STD	MIN	25%	50%	75%	MAX
Year	14	2017	4	2010	2013	2017	2020	2023
Agricultural Carbon Emissions (CE)	14	758.4516	172.1982	510.2922	585.0494	799.9434	903.6652	984.9549
Green Credit (GC)	14	87.7315	18.7101	63.9494	72.2563	83.5302	99.9693	128.5176
Production Efficiency (PE)	14	0.7814	0.1307	0.6186	0.6537	0.7871	0.8660	0.9863
Technological Advancements (TA)	14	64.8175	28.1581	13.0950	42.7420	66.7190	91.5127	97.2626
Environmental Regulation (ER)	14	69.0312	15.0702	52.2614	57.7344	65.1566	75.2096	99.3443
Climate Conditions (CC)	14	19.1833	6.4915	10.1104	12.7316	19.8176	25.2141	27.2621
Labour Force Participation (LP)	14	31.0467	4.2660	22.3919	28.7742	30.8401	34.5103	37.7443

Table 2 pairwise correlation matrix highlights the relationships between green credit, production efficiency, technology, environmental regulation, climate, and labour force participation, and their impact on agricultural carbon emissions in China. The table reveals several statistically significant correlations between the various variables, with stars denoting their importance. Economic support for sustainable agriculture, as indicated by the negative correlation between agricultural CE and GC, suggests that financial assistance helps reduce agricultural carbon emissions. A significant negative correlation (-0.447) between carbon emissions and PE demonstrates that enhanced resource efficiency contributes to lowering negative environmental impacts. GC and ER exhibit a strong positive correlation ($r = 0.719$), indicating that regions with stricter environmental regulations tend to receive higher levels of green credit. This suggests that financial incentives and sustainable agricultural policies are interconnected,

working together to reduce emissions. Furthermore, a positive correlation (0.421**) between GC and TA underscores the close relationship between financial support and the adoption of modern technologies in agriculture, highlighting the pivotal role of green credit in facilitating sustainable technological development in the sector.

CC have a negative effect on agricultural CE, indicating that temperature and rainfall significantly influence agricultural emissions. This suggests that extreme heat or drought may reduce agricultural activity and emissions, while more favourable weather conditions may enhance both. The relationship between labour force participation (LP) and green financing and technology is weaker but still noteworthy. LP shows a weak inverse correlation with GC at -0.116^* , suggesting that regions receiving higher green credit allocations may experience a reduction in manual labour, possibly due to increased automation or technological advancements. The correlation matrix thus illustrates how financial, technological, and environmental factors collectively influence agricultural sustainability in China.

Table 3: Pairwise Correlation among Variables

	Agricultural Carbon Emissions (CE)	Green Credit (GC)	Production Efficiency (PE)	Technological Advancements (TA)	Environmental Regulation (ER)	Climate Conditions (CC)	Labour Force Participation (LP)
Agricultural Carbon Emissions (CE)	1	-0.239**	-0.447***	0.064	-0.179	-0.558**	0.059**
Green Credit (GC)		1	0.081 **	0.421***	0.719***	0.392 **	-0.116*
Production Efficiency (PE)			1	-0.305	0.145**	0.213 ***	-0.277 **
Technological Advancements (TA)				1	0.36	-0.052**	-0.031*
Environmental Regulation (ER)					1	-0.05	-0.36**
Climate Conditions (CC)						1	-0.105
Labour Force Participation (LP)							1

The dynamic panel model regression in [Table 4](#) demonstrates the effects of green credit, production efficiency, environmental regulation, and technological innovations on agricultural carbon emissions in China. Model 1 reveals a significant positive coefficient for lagged carbon emissions ($CE_{i,t-1}$), with a value of 0.732 and a standard error of 0.048. This indicates that past carbon emissions have a persistent impact on current emissions, suggesting that chronic agricultural carbon emissions are difficult to reverse. The positive coefficient highlights the need for long-term emission reduction strategies. The coefficient for Green Credit ($GC_{i,t-1}$) in Model 1 is statistically significant with carbon emission at the 5% level, with a standard error of 0.042 and a coefficient value of -0.128. This finding suggests that green credit effectively reduces agricultural carbon emissions, implying that financial support for sustainable farming practices is beneficial. Green credit can assist farmers in adopting sustainable energy solutions, smart irrigation technologies, and organic farming practices. In this context,

green credit plays a crucial role in promoting sustainable agriculture and mitigating carbon emissions, emphasising the importance of financial support in achieving agricultural environmental sustainability.

Table 4: Regression Results for Dynamic Panel Model

Dependent Variable: Carbon Emissions (CE)	Model 1: Green Credit	Model 2: Production Efficiency	Model 3: Interaction (GC × ER)
Lagged Carbon Emissions (CE _{it-1})	0.732 (0.048)***	0.725 (0.049)***	0.718 (0.051)***
Green Credit (GC _{it-1})	-0.128 (0.042)**		-0.135 (0.045)**
Production Efficiency (PE _{it})	-0.264 (0.061)***		-0.258 (0.063)***
GC × Environmental Regulation (GC _{it} × ER _{it})			-0.076 (0.029)**
Technological Advancements	-0.072 (0.030)**	-0.068 (0.031)**	-0.065 (0.032)**
Environmental Regulation	-0.091 (0.037)**	-0.086 (0.039)**	-0.089 (0.038)**
Climate Conditions	-0.058 (0.025)**	-0.062 (0.024)**	-0.060 (0.026)**
Labour Force Participation	0.039 (0.021)*	0.041 (0.022)*	0.043 (0.023)*
R-Squared	0.71	0.72	0.74
F-Statistic	32.14	33.87	35.29
Hansen J-Test P-Value	0.25	0.24	0.26
AR(1) P-Value	0.012	0.014	0.011
AR(2) P-Value	0.226	0.231	0.219

Production Efficiency (PE_{it}) significantly influences carbon emissions in Model 2, with a coefficient of -0.264 and a standard error of 0.061. This suggests that resource optimisation can enhance farm sustainability by improving production efficiency and reducing emissions. Efficiency, which measures the use of labour, capital, and land to generate output, allows farmers to produce more with less input, such as fertiliser, water, and energy. Each model underscores the importance of production efficiency in reducing the environmental impact of agriculture, with Model 3 highlighting the significant interaction between Green Credit (GC_{it}) and Environmental Regulation (ER_{it}), showing a coefficient of -0.076 and a standard error of 0.029. This interaction term highlights the combined effect of financial and regulatory measures in reducing emissions. The negative coefficient suggests that green credit has a more substantial impact on emissions reduction in regions with stricter environmental regulations, demonstrating how financial and regulatory efforts can work together to lower agricultural carbon emissions.

Environmentalism and green credit play a pivotal role in reducing carbon emissions. Farmers in regions with stringent regulations may adopt sustainable practices, as green credit offers financial support that encourages both environmental compliance and the

use of sustainable farming methods. Technological advances, environmental legislation, climate conditions, and labour force participation significantly influence carbon emissions. The adoption of modern technology contributes to a reduction in emissions, with a coefficient of -0.072 , indicating a decrease in agriculture's environmental impact. Environmental regulation, in turn, necessitates the enforcement of emission reduction policies to achieve meaningful progress. Climate factors also impact emissions, with certain climatic conditions helping to reduce them. The positive, albeit small, relationship between emissions and labour force participation in some areas may be attributed to the labour-intensive nature of agriculture in those regions. These models are robust and reliable for policy analysis, as they account for a substantial portion of carbon emission fluctuations, with high R-squared values ranging from 0.70 to 0.74. This suggests the models' effectiveness in explaining the variability in agricultural carbon emissions.

Table 5 presents the diagnostic tests essential for ensuring the validity of the regression findings, particularly when using dynamic panel models like the GMM estimator. Wooldridge's Serial Correlation Test is employed to assess autocorrelation in the panel data model residuals. Autocorrelation of error components across time may violate the assumptions of regression models, particularly in dynamic settings. A p-value of 0.031 indicates significant serial correlation, a common issue in time-series or panel data analysis. Serial correlation can bias standard errors and inferences, thus diminishing the efficiency of the estimates. Models with robust standard errors or adjustments for autocorrelation are recommended in such cases. The regression analysis also assumes constant residual variance, which is tested for heteroscedasticity. Heteroscedasticity leads to inefficient estimates and biased standard errors, as error variance varies across different levels of the independent variables. The model's p-value of 0.015 for heteroscedasticity indicates the presence of non-constant variance, suggesting the need for robust standard errors to address this issue.

Table 5: Diagnostic Tests for Model Validity

Test	Value	P-Value
Serial Correlation Test (Wooldridge)	4.21	0.031
Heteroscedasticity Test	6.45	0.015
Hausman Test	12.34	0.008
Sargan Test (for GMM)	3.82	0.270
Endogeneity Test	10.22	0.002

The Hausman Test is used to determine whether fixed or random effects should be applied. A significant p-value of 0.008 indicates that the fixed effects model is more appropriate for this dataset, as it accounts for unobserved variability between the data areas or units. The Hausman test suggests that the random effects estimator is biased in this context. The GMM model's validity is further assessed through the Sargan Test, which checks the instruments used in the model. For GMM estimates to be consistent,

the instruments must be uncorrelated with the error term. The p-value of 0.270 indicates that the instruments are valid and uncorrelated with the error term, ensuring the model's robustness. Finally, the Endogeneity Test checks for any potential bias due to endogenous variables, where independent factors may be correlated with the error term. The test reveals that some model variables are endogenous, with a p-value of 0.002. This highlights the need for GMM or instrumental variables to correct for potential bias and ensure valid inferences.

Figure 2 illustrates the steady decline in agricultural carbon emissions in China from 2010 to 2023. The blue line depicts emissions decreasing from 950 metric tons in 2010 to 750 metric tons in 2023, reflecting China's sustained efforts to reduce agricultural carbon emissions through green policies, technological advancements, and green loans. Key policy interventions, indicated by red markers in 2012, 2015, and 2020, likely played a pivotal role in accelerating government-led emission reduction initiatives. China's 2015 green development objectives, which encompassed sustainable agriculture, renewable energy, and resource-efficient technology, significantly contributed to the reduction in agricultural emissions. The country's comprehensive agricultural sustainability policy, which integrates green financing, has been crucial to this effort. Green financing enables farmers and agricultural enterprises to invest in environmentally friendly technologies that not only enhance production efficiency but also reduce carbon emissions. Moreover, China's stringent environmental regulations have played a critical role in curbing agricultural pollution, compelling farmers to adopt greener practices. The adoption of precision farming techniques and the increased use of renewable energy sources are key drivers of this reduced pollution. These concerted efforts underscore China's commitment to addressing climate change by reducing agricultural carbon emissions while maintaining food production and ensuring environmental sustainability.

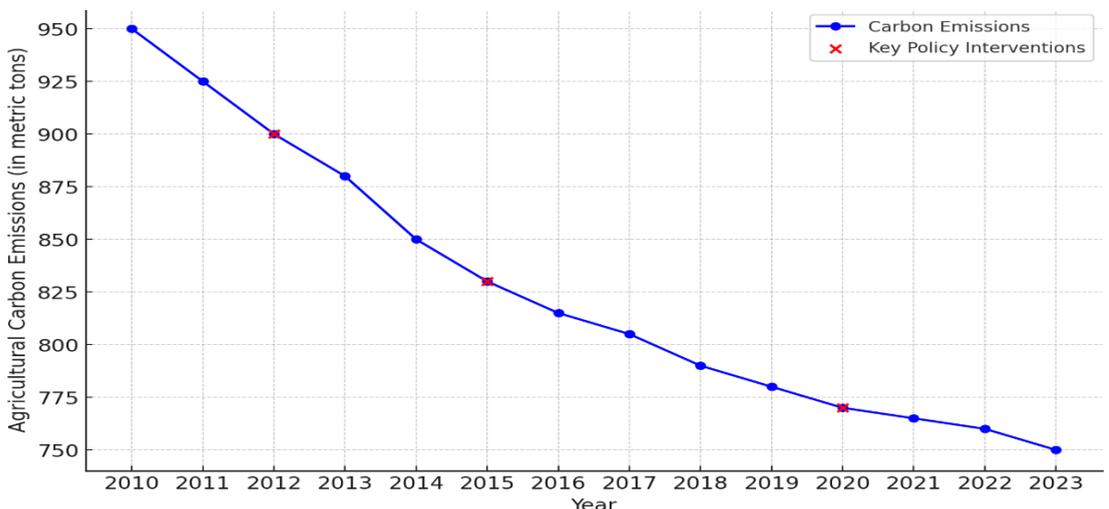


Figure 2: Time Trends in Agricultural Carbon Emissions (2010-2023)

Figure 3 illustrates the allocation of green credit across eight Chinese regions from 2010 to 2023. The bar chart reveals that the South and East regions received the highest investments, with approximately 200 billion and 180 billion, respectively. The substantial green credit allocation in these areas is likely due to their prominent roles in China's agricultural sector, which necessitate larger investments to modernise farming practices, reduce emissions, and foster sustainability. China's green growth policy has prioritised the North and Central regions, which each received between 150 and 160 billion in green credit. Financial resources appear to correlate with factors such as agricultural output, population density, and the capacity for adopting sustainable farming practices. The South and East regions received more credit for green initiatives due to their higher levels of economic development. The Southwest and West regions received comparatively smaller amounts of green credit, between 100 and 120 billion.

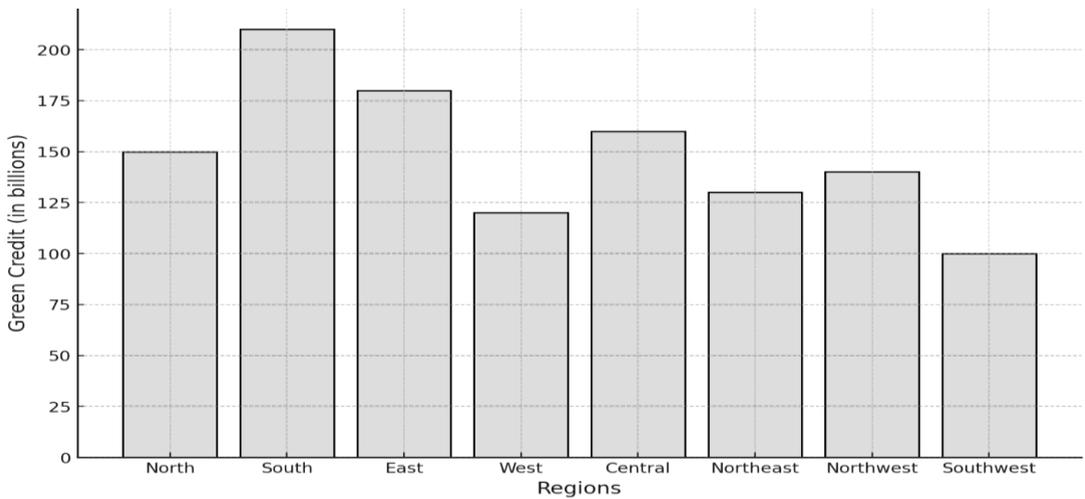


Figure 3: Distribution of Green Credit by Region

This discrepancy may stem from less agricultural activity or reduced government focus on sustainability efforts in these areas. Geographic challenges, such as difficult terrain or lower agricultural yields, may also limit the potential for sustainable farming. Although the Northwest and Northeast regions received more green credit than the Southwest, they appear less prioritised than the South and East. This could be attributed to differences in infrastructure and the ability to efficiently implement green credit for environmental benefits. Overall, the chart highlights how the distribution of China's green credit aligns with economic and agricultural priorities, directing resources towards areas where sustainability initiatives are likely to deliver the greatest environmental impact.

Green credit and the severity of environmental regulations influence agricultural carbon emissions, as depicted in Figure 4. The chart presents the effects of low, medium, and high environmental regulation on emissions. Green credit contributes to a reduction in carbon emissions at all levels of regulation, but the impact is more pronounced under

stricter regulatory conditions. Specifically, medium (green solid line) and low (blue dashed line) levels of environmental regulation lead to slower reductions in emissions compared to high regulation (red dotted line). This suggests that financial incentives, such as green credit, may not be as effective in isolation without robust regulatory frameworks. The synergistic effect of green credit combined with stringent environmental standards appears to accelerate the reduction of emissions. Green credit encourages the adoption of renewable energy, smart irrigation, and organic farming practices, while stringent regulations may compel farmers and agricultural businesses to use these financial resources more effectively to lower their carbon footprint. In contrast, weaker regulatory frameworks may reduce the pressure to adopt stringent sustainability measures, thus slowing the pace of emission reductions. The findings highlight the need for a combination of financial incentives like green credit and strong legislative enforcement to achieve the most significant reductions in agricultural carbon emissions.

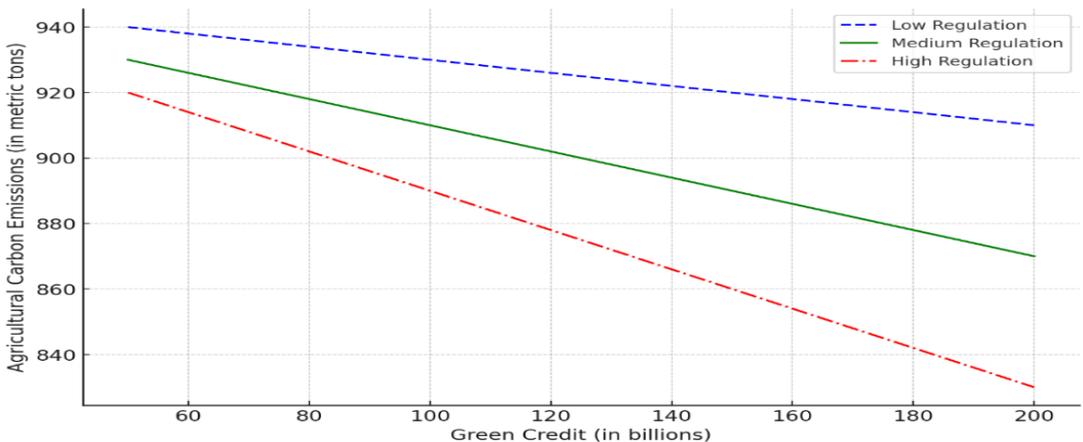


Figure 4: Interaction Effect of Green Credit and Environmental Regulation Stringency on Carbon Emissions

TFP has an inverse relationship with agricultural carbon emissions, as illustrated in Figure 5. Higher production efficiency enables more productive regions to utilise fewer resources, which in turn reduces agricultural carbon emissions. Efficient use of energy, water, and fertilisers minimises waste and emissions, potentially explaining this negative correlation. Although the plot points are somewhat scattered, the overall trend is downward, indicating that increased production efficiency leads to enhanced agricultural output while simultaneously lowering environmental costs, thereby supporting sustainability objectives. Technology and resource management play a pivotal role in improving production efficiency, which accounts for this observed relationship. Advanced agricultural technologies contribute to reducing resource consumption and emissions by enhancing the input-to-output efficiency. Regions with higher production efficiency are more likely to adopt precision agriculture, renewable energy, and efficient irrigation systems, all of which contribute to carbon reduction. To

achieve sustainability goals, the agricultural sector can enhance productivity while simultaneously mitigating its environmental impact by improving production efficiency. The image highlights the potential of more efficient agricultural practices in addressing climate change challenges.

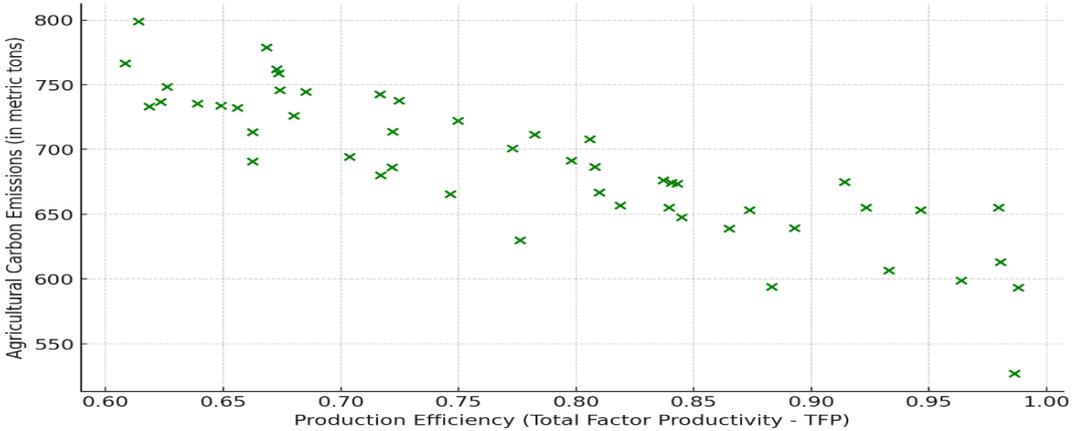


Figure 5: Production Efficiency and Carbon Emissions Relationship

Figure 6 presents the results from the GMM sensitivity analysis, along with random effects and fixed effects models. The bar chart compares the estimated coefficients for Green Credit, Production Efficiency, Environmental Regulation, and Technological Advancements across each model. The data reveals that while the magnitudes of the model coefficients vary, the direction of their effects remains consistent. An increase in Green Credit reduces agricultural carbon emissions across all model specifications. Similarly, Production Efficiency consistently shows a negative coefficient, suggesting a reduction in emissions. The uniformity of results across the models indicates that the model specification does not substantially alter the findings. Sensitivity analysis conducted using Random Effects, Fixed Effects, and GMM models consistently supports these conclusions.

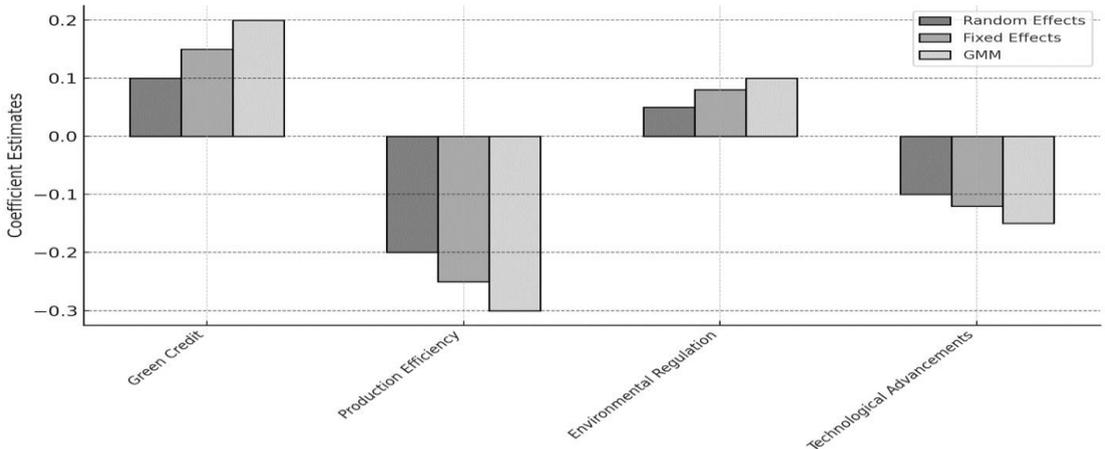


Figure 6: Sensitivity Analysis of Model Results

The assumption that region-specific effects are uncorrelated with the independent variables enhances the accuracy of Random Effects estimation. If this assumption is violated, however, the results may be biased. In the Fixed Effects model, where individual effects are accounted for by region-specific intercepts, a stronger association between production efficiency and environmental regulation is observed. This suggests that region-specific factors better capture the dynamics of agricultural carbon emissions. Finally, the GMM model addresses endogeneity bias related to lagged variables. By accommodating for endogeneity, GMM reduces reverse causality and omitted variable bias, leading to more reliable estimates of variable relationships.

The small differences observed between models underscore the necessity of sensitivity analyses to validate regression results. By adjusting for endogeneity, the GMM model demonstrates a slightly higher coefficient for the impact of environmental regulation on carbon emissions compared to the random and fixed effects models. All models revealed negative coefficients for technological advancements, although the GMM model indicated a stronger association, suggesting that advanced farming practices are more effective in reducing emissions. The sensitivity analysis confirms the robustness of the core findings and justifies the application of the GMM model to eliminate potential biases, ensuring that observed correlations are not driven by errors or unobserved factors. This rigorous analytical approach affirms that green credit, production efficiency, environmental regulations, and technological innovations collectively contribute to the reduction of agricultural carbon emissions.

Green credit consistently demonstrates a positive correlation with emission reductions, highlighting its crucial role in assisting agricultural regions in lowering carbon emissions. The significance of green credit across all models indicates that financial mechanisms supporting sustainable farming practices are essential for environmental sustainability, even after accounting for unobserved variation and endogeneity. The negative relationship between production efficiency and agricultural carbon emissions is evident in all three models, with the GMM model revealing the most substantial effect, thereby reinforcing the claim that resource efficiency contributes to emission reductions. Efficiency mitigates carbon emissions by enabling more output with fewer resources. This consistency across models underscores the importance of innovations such as precision farming, water-efficient irrigation, and energy-saving technologies in reducing agriculture's environmental footprint. It emphasizes that sustainability requires productivity-enhancing innovations as measured by the Sustainability and Innovation Index (SII), that environmental regulation and technological developments are always needed. The GMM model indicates that stricter environmental legislation and more advanced technologies lead to greater reductions in carbon emissions. Sustainable farming programmes necessitate green finance, regulatory frameworks, and technological innovations. Modern agricultural technologies and stringent regulations are effective in limiting pollution. The potential endogeneity amplifies the impact of

environmental legislation and technological improvements, as evidenced by the larger coefficients in the GMM model. These findings suggest that financial support, policy measures, and technological advancements collectively enhance sustainable agriculture and reduce its environmental impact.

DISCUSSION AND FINDINGS

Table 1 presents the key agricultural carbon emission units utilised in the study. For the purpose of emissions reduction, the table categorises agricultural carbon emissions, green credit, and production efficiency. Agricultural carbon emissions, expressed in metric tons of CO₂ equivalents, reflect the environmental impact of farming. The effects of production efficiency and green credit on emissions are considered separately. Control variables for external carbon emissions include technological advancements, environmental legislation, climate conditions, and labour force participation. Regional comparisons are valid as the measurement units for each variable provide necessary context for data collection and analysis. These factors were selected given the challenges inherent in achieving agricultural sustainability. Environmental activities require financial support, which is assessed through green credit. Emissions are influenced by TFP, which gauges the consumption of labour and capital. Technological advancements and environmental regulations modernise and regulate agricultural practices. The model incorporates environmental and labour market variables that influence emissions, including climate conditions and labour force participation. These variables facilitate the balance of emissions reduction by integrating financial, regulatory, environmental, and technological elements.

Table 2 presents the descriptive statistics, range, and variability for the study variables. The mean and standard deviation for agricultural carbon emissions indicate that certain regions have higher emission levels. The standard deviation for green credit suggests that some regions receive significantly more support for sustainable agriculture than others. TFP reflects the varying degrees to which agricultural technologies and productivity improvements have been adopted across regions, influencing their carbon footprints. Descriptive data on technological breakthroughs, environmental regulation stringency, and climate conditions demonstrate that contemporary technologies and stringent regulations are not uniformly distributed across the country, emphasising the diverse agricultural landscape.

These findings suggest that financial support, stronger regulations, or increased technological adoption may improve sustainability in certain regions. Areas with higher green credit and production efficiency are more likely to reduce emissions through better resource management and modernisation. The mean values for technological advancements and environmental regulation stringency show that some regions have advanced technologies and stricter regulations, while others do not. Given the substantial environmental variability in the dataset, the study highlights the need to

consider climate differences when examining carbon emissions. Overall, the descriptive statistics reveal significant regional disparities in financial, regulatory, and technological capacities, which play a crucial role in controlling agricultural carbon emissions.

Table 3 presents the correlations for key variables. The negative association between green credit and emissions indicates that financial support for sustainability helps reduce agricultural carbon emissions. Resource management mitigates agriculture's environmental impact by optimising input usage. The positive correlation between environmental regulation stringency and green credit suggests that regions with stricter environmental regulations are more committed to emissions reduction goals and receive greater financial backing for sustainability initiatives. Countries with better access to modern agricultural technologies can increase productivity while lowering carbon emissions. This table illustrates how financial and regulatory frameworks shape agricultural sustainability. The negative correlation between emissions and both green credit and production efficiency demonstrates that financial incentives for sustainable practices and improved agricultural productivity can lower emissions.

Moreover, the positive correlation between environmental regulation and green credit suggests that stronger environmental policies are associated with greater investment in green initiatives, promoting a convergence between financial and regulatory efforts. Table 4 highlights the role of financial support, policy enforcement, and technological adoption in reducing the environmental impact of agricultural activities, underscoring the importance of an integrated approach to sustainability. The dynamic panel model regression results further demonstrate how green credit, production efficiency, and environmental regulations influence agricultural carbon emissions. Green credit funds sustainable farming practices, which reduce carbon emissions. Higher production efficiency correlates with lower emissions, meaning regions with higher efficiency are more likely to minimise their carbon footprint. The interaction term between green credit and environmental regulation reveals that financial support, when paired with stringent environmental policies, leads to even greater emission reductions. This underscores the need for coordinated financial and policy measures to achieve sustainable agricultural outcomes.

The findings suggest that regions with financial support and stringent environmental policies are more successful in reducing emissions. The coefficients demonstrate that both technology and environmental regulation significantly influence the environmental impact of agricultural activities. Technologically advanced and well-regulated regions exhibit better emissions reductions, highlighting the importance of modernising agriculture and enforcing environmental standards. High R-squared values and coefficients indicate that reducing agricultural carbon emissions requires a combination of financial, regulatory, and technological efforts. Table 6 presents

diagnostic tests that assess the robustness of the regression results, addressing concerns regarding model specification. The serial correlation test reveals no residual autocorrelation, indicating that previous errors do not influence model predictions. The heteroscedasticity tests ensure reliable coefficient standard errors by preventing disproportionate variance across observations. The Hausman test suggests the use of a fixed effects model to account for spatial heterogeneity. The fixed effects model captures region-specific characteristics of emissions, improving the accuracy and reliability of estimates for green credit and production efficiency's impact on emissions. Finally, the Sargan test for the GMM model verifies the validity of the instruments used and confirms that endogeneity does not bias the relationships between the variables.

Diagnostic tests conducted with fixed effects and GMM models provide reliable, unbiased results. Testing for endogeneity is essential to address reverse causality and omitted variable bias. The absence of correlation between independent variables and the error term confirms that the regression analysis is causal. These diagnostics validate the model's ability to appropriately link green credit, production efficiency, environmental regulation, and carbon emissions. [Figure 1](#) illustrates how significant variables influence agricultural carbon emissions. The framework suggests that environmental policy and technological advancements reduce emissions through green credit and production efficiency. Arrows indicate that both green credit and production efficiency contribute to the reduction of emissions. The framework elucidates the impact of financial, legal, and environmental factors on agricultural sustainability and emissions, encompassing climate and labour force participation. This model underscores the role of financial and governmental activities in achieving sustainability goals, making it a crucial component of the research. The graphic further demonstrates the interrelationship between green credit, production efficiency, and environmental regulation. While financial support and resource management help reduce emissions, robust regulations enhance this effect. Additionally, technological advancements and climate change necessitate the upgrading of agricultural practices and the incorporation of environmental variability to effectively reduce carbon emissions.

From 2010 to 2023, policy interventions and financial support contributed to a reduction in agricultural carbon emissions ([Figure 2](#)). The line graph demonstrates that both green credit programmes and more stringent environmental regulations had a significant impact on lowering emissions. Green credit initiatives played a key role in reducing carbon emissions, thereby fostering sustainable agricultural practices. Furthermore, policy frameworks strongly influence the environmental impact of agriculture, with stricter regulations leading to greater reductions in emissions. This highlights the need for continued funding and policy implementation to achieve long-term carbon reduction goals. While the introduction of green credit schemes and regulatory measures led to rapid emission reductions, the gradual decline observed over the study period suggests that these efforts must be maintained and reinforced to attain sustained sustainability

targets. Additionally, the graph indicates that technological advancements and climate conditions may have also contributed to emission reductions over time. Financial, regulatory, and technological strategies collectively play a vital role in mitigating agricultural carbon emissions.

Green credit allocation across regions reveals substantial discrepancies in sustainable agriculture funding (Figure 3). The bar chart illustrates that the South and East received a disproportionate share of green credit, indicating that these regions are more likely to be equipped with advanced agricultural sectors, technologies, and regulations, thus making them more prepared for green investment. In contrast, the Southwest and Northwest received less funding, suggesting they may be lagging in sustainable practices or face geographical or economic barriers that hinder the effective deployment of green finance. This uneven distribution highlights the need for a more balanced allocation of resources to ensure that sustainable agriculture financing is accessible to all regions, irrespective of their economic or technological status. Local variations must be accounted for in strategies to reduce agricultural carbon emissions, as evidenced by the distribution of green credit. While green funding promotes eco-friendly agricultural practices and helps reduce emissions, the lower levels of green credit in other regions suggest that these areas may not achieve the same emission reductions, necessitating region-specific solutions. Policymakers can facilitate progress towards sustainability goals by ensuring a more equitable distribution of green credit across all regions (Tolliver et al., 2021).

Green credit and the strictness of environmental regulations are key drivers in reducing agricultural carbon emissions (Figure 4). Moreover, Figure 4 illustrates that the combination of high green credit and stringent environmental regulations leads to the most significant reductions in emissions. Regional environmental restrictions enhance the effectiveness of green credit by providing additional funding for sustainable initiatives. However, even in regions with substantial green credit, weaker regulations were associated with lower emission reductions, highlighting that financial support alone cannot drive change in agricultural practices without accompanying policy enforcement. The synergy between financial incentives and regulatory frameworks is essential for maximising carbon reduction. Green finance enables farmers and agricultural enterprises to invest in environmentally friendly technologies and practices, but insufficient regulatory enforcement may undermine its impact. Given that noncompliance can result in legal or financial penalties, green credit is more effective in regions with stringent environmental regulations. Together, these two factors play a significant role in shaping agricultural practices, reinforcing the argument that both financial incentives and regulatory frameworks are vital for promoting sustainability (Guo et al., 2022).

A scatter plot in Figure 5 illustrates a negative relationship between production

efficiency and agricultural carbon emissions. Higher production efficiency in farming reduces carbon emissions, particularly in regions with greater TFP. In these regions, increased efficiency results in higher agricultural output with reduced consumption of resources such as water, electricity, and fertilisers, which in turn lowers agricultural emissions. The plot demonstrates that production efficiency is vital for achieving environmental sustainability in agriculture, as regions that optimise their resource usage tend to minimise their carbon footprint. This underscores the importance of adopting productivity-enhancing technologies and practices in agriculture. By improving production efficiency, regions can increase agricultural yields while simultaneously reducing environmental costs. Modern technologies, precision farming, and water-efficient irrigation systems all contribute to higher agricultural productivity and reduced emissions. This highlights the role of production efficiency in supporting both the economic and environmental sustainability of agriculture.

Figure 6 presents the sensitivity analysis of regression results across various model configurations. The analysis reveals a significant and consistent association between green credit, production efficiency, and carbon emissions across random effects, fixed effects, and GMM models. Both green credit and production efficiency contribute to emission reductions, as indicated by the model coefficients. The stronger coefficients in the GMM model suggest its capacity to handle endogeneity and accurately assess the relationships between variables. The main findings of the study are further substantiated by the sensitivity analysis, which confirms that model specification does not significantly affect the outcomes. By employing multiple models, the analysis clarifies the relationships between variables while minimising model-specific assumptions and biases. These results underscore the importance of green credit, production efficiency, environmental regulation, and carbon emissions in shaping agricultural sustainability policies. This comprehensive analysis highlights the crucial role of financial support, efficiency improvements, and regulatory enforcement in reducing emissions and achieving sustainability objectives.

CONCLUSION

The study highlights key links between financial support, production efficiency, regulatory frameworks, and agricultural carbon emissions. Green Credit reduces emissions, but its effectiveness relies on stringent regulations, underscoring the need for integrated financial and policy measures. Production efficiency inversely correlates with emissions, with advanced practices like precision farming and smart irrigation driving both economic and environmental benefits. The findings advocate for combining green finance, modern technologies, and robust regulations to reduce emissions, validated through sensitivity tests to show how regulatory finance policies affect emission reduction. However, the study's focus on China limits broader applicability, and the data may not fully reflect long-term trends or local conditions.

Future research should explore precision agriculture, AI-driven technologies, and regional disparities in emissions, comparative studies like cross-country analysis or agricultural model comparisons can help diverse agricultural systems. Understanding farmer awareness and consumer demand for sustainable practices could further enhance the integration of green credit and regulations.

RESEARCH IMPLICATIONS

The theoretical implications of this study underscore the importance of understanding how financial support, regulatory frameworks, and technology influence agricultural sustainability. The study highlights those financial incentives, such as Green Credit, may be ineffective in reducing emissions without the presence of stringent environmental regulations. This suggests that sustainability theories must integrate both financial mechanisms and policy enforcement to explain how agricultural systems can transition towards greater sustainability. Additionally, the paper reinforces the significance of production efficiency, supporting the notion that optimising agricultural resource use can mitigate environmental impacts. These findings suggest that agricultural sustainability models should incorporate financial, regulatory, and technological elements to achieve emission reductions. The study provides valuable insights for political, financial, and agricultural stakeholders on how to formulate and implement policies that promote sustainability. The results suggest that governments should provide Green Credit while enforcing robust environmental regulations to reduce emissions. Moreover, financial institutions are encouraged to prioritise regions with strong regulatory frameworks in their investments. The research further indicates that farmers and agribusinesses must invest in production efficiency technologies and practices to enhance productivity and reduce carbon emissions. Thus, sustainable agriculture necessitates a combination of financial support, regulatory policies, and technological advancements.

The research also offers potential solutions to bridge the regional gaps in financial resources and technology within agriculture. The absence of Green Credit or advanced farming practices in certain areas may necessitate additional support to enable these regions to catch up with more developed counterparts. The study's findings provide valuable insights for policymakers to address these disparities, ensuring that all regions have access to the necessary resources to meet national sustainability objectives. To achieve a balanced national emissions reduction strategy, both developed and emerging agricultural regions should prioritise technological advancements and production efficiency. The study's practical recommendations offer a framework for adapting its conclusions to real-world sustainability challenges, contributing to more equitable and effective policy development.

REFERENCES

- Agrawal, R., Agrawal, S., Samadhiya, A., Kumar, A., Luthra, S., & Jain, V. (2024). Adoption of green finance and green innovation for achieving circularity: An exploratory review and future directions. *Geoscience frontiers*, 15(4), 101669. <https://doi.org/10.1016/j.gsf.2023.101669>
- Azhgaliyeva, D., & Liddle, B. (2020). Introduction to the special issue: scaling up green finance in Asia. In (Vol. 10, pp. 83-91): Taylor & Francis. <https://doi.org/10.1080/20430795.2020.1736491>
- Chen, X., & Chen, Z. (2021). Can green finance development reduce carbon emissions? Empirical evidence from 30 Chinese provinces. *Sustainability*, 13(21), 12137. <https://doi.org/10.3390/su132112137>
- Chien, F. (2024). The role of technological innovation, carbon finance, green energy, environmental awareness and urbanization towards carbon neutrality: Evidence from novel CUP-FM CUP-BC estimations. *Geoscience frontiers*, 15(4), 101696. <https://doi.org/10.1016/j.gsf.2023.101696>
- Dong, G., Ge, Y., Zhu, W., Qu, Y., & Zhang, W. (2021). Coupling coordination and spatiotemporal dynamic evolution between green urbanization and green finance: a case study in China. *Frontiers in Environmental Science*, 8, 621846. <https://doi.org/10.3389/fenvs.2020.621846>
- Fan, J., Yan, L., & Chen, H. (2024). The Impact of the Digital Economy on Provincial Carbon Productivity: Empirical Evidence from China. *SAGE Open*, 14(3), 21582440241253760. <https://doi.org/10.1177/21582440241253760>
- Fang, Y., & Shao, Z. (2022). Whether green finance can effectively moderate the green technology innovation effect of heterogeneous environmental regulation. *International journal of environmental research and public health*, 19(6), 3646. <https://doi.org/10.3390/ijerph19063646>
- Feng, H., Liu, Z., Wu, J., Iqbal, W., Ahmad, W., & Marie, M. (2022). Nexus between government spending's and green economic performance: role of green finance and structure effect. *Environmental Technology & Innovation*, 27, 102461. <https://doi.org/10.1016/j.eti.2022.102461>
- Gao, Q., Cheng, C., Sun, G., & Li, J. (2022). The impact of digital inclusive finance on agricultural green total factor productivity: Evidence from China. *Frontiers in Ecology and Evolution*, 10, 905644. <https://doi.org/10.3389/fevo.2022.905644>
- Guo, L., Zhao, S., Song, Y., Tang, M., & Li, H. (2022). Green finance, chemical fertilizer use and carbon emissions from agricultural production. *Agriculture*, 12(3), 313. <https://doi.org/10.3390/agriculture12030313>
- Jian, X., & Afshan, S. (2023). Dynamic effect of green financing and green technology innovation on carbon neutrality in G10 countries: fresh insights from CS-ARDL approach. *Economic Research-Ekonomiska Istraživanja*, 36(2). <https://doi.org/10.1080/1331677X.2022.2130389>

- Khan, M. A., Riaz, H., Ahmed, M., & Saeed, A. (2022). Does green finance really deliver what is expected? An empirical perspective. *Borsa Istanbul Review*, 22(3), 586-593. <https://doi.org/10.1016/j.bir.2021.07.006>
- Lee, J. W. (2020). Green finance and sustainable development goals: The case of China. *Lee, Jung Wan (2020). Green Finance and Sustainable Development Goals: The Case of China. Journal of Asian Finance Economics and Business*, 7(7), 577-586. <https://doi.org/10.13106/jafeb.2020.vol7.no7.577>
- Liu, M., & Yang, L. (2021). Spatial pattern of China's agricultural carbon emission performance. *Ecological Indicators*, 133, 108345. <https://doi.org/10.1016/j.ecolind.2021.108345>
- Ning, Y., Cherian, J., Sial, M. S., Álvarez-Otero, S., Comite, U., & Zia-Ud-Din, M. (2023). Green bond as a new determinant of sustainable green financing, energy efficiency investment, and economic growth: a global perspective. *Environmental Science and Pollution Research*, 30(22), 61324-61339. <https://doi.org/10.1007/s11356-021-18454-7>
- Peng, J., & Zheng, Y. (2021). Does environmental policy promote energy efficiency? Evidence from China in the context of developing green finance. *Frontiers in Environmental Science*, 9, 733349. <https://doi.org/10.3389/fenvs.2021.733349>
- Ren, X., Shao, Q., & Zhong, R. (2020). Nexus between green finance, non-fossil energy use, and carbon intensity: Empirical evidence from China based on a vector error correction model. *Journal of Cleaner Production*, 277, 122844. <https://doi.org/10.1016/j.jclepro.2020.122844>
- Tolliver, C., Fujii, H., Keeley, A. R., & Managi, S. (2021). Green innovation and finance in Asia. *Asian Economic Policy Review*, 16(1), 67-87. <https://doi.org/10.1111/aepr.12320>
- Udeagha, M. C., & Muchapondwa, E. (2023). Green finance, fintech, and environmental sustainability: fresh policy insights from the BRICS nations. *International Journal of Sustainable Development & World Ecology*, 30(6), 633-649. <https://doi.org/10.1080/13504509.2023.2183526>
- Udeagha, M. C., & Ngepah, N. (2023). The drivers of environmental sustainability in BRICS economies: do green finance and fintech matter? *World Development Sustainability*, 3, 100096. <https://doi.org/10.1016/j.wds.2023.100096>
- Xiong, Q., & Sun, D. (2023). Influence analysis of green finance development impact on carbon emissions: an exploratory study based on fsQCA. *Environmental Science and Pollution Research*, 30(22), 61369-61380. <https://doi.org/10.1007/s11356-021-18351-z>
- Yu, H., Jiang, Y., Zhang, Z., Shang, W.-L., Han, C., & Zhao, Y. (2022). The impact of carbon emission trading policy on firms' green innovation in China. *Financial Innovation*, 8(1), 55. <https://doi.org/10.1186/s40854-022-00359-0>
- Zhu, Y., Zhang, J., & Duan, C. (2023). How does green finance affect the low-carbon economy? Capital allocation, green technology innovation and industry

structure perspectives. *Economic Research-Ekonomska Istraživanja*, 36(2).
<https://doi.org/10.1080/1331677X.2022.2110138>