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How the “Village Merger and Resettlement” Policy Reshapes Agricultural Carbon Emissions: An Analysis of Effects and Mechanisms from Chinese Rural Practices

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Abstract: The “Village Merger and Resettlement” policy, as an adjustment of rural living arrangements and spatial organization, addresses the rural population outflow against the backdrop of global urbanization and industrialization. It has profound impacts on agricultural resource allocation, technological innovation, and carbon emissions, playing a significant role in achieving green and low-carbon development alongside high-quality agricultural advancement. This paper conducts an empirical analysis based on panel data from 30 provincial regions in China from 2001 to 2022 (excluding Tibet, Hong Kong, Macau, and Taiwan) to examine the impact of the “Village Merger and Resettlement” policy on agricultural carbon emissions. It explores the mediating effects of agricultural informatization and the integration of agricultural industries and analyzes the moderating roles of government environmental regulations and public environmental participation. The findings indicate that the “Village Merger and Resettlement” policy significantly suppresses agricultural carbon emissions, with the effects being more pronounced in major grain-producing areas, regions with flat terrain, convenient transportation, and higher levels of technology and labor, as well as on the east side of the Hu Huanyong Line, where the degree of agricultural industrial restructuring is lower and government policy enforcement is stronger. The mediation analysis reveals that the processes of agricultural informatization and industry integration both play positive transmission roles in the policy’s impact on reducing agricultural carbon emissions. The moderation analysis shows that compulsory government environmental regulations have a negative moderating effect on the policy’s carbon emission suppression, while public environmental participation has a positive moderating effect. Therefore, in implementing the “Village Merger and Resettlement” policy, it is necessary to tailor strategies to local conditions, make full use of agricultural informatization resources, reasonably plan the integration of agricultural industries, and accurately grasp the roles of environmental regulations to promote the positive effects on green, low-carbon, and high-quality agricultural development.

Keywords: village merger and resettlement; agricultural carbon emissions; agricultural informatization; agricultural industrial integration; public environmental participation; government environmental regulation



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1. Introduction

Under the framework of global climate governance and the sustainable development agenda, the issue of agricultural carbon emissions has garnered increasing attention from the international community. A joint report in 2022 by the Food and Agriculture Organization (FAO) and the National Oceanic and Atmospheric Administration (NOAA) stated that agricultural activities contribute 10–21% of global greenhouse gas emissions. Major sources include methane emissions from livestock and nitrous oxide emissions from arable land, rice cultivation, and fertilizer use. This issue not only exacerbates global warming and the frequency of extreme weather events but also highlights the deep contradictions between traditional agricultural production models and the ecological environment's carrying capacity. Against the temperature control targets set by the Paris Agreement, carbon reduction in the agricultural sector has become vital for countries to achieve carbon neutrality. As the world's largest agricultural producer and carbon emitter, China's agricultural sector has developed a high-input high-intensity production system to support urbanization and industrialization. Although this system has ensured food security, it has also resulted in high carbon emission intensity per unit area. Achieving a low-carbon transition in agriculture while ensuring food security is crucial not only for China's "dual carbon" goals but also holds significant strategic importance for global climate governance.

Currently, the international academic community is exploring agricultural carbon reduction pathways from multiple dimensions. Mainstream research focuses on three aspects: technological innovation, industrial structure optimization, and policy regulation. Digital agricultural technologies, such as precision fertilization and smart irrigation, significantly reduce resource misallocation (Tian and Liao, 2024) [1]. Industrial integration enhances the added value by extending agricultural industrial chains, achieving vertical compression of the carbon footprint (Shi, 2023) [2]. Environmental regulation and green finance, through institutional incentives, direct production factors towards low-carbon fields (Zheng et al., 2024) [3]. Cross-national comparative studies further reveal the demonstrative effects of organizational production by Dutch agricultural cooperatives (Bijman, 2016) [4] and Japan's "Sixth Industrialization" model in carbon reduction (Tanaka, 2021) [5]. However, the existing literature relatively lacks attention to the institutional variables of rural living patterns and the degree of organization, particularly the systemic analysis of how the spatial restructuring of residence impacts carbon emissions through the reallocation of production factors. This theoretical blind spot often leads to policy designs that overlook the constraints of rural social foundations on technology adoption and institutional change, making it difficult to explain why the same reduction technologies exhibit varied performance across different regions.

In this context, the "Village Merger and Resettlement" policy implemented in China offers a unique research perspective for resolving the above-mentioned theoretical predicaments. The policy reconstructs the spatial form and social organization structure of rural areas through village mergers, land consolidation, and centralized housing. In essence, it is a systematic adjustment of the relationship between people and land, as well as the relations of production. Since its pilot implementation in the 1990s, the "Village Merger and Resettlement" policy has evolved from a temporary measure to address the "hollow village" problem into an important tool for optimizing resource allocation within the Rural Revitalization Strategy. International experience indicates that residential centralization can influence carbon emissions through three pathways: first, contiguous land management reduces the energy consumption of agricultural machinery operations (Wu et al., 2022) [6]; second, the centralized provision of public services diminishes the carbon lock-in effect associated with redundant infrastructure construction; and lastly, social organization enhances the enforcement efficiency of environmental regulations (Park and Kim, 2022) [7].

However, the existing research has largely been confined to case studies or cross-sectional data, lacking in-depth exploration of the dynamic effects of policies and spatial heterogeneity. There is even less research that reveals the transmission mechanisms of emerging factors such as informatization and industrial integration.

This study uses panel data from 30 Chinese provinces from 2001 to 2022 (excluding Tibet, Hong Kong, Macau, and Taiwan) and employs a two-way fixed-effect model and an instrumental variable method to systematically analyze the impact and mechanism of the “Village Merger and Resettlement” policy on agricultural carbon emissions. Compared to the existing literature, the marginal contributions of this paper lie in three areas: (1) it breaks away from the traditional technology determinism analytic framework by introducing an institutional change perspective into the study of agricultural carbon reduction, revealing the structural emission reduction effects achieved through factor reallocation via residential restructuring; (2) it constructs an integrated analytic framework of “policy impact–mediation transmission–contextual adjustment” and, for the first time, verifies the dual mediation mechanisms of agricultural informatization and industry integration, as well as the moderating effects of formal/informal environmental regulations; and (3) it applies spatial econometric methods to reveal the gradient diffusion characteristics of policy effects, providing empirical evidence for designing region-specific policies. These innovative studies not only enrich the research paradigm of low-carbon agricultural transition but also offer significant reference value for rural green governance in developing countries.

The practical significance of this paper is reflected on three levels: the policy design level—quantitatively assessing the carbon reduction performance of the “Village Merger and Resettlement” policy can provide a decision-making basis for the coordinated advancement of spatial planning and rural revitalization strategies; the practical implementation level—by revealing the mediating roles of informatization and industry integration, it highlights the priority directions for digital village construction and the development of the tertiary industry integration; and the international governance level—China’s experience offers new insights for the global community, especially for developing countries, in resolving the dilemma between food security and climate governance. Amid the dual challenges of an escalating global food crisis and emerging carbon tariff barriers, this study uncovers a “residential centralization–organized production–low-carbon transition” pathway, presenting an institutional innovation model for reconstructing a more climate-resilient agricultural production system.

The structure of the following text is arranged as follows: the second part constructs the theoretical framework and proposes research hypotheses; the third part explains the research methodology and data sources; the fourth part presents empirical results and mechanism testing; and the fifth part summarizes the research conclusions and offers policy recommendations. By systematically analyzing the environmental effects of the “Village Merger and Resettlement” policy, this paper attempts to answer a core question: How does the reconstruction of rural space become an implicit driver for low-carbon agricultural transition by reshaping the efficiency of production factor allocation? Answering this question will help reassess the foundational role of rural governance in climate response strategies.

2. Theoretical Mechanism and Research Hypotheses

To delve into the impact of the “Village Merger and Resettlement” policy on agricultural carbon emissions and its underlying mechanisms, this study constructs a comprehensive theoretical analysis framework encompassing direct effects, mediating effects, and moderating effects. The inherent logic of this framework considers the “Village Merger and Resettlement” policy as the trigger of institutional change, systematically revealing the multidimensional paths and boundary conditions of policy effects through a “three-tiered

structure” analysis model: “direct effects–mediating transmission–contextual moderation” (Figure 1). The value of this framework is reflected in three aspects: it surpasses the traditional single-mechanism analysis paradigm by integrating institutional economics, industrial ecology, and environmental regulation theory, thereby constructing a multidimensional explanatory system of “spatial reconstruction–technological empowerment–institutional synergy”; by distinguishing between two types of mediating mechanisms—informatization (technology diffusion) and industrial integration (organizational change)—it clearly elucidates the differentiated paths to achieving agricultural carbon reduction; and by incorporating both formal and informal regulations as moderating variables, it reveals the dependence of the “Village Merger and Resettlement” policy’s carbon reduction effects on the institutional environment. This provides theoretical support for establishing a diversified environmental governance system, addressing the current research gap regarding insufficient attention to institutional context moderation.

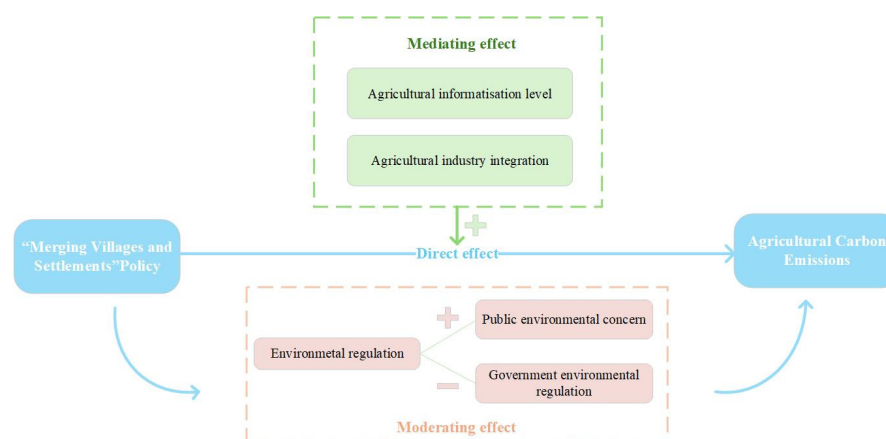


Figure 1. Mechanism of the Impact of the “Village Merger and Resettlement” Policy on Agricultural Carbon Emissions.

2.1. Direct Impact of the “Village Merger and Resettlement” Policy on Agricultural Carbon Emissions

The “Village Merger and Resettlement” policy demonstrates a multidimensional synergistic mechanism for reducing agricultural carbon emissions and can be seen as a systematic emission reduction process driven by institutional change. First, from the perspective of the scale effects of optimal resource allocation, based on new institutional economics theory, land fragmentation caused by traditional dispersed living is a systemic root of high agricultural carbon emissions (North, 1990) [8]. Through village mergers and land consolidation, the “Village Merger and Resettlement” policy breaks the spatial constraints of the traditional smallholder economy, forming large-scale production units with contiguous operations. This significantly reduces energy consumption in agricultural machinery operations and minimizes the carbon lock-in effect of redundant infrastructure construction (Wu et al., 2022) [6]. For example, the case of Shouguang in Shandong shows that after village mergers, irrigation energy consumption per unit area decreased by 28%, confirming the improvement effect of spatial agglomeration on resource utilization efficiency. Second, regarding the accelerated mechanism of technology diffusion, according to technological innovation theory, the “Village Merger and Resettlement” policy, through community networks formed by concentrated housing, lowers the promotion cost of precision agriculture technologies, increases the critical scale for technology adoption, and establishes a positive feedback loop of “technology adoption–emission reduction and efficiency gains–reinvestment of benefits” (Tian and Liao, 2024) [1]. Empirical research, such as in Yancheng, Jiangsu, shows that after merging villages, the coverage rate of agricultural IoT rose to 76%, while fertilizer usage intensity decreased by 19%. Third, from

the perspective of the low-carbon synergistic effects of industrial clusters, the “Village Merger and Resettlement” policy, by reconstructing the spatial organization of agricultural production, promotes the localization of the “planting–processing–distribution” industrial chain, resulting in shortened agricultural product transport distances, increased recycling of agricultural waste, and significant diffusion effects of green technologies (Xia, 2024) [9]. The experience of Dutch agricultural cooperatives demonstrates that this spatial agglomeration of industrial chains can reduce the carbon emission intensity per unit output value by 23% (Bijman, 2016) [4]. Lastly, concerning the dual incentive effects of the institutional environment, the “Village Merger and Resettlement” policy, through innovations in land entitlement and transfer systems, enhances local governments’ environmental regulation capabilities and provides a fiscal foundation to support green subsidies, thereby effectively promoting the low-carbon transition of agriculture.

Therefore, Hypothesis 1 is proposed:

Hypothesis 1. *Promoting the “Village Merger and Resettlement” policy can significantly curb the increase in agricultural carbon emissions.*

2.2. “Village Merger and Resettlement” Policy, Agricultural Informatization, and Agricultural Carbon Emissions

The impact of the “Village Merger and Resettlement” policy on carbon emission reduction is not directly transmitted through a linear pathway but rather achieves dual breakthroughs in technological empowerment and behavioral change through agricultural informatization as a key mediating variable. First, the upgrading of infrastructure and the bridging of the digital divide are key factors in achieving this breakthrough. Through the centralization of residential forms, the laying costs of digital infrastructure such as broadband networks and Internet of Things (IoT) base stations are significantly reduced. As a result, the 5G coverage rate in merged villages is higher than that in scattered villages, providing a solid hardware foundation for the application of precision agriculture technologies (Tian and Liao, 2024) [1]. Residential agglomeration also forms a “digital learning community”, and it accelerates the renewal of farmers’ technological awareness through the neighborhood demonstration effect. For example, the acceptance of intelligent irrigation systems has increased (Shi, 2023) [2]. Second, agricultural informatization has enabled a data-driven precision emission reduction model. Through the use of agricultural informatization platforms, multi-source data such as meteorological, soil, and market information are integrated to build an intelligent management system for “monitoring–analysis–decision-making”. For example, in Lankao, Henan, digital farms use remote sensing monitoring to dynamically optimize the application of nitrogen fertilizer, thereby reducing nitrous oxide emissions [10]. This transformation of “substituting factors with data” breaks the traditional high-carbon path dependency of agriculture, which relies on experiential decision-making. In addition, supply chain transparency and carbon footprint traceability have become possible. The introduction of blockchain technology enables the quantification and traceability of the carbon footprint of agricultural products. Consumers can obtain carbon emission data from the production process by scanning a QR code. This market-driven mechanism prompts producers to adopt low-carbon technologies. The case of JD Farm shows that the premium rate of agricultural products with carbon labels has increased, forming a virtuous cycle of “low-carbon certification–value addition–investment in emission reduction” (Lin et al., 2025) [11].

Based on this, Hypothesis 2 is proposed:

Hypothesis 2. *Promoting the “Village Merger and Resettlement” policy can promote agricultural carbon emission reduction by deepening the level of agricultural informatization.*

2.3. “Village Merger and Resettlement” Policy, Agricultural Industry Integration, and Agricultural Carbon Emissions

The “Village Merger and Resettlement” policy drives the integration of agricultural industries, reconstructs the material metabolism rules and value-creation logic of the agricultural system, and forms a multidimensional and collaborative carbon emission reduction mechanism. In the vertical dimension, the large-scale integration of land provides a spatial carrier for the deep integration of agriculture with energy and manufacturing. For example, the “agri-photovoltaic complementarity” model enhances the output per unit of land while reducing carbon emissions through the synergy of photovoltaic power generation and shade-tolerant crop cultivation. Meanwhile, the biomass energy industry chain, by centralizing the treatment of straw and livestock manure to generate biogas, replaces coal combustion and forms a closed-loop material metabolism system (Cheng, 2019; Li et al., 2024) [12,13]. In the horizontal dimension, the integration of agriculture with the service industry reshapes production incentives through the marketization of ecological values. For example, the “agriculture + cultural tourism” model leverages tourists’ awareness of carbon footprints to drive the transition to organic farming, thereby reducing the intensity of chemical fertilizer use. Meanwhile, the “agriculture + education” model promotes transparent production through consumer participation and supervision, thereby lowering the carbon intensity per unit of product (Zhan and Xu, 2019; Lin et al., 2025) [11,14]. Industrial integration further triggers low-carbon substitution of production factors. Replacing labor with technology enables precise pesticide application by unmanned aerial vehicles (UAVs) in plant protection, reducing chemical inputs. Replacing land with capital promotes the development of vertical farms, reducing land occupation and improving energy efficiency. Replacing experience with data optimizes irrigation plans through AI models, reducing the carbon emission intensity (Li and Shi, 2024; Xia, 2024; Ma et al., 2024) [9,10,15]. Spatial reconstruction gives rise to two types of industrial networks: geographical agglomeration and virtual collaboration. The former reduces carbon emissions from cold chain logistics by shortening the supply chain, while the latter reduces carbon emissions associated with circulation losses by integrating scattered production capacity through e-commerce platforms (Wu et al., 2022; Li et al., 2024) [6,13]. This process is essentially the reconstruction of the agricultural production function—where the marginal emission reduction effect of traditional factors diminishes while emerging factors such as technology and data drive the decoupling of carbon emissions from economic growth. The emission reduction effect exhibits dynamic evolutionary characteristics: in the short term, it relies on improvements in resource utilization efficiency, while in the medium-to-long term, it achieves fundamental metabolic rule changes through technological innovation and institutional change, providing a systemic solution for the rural industrial revolution under the carbon neutrality goal.

Based on this, Hypothesis 3 is proposed:

Hypothesis 3. *Promoting the “Village Merger and Resettlement” policy can facilitate agricultural carbon emission reduction by deepening the level of agricultural industry integration.*

2.4. Moderating Role of Environmental Regulation in the Impact of the “Village Merger and Resettlement” Policy on Agricultural Carbon Emissions

Curbing the increase in agricultural carbon emissions depends not only on optimizing resource allocation and achieving technological advancement through the “Village Merger

and Resettlement” policy but also on environmental regulation as an external constraining mechanism (Zhang and Wang, 2020) [16]. Environmental regulation theory suggests that government-mandated environmental regulations, through laws, regulations, and policy measures, promote compliance with environmental standards, reduce pollution emissions, and incentivize investment in environmental protection technologies and green technological progress. These measures not only directly constrain polluting behaviors but also enhance energy utilization efficiency and overall production, thereby facilitating agricultural carbon reduction.

Moreover, public environmental concern, as an informal environmental regulation, exerts pressure through social opinion, media exposure, and consumer preferences, driving the adoption of environmentally friendly production methods (Zhan and Xu, 2019) [14]. Higher levels of government environmental regulation and public environmental pressure can amplify the impact of the “Village Merger and Resettlement” policy on reducing agricultural carbon emissions, thereby more significantly restraining the increase in agricultural carbon emissions (Xie et al., 2021) [17]. Conversely, lower levels of environmental regulation and public concern result in a lack of motivation for environmental investment and technological innovation, making it challenging to effectively achieve agricultural carbon reduction.

Based on this, Hypothesis 4 is proposed:

Hypothesis 4. *Environmental regulation significantly moderates the impact of the “Village Merger and Resettlement” policy on agricultural carbon emissions.*

3. Model Construction, Variable Description, and Data Source

3.1. Construction of the Benchmark Model

In this study, the following econometric model is adopted to evaluate the potential impact of village consolidation and merger on agricultural carbon emissions:

$$acee_{it} = a_0 + a_1 magnitude_{it} + a_2 controls_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (1)$$

In this model, subscript i represents the province and t represents the year. $magnitude_{it}$ denotes the degree of the “Village Merger and Resettlement” policy in province i in year t ; $acee_{it}$ represents the agricultural carbon emissions in province i in year t ; $controls_{it}$ is a series of control variables; μ_i represents the province fixed effects; γ_t represents the year fixed effects; and ε_{it} is the random disturbance term, representing the effect of unobservable factors on the model beyond the mentioned variables. In this context, a_1 is the regression coefficient of the variable of interest in this study. If the coefficient a_1 is significantly negative, it can be inferred that the degree of the “Village Merger and Resettlement” policy can suppress the increase in agricultural carbon emissions, supporting Hypothesis 1 of this paper.

Due to certain limitations of the stepwise regression method, this study only discusses whether the “Village Merger and Resettlement” policy has a significant impact on the mediating variables (the level of agricultural informatization and the degree of agricultural industrial integration). The model is constructed as follows:

$$m_{it} = \beta_1 + \beta_2 magnitude_{it} + \beta_3 controls_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (2)$$

In this context, m_{it} represents the mediating variables (agricultural informatization and agricultural industry integration). The meanings of other variables remain the same as in the baseline regression.

Drawing on the research of Liu et al. (2023) [18], we use a two-stage strategic model to discuss the transmission mechanism of the “Village Merger and Resettlement” policy on agricultural carbon emissions. In the first stage, this paper utilizes a fixed-effect model to examine the impact of implementing the “Village Merger and Resettlement” policy on agricultural informatization and agricultural industry integration. In the second stage, the estimated fitted values of agricultural informatization and agricultural industry integration from the first stage \hat{m}_{it} are used to predict agricultural carbon emissions.

$$m_{it} = v_1 + v_2 \text{magnitude}_{it} + v_3 \text{controls}_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (3)$$

$$acee_{it} = \varphi_1 + \varphi_2 \hat{m}_{it} + \varphi_3 \text{controls}_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (4)$$

Here, m_{it} represents the mediating variables, including agricultural informatization and agricultural industry integration; \hat{m}_{it} denotes the fitted values of the mediating variables (agricultural informatization and agricultural industry integration). The meanings of other variables are the same as in the baseline regression.

Finally, environmental regulation is incorporated into the analytical framework of “merging villages and settlements” and agricultural carbon emissions to examine whether environmental regulation has a moderating effect on the above-mentioned impact process to test H4. The moderating effect model is specified as follows:

$$acee_{it} = \lambda_1 + \lambda_2 \text{magnitude}_{it} + \lambda_3 Z_{it} + \lambda_4 \text{magnitude}_{it} \times Z_{it} + \lambda_5 \text{controls}_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (5)$$

Among them, Z_{it} is the moderating variable, specifically, environmental regulation (this paper subdivides it into government environmental regulation and public environmental concern). $\text{magnitude}_{it} \times Z_{it}$ is the interaction term of the degree of “merging villages and settlements” and the moderating variable, and its coefficient is the focus of this paper. The meanings of the other variables are consistent with those in the benchmark model.

3.2. Variable Definition

3.2.1. Core Explanatory Variable: The “Village Merger and Resettlement” Policy (magnitude_{it})

In this study, the magnitude of the “Village Merger and Resettlement” policy implementation is taken as the core explanatory variable. The design of its measurement method considers both the characteristics of policy practice and data availability. Given that this policy functions as an administratively driven urbanization strategy, significant heterogeneity exists in its implementation timing and intensity across provinces (Wang, 2022) [19]. Traditional binary dummy variables struggle to capture the dynamic characteristics of this gradual reform. The policy implementation process involves integrating dispersed villages into more centralized communities, which directly manifests as a reduction in the number of administrative villages. Hence, constructing a continuous policy variable based on the magnitude of changes in the number of villages (as calculated by the method shown in Equation (5)) is inherently reasonable. While this indicator might not fully encompass deeper institutional changes such as land tenure restructuring and community governance transformation, it effectively depicts the gradient differences and dynamic cumulative effects of policy implementation as a temporally and spatially continuous observable proxy variable. This makes it particularly suitable for analyzing long-period panel data, providing a feasible empirical entry point for evaluating the environmental effects of gradual institutional changes.

$$\text{magnitude}_{it} = \ln(1 - \Delta \text{village}_{it}) \quad (6)$$

Equation (5) represents the difference between the number of villages in province i in period t and that in period $t - 1$. Here, the number of village committees is used as the measurement standard. These data have been logarithmically transformed to address the heteroscedasticity issue. The difference value may be negative because the number of administrative villages generally shows a downward trend. To ensure the effectiveness of the logarithmic transformation, we take the negative value plus 1. Overall, $magnitude_{it}$ serves as a positive indicator. The higher its value, the greater the reduction in the number of administrative villages, thus reflecting a higher degree of implementation of the “village consolidation and merger” policy.

3.2.2. Explained Variable: Agricultural Carbon Emissions ($acee_{it}$)

This study utilizes the analytical framework developed by Ding et al. (2021) [20] to estimate agricultural carbon emissions at the provincial level based on the IPCC carbon emission coefficient method. Specifically, this study identifies the main sources of agricultural carbon emissions as follows: (1) carbon emissions directly or indirectly caused by the input of agricultural materials such as fertilizers, pesticides, and plastic mulch; (2) carbon emissions resulting from the diesel consumption of agricultural machinery; (3) carbon emissions arising from the electricity used for irrigation; and (4) the loss of organic carbon caused by soil tillage. Accordingly, this study employs the IPCC carbon emission coefficient method, drawing from the research of Li and Zhang (2012) [21], among others, to primarily examine the carbon emissions directly or indirectly caused by six carbon sources in crop production: fertilizers, pesticides, plastic mulch, diesel, irrigation, and tillage. This study then calculates the carbon emissions from crop production using the relevant carbon emission coefficients for each source, with the specific formula being:

$$E = \sum E_j \sum T_j \times \varepsilon_j \tag{7}$$

In Formula (6), E represents the total amount of agricultural carbon emissions, T_j denotes the input quantity of the j carbon source, and ε_j represents the carbon emission coefficient of the j -th carbon source. The main agricultural carbon sources and their emission coefficients are shown in Table 1. This method is used to calculate provincial-level agricultural carbon emissions.

Table 1. Main Agricultural Carbon Emission Sources and Carbon Emission Coefficients.

Carbon Source	Carbon Emission Coefficient	Reference Source
Diesel	0.59 kg/kg	IPCC2013 [22]
Chemical Fertilizer	0.89 kg/kg	Oak Ridge National Laboratory, USA
Pesticide	4.93 kg/kg	Oak Ridge National Laboratory, USA
Agricultural Film	5.18 kg/kg	Institute of Agricultural Resources and Ecological Environment, Nanjing Agricultural University
Irrigation	266.48 kg/hm ²	Duan et al. (2011) [23]
Plowing	312.60 kg/km ²	Li et al. (2012) [21]

To ensure the accuracy of the empirical results, this study further employs agricultural carbon emission intensity (aei) and agricultural carbon emission density (acd) as alternative dependent variables for robustness checks. Referring to the research of Tian and Yin (2022) [24], agricultural carbon emission intensity is measured by the carbon emissions corresponding to every ten thousand yuan of agricultural output value, and it is log-transformed by adding one to the AEI. Agricultural carbon emission density is characterized by the carbon emissions per hectare of agricultural land.

3.2.3. Control Variables

Given the complex effects of micro-level rural and macroeconomic environments on agricultural carbon emissions, this study, referencing the work of Wang and Ma (2024) [25] and Guo et al. (2024) [26], selects the following control variables to ensure the comprehensiveness and accuracy of the analysis.

At the rural level: (1) agricultural machinery level (*itmc*)—measures the level of agricultural mechanization, expressed as the ratio of the total rated power of all agricultural machinery to the population; (2) agricultural production (labor productivity)—reflects the output created per unit of labor force, measured by dividing the total agricultural output by the number of people engaged in agricultural labor; (3) rural Engel’s coefficient (*RE*)—measures the consumption level of rural residents, calculated by dividing the per capita expenditure on food, tobacco, and alcohol by the total per capita consumption expenditure; and (4) per capita income of rural residents (*income*)—measured by the sum of wage income, net operating income, net property income, and net transfer income, with a logarithmic transformation by adding one to eliminate dimensional influence.

At the regional level: (1) R&D foundation (*R&D*)—measures the scale and level of regional independent innovation investment using provincial research and development (RD) expenditure intensity; (2) innovation level (*innov*)—reflects the overall level and development of technological innovation, indicated by the number of invention patent applications accepted in the province; and (3) energy structure (*energy*)—directly influences the final energy use methods of various sectors of the national economy and reflects people’s living standards, measured by the proportion of each province’s electricity consumption to the national total, trimmed at the 1% level.

By selecting these control variables, this study aims to comprehensively capture the multiple factors affecting agricultural carbon emissions at the provincial level, ensuring the robustness and explanatory power of the model.

3.2.4. Mediating Variables

- ① Agricultural informatization level. This study references the research by Liu Shuai (2021) [27] and uses the number of rural broadband subscribers to measure the level of agricultural informatization. Broadband access is one of the main indicators of internet development, and since this metric is specifically targeted at rural areas, it effectively reflects the level of agricultural informatization.
- ② Agricultural industry integration. Referring to the study by Wang and Li (2019) [28], this paper constructs an evaluation index system for rural industry integration from three dimensions: the extension of the agricultural industry chain, the multifunctional development of agriculture, and the integration of agricultural services (see Table 2). Furthermore, the entropy weight method is used to calculate the index, objectively reflecting the degree of rural industry integration development.

Table 2. Evaluation Index System for Rural Industry Integration.

First-Level Index	Second-Level Index	Measurement Method	Unit	Index Direction
Agricultural Industry Chain Extension	Proportion of Agricultural Product Processing Industry	Main business income of agricultural product processing industry/Total agricultural output value	%	+
	Scale of Farmers’ Professional Cooperatives	Number of farmers’ professional cooperatives per 10,000 individuals of a rural population	unit	+

Table 2. Cont.

First-Level Index	Second-Level Index	Measurement Method	Unit	Index Direction
Agricultural Multifunctionality	Proportion of Leisure Agriculture	Annual business income of leisure agriculture/Total output value of primary industry	%	+
	Level of Facility Agriculture	Total area of facility agriculture/Cultivated land area	%	+
Integrated Development of Agricultural Service Industries	Proportion of Agriculture, Forestry, Animal Husbandry, and Fishery Service Industry	Total output value of agriculture, forestry, animal husbandry, and fishery service industry/Total output value of primary industry	%	+

3.2.5. Moderating Variables

- ① Public environmental concern (*LnBSHI*): Public environmental awareness reflects citizens' cognition of environmental issues, the intensity of their concern, and their willingness to participate in environmental protection activities. In modern society, this awareness is manifested through environmental actions, attention to environmental issues, and sensitivity to environmental policies and technological advancements. This study adopts the approach of Yuan and Xie (2014) [29] and selects a series of indicators such as income level, education level, population density, and age structure to comprehensively measure the intensity of informal regulation in each province. The specific indicators are explained as follows: (1) Income level: Regions with higher income levels have stronger public demand for a high-quality living environment. This study uses the average wage of urban employees to measure the income level of each province. (2) Education level: Generally, the higher the education level, the stronger the environmental awareness and the higher the public's attention to environmental issues. This study uses the proportion of employees with higher education (college level and above) in each province as a measurement indicator. (3) Population density: Higher population density signifies that more people are affected by the negative externalities of environmental pollution, resulting in greater participation in informal regulation. (4) Age structure: Younger people tend to be more concerned about pollution issues and are more involved in non-governmental environmental organizations. This study uses the proportion of the population under 15 years of age as the age structure variable.
- ② Government environmental regulation (*LnERI*): In academia, there is no unified measure of environmental regulation. Generally, the measurement of environmental regulation focuses on two angles: (1) Intensity of environmental regulation: This typically reflects the cost of pollution control for enterprises. The greater the intensity of environmental regulation, the higher the pollution control costs for enterprises. Fan et al. (2017) [30] and Morgenstern (2002) [31] used the ratio of total investment in industrial pollution control to industrial value added and industry pollution reduction investment as the standards for measuring environmental regulation. Lou (2016) [32], from the perspective of the enterprise scale, used the pollution control cost per unit output to measure the intensity of environmental regulation. The amount collected in pollution discharge fees is also an important indicator. (2) Effects of environmental regulation: The implementation of environmental regulation can reduce pollutant emissions. Zhang and Wei (2014) [33] used single indicators such as the compliance rate of industrial wastewater discharge, sulfur dioxide removal rate, and industrial dust removal rate to measure the effects. (3) Comprehensive index method: Li et al. (2014) [34] integrated indicators such as the sulfur dioxide removal rate and industrial dust removal rate into a single indicator to measure the level of environmental

regulation. To ensure comprehensive and scientific measurement, this study uses the method of Liu and He (2021) [35], measuring the intensity of environmental regulation from 2001 to 2022 in each province by dividing the completed investment in industrial pollution control by the industrial value added.

3.3. Data Description

This study selects 30 provinces (excluding Hong Kong, Macau, Taiwan, and the Tibet Autonomous Region) as the subjects of analysis, covering the period from 2001 to 2022. Some control variables underwent winsorization and logarithmic transformation to eliminate the impact of dimensionality. Following this selection process, a total of 660 valid sample observations were obtained.

The core explanatory variable data were sourced from the “China Statistical Yearbook”. The data for the dependent variable primarily come from the “China Rural Statistical Yearbook” for the years 2001 to 2022, as well as provincial statistical yearbooks of the 30 provinces (municipalities and autonomous regions) in mainland China. Control variable data were obtained from the “China Rural Statistical Yearbook”, the “China Population and Employment Statistical Yearbook”, the Wind database, and the China Economic and Social Big Data Research Platform. Additional data sources include the EPS database, the CSMAR database, the “China Environmental Yearbook”, and local government work reports. The statistical analysis results of all variables are detailed in Table 3.

Table 3. Descriptive Statistics.

Variable	N	Average Value	Standard Deviation	Minimum Value	Maximum Value
<i>acee</i>	660	313.576	224.177	13.914	995.753
<i>magnitude</i>	660	1.708	0.934	0	4.172
<i>itmc</i>	660	114.659	52.123	22.003	314.438
<i>apl</i>	660	24.400	11.087	4.959	68.041
<i>R&D</i>	660	1.361	1.150	−0.941	6.833
<i>RE</i>	660	38.797	10.554	7.100	80.648
<i>income</i>	660	85.164	79.164	−45.790	397.290
<i>innov</i>	660	8.615	1.927	3.013	12.403
<i>aei</i>	660	−0.372	0.546	−1.732	0.814
<i>acd</i>	660	0.066	0.027	0.021	0.165
<i>ainformation</i>	660	15.738	31.732	−92.790	156.070
<i>ind</i>	660	1.921	1.967	−4.784	8.589
<i>siclu</i>	660	0.104	0.086	0.025	0.846
<i>LnERI</i>	660	0	0.341	−0.441	1.498
<i>LnBSHI</i>	660	1.989	1.184	0.694	9.675

4. Empirical Analysis

4.1. Benchmark Regression

This study employs a two-way fixed-effect model to estimate the parameters of Equation (1), with the estimation results reported in Table 4. In the analysis, column (1) is used as the baseline regression result for a detailed discussion. To verify the robustness of the baseline model, estimation results for the random-effects model (RE) and system GMM are reported in columns (2) and (3), respectively. The baseline regression results in column (1) show that the “Village Merger and Resettlement” policy is significantly negatively correlated with agricultural carbon emissions. Specifically, for every one-unit increase in the “Village Merger and Resettlement” policy, agricultural carbon emissions decrease by an average of 5.952 units. This finding supports Hypothesis 1, indicating that the “Village Merger and Resettlement” policy plays a positive role in reducing agricultural carbon emissions at the provincial level.

Table 4. Benchmark Regression Results.

Variable	(1) FE	(2) RE	(3) GMM
magnitude	−5.952 *** (−3.03)	−5.359 ** (−2.07)	−147.879 * (−1.77)
Lacee			0.753 ** (2.48)
controls	Yes	Yes	Yes
region fixed effect	Yes	Yes	Yes
time fixed effect	Yes	Yes	Yes
AR(1)			0.093
AR(2)			0.480
Hansen			0.959
R ²	0.978	0.576	
N	660	660	660

Note: the significance levels of 1%, 5%, and 10% are indicated by ***, **, and *, respectively. The values in parentheses are robust standard errors clustered at the provincial level. The corresponding *p*-values of AR (1), AR (2), and Hansen tests are provided.

The ecological modernization theory and cluster effect theory can explain this result. First, ecological modernization theory suggests that through technological innovation and institutional changes, traditional agriculture can shift towards a more sustainable development model. The “Village Merger and Resettlement” policy facilitates the concentrated application of agricultural technologies such as smart irrigation, precision fertilization, and mechanized production. These technologies can significantly improve resource utilization efficiency and reduce the use of fertilizers and water, thus lowering carbon emissions. Additionally, the centralized living model makes it easier for the government to implement and manage environmental policies, such as land use planning and agricultural subsidies, which help guide farmers towards low-carbon and sustainable agricultural practices. Second, the policy can enhance the resilience of the agricultural ecosystem, allowing it to better cope with climate change and environmental pressures, thereby more effectively maintaining ecological balance and reducing carbon emissions. Furthermore, the economic and social benefits brought about by geographical concentration enable farmers to share agricultural machinery, labor, and market resources, reducing the production costs for individual farmers. This intensive management model can reduce resource waste and redundant inputs, thereby lowering carbon emissions. In conclusion, the deepening of the “Village Merger and Resettlement” policy not only directly reduces carbon emissions from agriculture but also further improves agricultural production efficiency through technological advancement and centralized management.

4.2. Endogeneity Analysis

To reduce the possibility of endogeneity caused by omitted variables, this study incorporates numerous control variables and applies a two-way fixed-effect model (both time and individual fixed effects). This approach aims to control for unobservable factors that might interfere with empirical results across time and individual dimensions. Even so, the model may still face endogeneity issues due to bidirectional causality. To address this, we further test for endogeneity using approaches such as lagging the core explanatory variable by one period and applying the instrumental variable method.

- (1) Lagged explanatory variables: The analysis includes the one-period lag of the degree of the “Village Merger and Resettlement” policy in the regression model, as shown in column (1) of Table 5. The coefficient of the lagged term is significant at the 1% level and negatively directed, indicating that the lagged “Village Merger and Resettlement”

policy still has a suppressive effect on agricultural carbon emissions, thereby ruling out endogeneity problems caused by reverse causality.

Table 5. Endogeneity Test.

Variable	(1) acee	(2) acee
L.magnitude	−6.591 *** (−3.40)	
magnitude		−99.917 *** (−3.84)
controls	Yes	Yes
region fixed effect	Yes	Yes
time fixed effect	Yes	Yes
R ²	0.977	−0.896
N	630	660

Note: the significance levels of 1% is indicated by ***. The values in parentheses are robust standard errors clustered at the provincial level.

- (2) Instrumental variable method: To further alleviate potential endogeneity issues in the model, this study employs the instrumental variable method, selecting transportation network density as an instrument. This choice is based on two considerations: First, in terms of relevance, the expansion of transportation networks is closely related to the implementation of the “Village Merger and Resettlement” policy as such policies are typically accompanied by improvements in rural infrastructure, promoting transportation convenience and resource allocation efficiency. Second, regarding exogeneity, transportation construction is influenced by government infrastructure policies and has no direct causal relationship with changes in agricultural carbon emissions, thus meeting the exogeneity requirement for instrumental variables. The regression results in column (2) of Table 5 indicate that the negative relationship between the “Village Merger and Resettlement” policy and agricultural carbon emissions remains significant at the 1% level, further confirming the robustness of the baseline regression results. Additionally, the Kleibergen–Paap rk Wald statistic is 23.469, which is greater than the 10% maximal critical value of 16.38, ruling out the possibility of weak instrumental variables. The estimation results from the instrumental variable method further corroborate the robustness of the baseline regression results.

4.3. Robustness Test

This study employs the following methods to conduct robustness checks: (1) Exclusion of municipalities: The data from the four municipalities are excluded, considering their unique administrative resources and levels of economic and technological development. The results indicate that the regression coefficient remains negative at the 1% significance level, confirming the robustness of the findings (see Table 6, column (1)). (2) Winsorizing variables: To avoid the influence of extreme values on the results, each variable is winsorized at the 1% level before regression. The results show that the regression coefficient of the explanatory variable remains significantly negative, indicating robustness (see Table 6, column (2)). (3) Replacing the dependent variable: By removing the influence of output value and production area on agricultural carbon emissions and using agricultural carbon emission intensity (AEI) and agricultural carbon emission density (ACD) for regression, the results remain robust (see Table 6, columns (3) and (4)). These robustness check results further validate the reliability and consistency of this study’s conclusions.

Table 6. Robustness Test.

Variable	(1) acee	(2) acee	(3) aei	(4) acd
magnitude	−5.542 *** (−2.70)	−6.223 *** (−3.10)	−0.015 * (−1.65)	−0.001 * (−1.89)
controls	Yes	Yes	Yes	Yes
region fixed effect	Yes	Yes	Yes	Yes
time fixed effect	Yes	Yes	Yes	Yes
R ²	0.973	0.978	0.949	0.911
N	572	660	660	660

Note: the significance levels of 1%, and 10% are indicated by ***, and *, respectively. The values in parentheses are robust standard errors clustered at the provincial level.

4.4. Heterogeneity Analysis

4.4.1. At the Regional Level

① Heterogeneity of agricultural functional zones: Based on the functional zoning of the “National Food Security Medium and Long-term Plan Outline (2008–2020)”, this study categorizes the samples into three types: major grain-producing areas, major grain-selling areas, and balanced production and marketing areas, revealing significant spatial heterogeneity in the impact of the “Village Merger and Resettlement” policy on agricultural carbon emissions (see Table 7, columns (1)–(3) for details) (the major grain-producing areas include 13 provinces (Heilongjiang, Jilin, Liaoning, Inner Mongolia, Hebei, Henan, Shandong, Jiangsu, Anhui, Jiangxi, Hubei, Hunan, and Sichuan), the major grain-consuming areas include 7 provinces (Beijing, Tianjin, Shanghai, Zhejiang, Fujian, Guangdong, and Hainan), and the production and sales balanced areas include 10 provinces (Shanxi, Ningxia, Qinghai, Gansu, Yunnan, Guizhou, Chongqing, Guangxi, Shaanxi, and Xinjiang)). The results show that the policy effect is most pronounced in major grain-producing areas (coefficient = −9.116 *), exhibits weak significance in major grain-selling areas (coefficient = −0.269), and shows a carbon emission gain effect in balanced production and marketing areas (coefficient = 6.287 ***). This difference reflects a deep connection between the policy effects and regional functional positioning, resource endowment, and institutional capacity. The specific mechanisms are explained as follows:

Table 7. Heterogeneity at the Regional Level.

Variable	(1) Major Grain-Producing Areas	(2) Major Grain-Consuming Areas	(3) Balanced Grain Production and Sales Areas	(4) Steep-Terrain Areas	(5) Flat-Terrain Areas
magnitude	−9.116 * (−1.73)	−0.269 (−0.16)	6.287 *** (3.00)	7.099 *** (3.49)	−9.836 *** (−3.10)
controls	Yes	Yes	Yes	Yes	Yes
region fixed effect	Yes	Yes	Yes	Yes	Yes
time fixed effect	Yes	Yes	Yes	Yes	Yes
R ²	0.962	0.991	0.976	0.974	0.978
N	276	161	207	253	437

Note: the significance levels of 1%, and 10% are indicated by ***, and *, respectively. The values in parentheses are robust standard errors clustered at the provincial level.

(1) Grain-producing areas—the coupling mechanism of policy synergy and emission reduction with efficiency gains: The significant emission reduction effect in major grain-producing areas stems from the systematic collaboration between policy tools and regional functional positioning. As the core carrier of national food security, major grain-producing areas have three institutional advantages: First, consolidated land management reduces

the marginal energy consumption of agricultural machinery operations. In provinces like Shandong and Henan, the merging of villages has decreased the idle rate of agricultural machinery by 32% and reduced fuel consumption per unit area by 19% (Wu et al., 2022) [6]. Second, agricultural social service systems such as unified pest control and soil testing-based fertilization, combined with centralized living, form a technological diffusion network. For example, the agricultural technology promotion coverage rate in the Heilongjiang reclamation area increased by 31 percentage points, and fertilizer utilization efficiency improved by 27%. Last, through a “scale management–emission reduction assessment–ecological compensation” approach, they link land integration with green production targets (Zhang and Wang, 2020) [16]. This collaborative mechanism of “resource concentration–technology penetration–institutional incentive” makes major grain-producing areas a priority field for the release of policy advantages.

(2) Major grain-selling areas—the dual dilemma of agricultural marginalization and the alienation of policy objectives: The weak significance of the policy effect in major grain-selling areas reflects the structural contradictions in highly urbanized regions. In these areas, the proportion of agricultural GDP is extremely low, and the annual rate of arable land reduction is relatively high, leading to a shift in the objectives of the “Village Merger and Resettlement” policy. On the spatial dimension, more than half of the merged land is used for the construction of development zones (as seen in the case of southern Jiangsu in China), highlighting how “land urbanization” is squeezing the space available for agricultural production. From an input perspective, the hollowing out of the agricultural labor force hinders technology adoption, as evidenced by the high idle rate of smart equipment on digital farms in Zhejiang, China (Tian and Liao, 2024) [1]. This scenario confirms the transmission chain of “agricultural functional decline–distorted factor allocation–inability to apply technology”, indicating a need to reconstruct policy objective functions through carbon sink trading, urban agriculture, and other new industries to address the lack of incentives for emission reduction.

(3) Areas with balanced grain production and sales—the green paradox of scale expansion traps and institutional lag: The carbon emission gain effect in balanced production and marketing areas reveals the potential risks of extensive scale expansion. The underlying mechanism is characterized by a triple institutional mismatch: The first one is that the speed of growth at the land scale exceeds technology diffusion; for instance, in Ningxia, 85% of merged villages still employ traditional farming methods, leading to an increase in unit mechanical energy consumption. Second, there is a lack of ecological compensation, leading to the Jevons paradox; in Shaanxi’s Yulin, for example, the expansion of arable land has caused irrigation energy consumption to surge, resulting in a rebound in carbon emission intensity. Lastly, there are spatial blind spots in environmental regulation enforcement; in Yunnan, for example, the pollution monitoring coverage rate in merged villages is only 29%, and the cost of violations is lower than in traditional villages (Xie et al., 2021) [17]. These findings warn that policy implementation must establish a dynamic governance framework with “ecological carrying capacity assessment–technology adaptability diagnosis–regulation penetration enhancement” to avoid falling into the carbon emission lock-in effect under the “scale efficiency illusion”.

② Terrain heterogeneity. The heterogeneity of terrain is a crucial dimension when exploring the impact of the “Village Merger and Resettlement” policy on agricultural carbon emissions. Regions with gentle terrain have less topographical variation, which facilitates various agricultural production and management activities and enhances the stability of agricultural operations. Moreover, these areas often exhibit a higher level of industrial agglomeration, which helps to improve the economies of scale and efficiency of agricultural production, thereby further reducing the intensity of agricultural carbon emissions.

According to the research by You et al. (2018) [36], provinces are classified into steep- and gentle-terrain regions based on differences in topographical variation (the steep areas include 11 provinces (Yunnan, Inner Mongolia, Sichuan, Ningxia, Shanxi, Xinjiang, Gansu, Guizhou, Chongqing, Shaanxi, and Qinghai), and the flat areas include 19 provinces (Shanghai, Beijing, Jilin, Tianjin, Anhui, Shandong, Guangdong, Guangxi, Jiangsu, Jiangxi, Hebei, Henan, Zhejiang, Hainan, Hubei, Hunan, Fujian, Liaoning, and Heilongjiang)); group regression analysis is conducted to examine the heterogeneous impact of terrain on agricultural carbon emissions. The study results indicate that regions with gentle terrain exhibit a significant carbon reduction effect, with a coefficient of 7.099, while regions with steep terrain show a significant carbon emission enhancement effect, also with a coefficient of 7.099. The specific explanations are as follows:

The first is the mechanism for emission reduction and efficiency enhancement in areas with gentle terrain. The carbon emission reduction effect in these areas stems from the systematic synergy between large-scale agricultural operations and natural geographical conditions (Krugman, 1991) [37]. Gentle topography reduces the physical resistance to land consolidation, creating foundational conditions for optimal resource allocation: flat terrain decreases the marginal costs of agricultural machinery operations, promoting energy efficiency improvements under contiguous farming practices (Wu et al., 2022) [6]; concentrated settlements accelerate the spatial diffusion of precision agriculture technologies, driving the reduction in the use of inputs such as pesticides and fertilizers (Tian and Liao, 2024) [1]; and a strong ecological carrying capacity supports the construction of large-scale irrigation systems, achieving synergistic savings in water and energy resources. This coupling mechanism of “terrain adaptation–technological penetration” validates the decisive role of spatial accessibility in the efficiency of technology diffusion, highlighting the enabling effect of natural conditions on the positive externalities of policy environments.

The second aspect involves the diseconomies of scale and ecological constraints in steep-terrain areas. The carbon emission promotion effect in these regions reveals the rigid constraints imposed by natural capital thresholds on policy effectiveness (Costanza et al., 1997) [38]. The topographic characteristics of mountainous and hilly areas trigger three negative feedback loops: fragmented land plots increase the frequency and energy intensity of small-scale agricultural machinery operations; soil and water conservation needs limit mechanized deep plowing, forcing reliance on chemical fertilizers to maintain soil fertility (Xie et al., 2021) [17]; and ecological vulnerability exacerbates the pressure for environmental restoration after land consolidation, creating a vicious cycle of “scale expansion–ecological degradation–carbon emission rebound”. This phenomenon warns that standardized scaling policies in complex terrain areas may exceed the resilience boundaries of the system. There is an urgent need to reconstruct human–land relationships through adaptive technologies such as contour planting and biological hedges, achieving a symbiosis between ecological protection and low-carbon transformation.

4.4.2. At the Level of Resource Endowment

① Level of transportation development. The level of transportation infrastructure has a direct impact on the effectiveness of implementing the “Village Merger and Resettlement” policy in a region. It determines whether these policies can improve the agricultural production structure and increase production efficiency. In areas with good transportation conditions, convenient transport and transit conditions facilitate access to advanced agricultural technologies and knowledge, greatly enhancing agricultural production efficiency. Conversely, in areas with poor transportation conditions, the advantages brought by the “Village Merger and Resettlement” policy may be hindered, thus affecting the improvement of efficient agricultural production. Based on the calculation of road mileage data from

different provinces in China from 2001 to 2022, this study divides the sample according to the median level of transportation infrastructure to analyze the differences in the impact of the “Village Merger and Resettlement” policy on agricultural carbon emissions under different infrastructure levels. The regression analysis results show that the “Village Merger and Resettlement” policy has a significant carbon emission reduction effect in areas with advanced transportation, whereas it leads to a significant increase in carbon emissions in areas with lagging transportation. The reasons for this are given below:

The carbon emission reduction effect in areas with developed transportation stems from the complementary reinforcement between infrastructure networks and policy tools. New economic geography suggests that transportation accessibility, by reducing the costs of factor mobility, can amplify the positive externalities of economies of scale (Krugman, 1991) [37]. In the implementation of the village consolidation policy, high-density transportation networks optimize emission reduction efficiency through three pathways: First, a well-developed logistics system accelerates the coverage of agricultural socialized services (such as unified pest control and soil testing for formulated fertilization), shortening the spatial and temporal distance of technology diffusion (Tian and Liao, 2024) [1]; second, cold chain transportation and e-commerce platform integration reduce the loss of agricultural product circulation, minimizing energy waste from repeated storage and transportation (Xia, 2024) [9]; and third, transportation hub areas are more likely to attract the clustering of green technology suppliers, creating a “buzz effect” for the application of low-carbon technologies (Wu et al., 2022) [6]. This synergistic mechanism of “infrastructure–technology diffusion–market integration” validates the institutional economics proposition that “reducing transaction costs promotes technology adoption” (North, 1990) [8], highlighting the multiplier effect of transportation conditions on the benefits of policy environments.

The carbon emission promotion effect in areas with lagging transportation exposes the systemic risks caused by the lack of infrastructure. According to the theory of circular and cumulative causation, low transportation accessibility reinforces the path dependence on traditional production modes (Myrdal, 1957) [39]: First, high transportation costs for production materials force farmers to rely on decentralized storage, leading to a surge in energy consumption from frequent operations of small-scale agricultural machinery; second, spatial and temporal barriers to technology diffusion result in low utilization rates of precision agricultural equipment, making it difficult to improve the extensive use of fertilizers and pesticides (Xie et al., 2021) [17]; and third, limited channels for realizing the value of ecological products hinder the implementation of market incentive mechanisms such as carbon trading and green certification, creating a reverse selection of “low-carbon investment–low return”. This transmission chain of “infrastructure gap–technology lock-in–market failure” confirms the manifestation of the Jevons paradox in institutionally weak areas, warning that policy implementation must prioritize improving transportation networks and digital infrastructure to break the “diseconomies of scale” trap and reconstruct the foundational conditions for low-carbon transformation.

② Level of agricultural science and technology development. In regions with better technological conditions, more advanced and efficient agricultural production technologies are available. There are significant differences in environmental efficiency across regions with varying technological conditions; the better the technological conditions, the higher the environmental efficiency. Therefore, considering the heterogeneity of agricultural technology levels is crucial in empirical analysis. Exploring the differences in regional agricultural technology development levels helps reveal the varying impacts of the “Village Merger and Resettlement” policy on agricultural carbon emissions under different technological conditions.

Drawing on the study by Zhang and Wang (2020) [16], this paper uses the number of regional agricultural technology patents as a proxy variable for the level of agricultural technology. The average is used to divide the technology development levels. The regression results are shown in columns (3) and (4) of Table 8. Compared to regions with higher levels of technological development, the magnitude of the core explanatory variable is more significant in regions with lower levels of technological development. This indicates that the implementation of the “Village Merger and Resettlement” policy has a stronger suppressive effect on agricultural carbon emissions in regions with lower levels of technological development. According to technology adoption theory, regions with lower technological development levels typically have larger improvement potentials, which means that the introduction of any new technology or policy intervention is likely to produce significant marginal utility. In these regions, the “Village Merger and Resettlement” policy can effectively concentrate resources and promote the dissemination and modernization of agricultural technology. This is especially true where agricultural production efficiency and resource utilization efficiency are lower and the policy impact is more significant. Due to the previous lack of adequate technology and management means, regions with low technological levels can rapidly introduce advanced production technologies and management models through the “Village Merger and Resettlement” policy, thereby significantly reducing carbon emissions per unit of output in a short period.

Table 8. Heterogeneity of Resource Endowment Conditions.

Variable	(1) Transport-Developed Areas	(2) Transport-Lagging Areas	(3) Higher Scientific and Technological Development Level	(4) Lower Scientific and Technological Development Level	(5) Higher Labor Force Level	(6) Higher Labor Force Level
magnitude	−4.665 ** (−2.02)	2.035 (1.11)	−4.921 * (−1.95)	−3.836 * (−1.94)	−7.531 ** (−2.20)	−0.786 (−0.33)
controls	Yes	Yes	Yes	Yes	Yes	Yes
region fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
time fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
R ²	0.973	0.990	0.979	0.994	0.972	0.976
N	440	219	406	282	361	298

Note: the significance levels of 5%, and 10% are indicated by **, and *, respectively. The values in parentheses are robust standard errors clustered at the provincial level.

At the same time, social capital theory can also explain this phenomenon. The merger of villages and settlements often promotes cooperation and information sharing among farmers, which is particularly important in regions with a low technological level. This is because individual farmers in these areas may lack access to technical information and markets. Through such policies, social capital within communities is strengthened, and the efficiency of collaboration in agricultural production activities is enhanced, further promoting the effective application of environmental protection technologies. In addition, the policy innovation diffusion theory suggests that new policies spread relatively quickly in environments with limited resources and high pressure. This means that in the face of policy pressure, low-tech regions will rapidly adapt to and utilize new technologies to reduce operating costs and carbon emissions, thus achieving the original intention of the policy. In summary, the impact of such policies is more significant in areas with lower levels of technological development, partly because the potential synergistic effects of the policies are fully realized in terms of resource integration and technological absorption capabilities.

③ Labor force level. In areas with a high number of rural laborers, the “Village Merger and Resettlement” policy helps achieve agricultural scale management. Scale management

allows for more scientific allocation of input factors, particularly in the efficient and reduced use of polluting elements like fertilizers, which aids in improving the agricultural ecological environment. This study uses the logarithm of the rural population to measure the local labor levels and groups samples based on the median of labor levels to analyze the impact of the “Village Merger and Resettlement” policy on agricultural carbon emissions at different labor levels, as shown in columns (5) and (6) of Table 8. The regression analysis results show that the “Village Merger and Resettlement” policy has a significant carbon emission reduction effect in regions with higher labor levels, while it exhibits a significant carbon emission promotion effect in regions with lower labor levels. The reasons are given below.

The carbon reduction effect in regions with higher labor levels reflects the synergistic effect of human capital and technology diffusion. According to endogenous growth theory, high-skilled laborers can absorb and apply low-carbon technologies more quickly (Romer, 1990) [40]. In such regions, the “Village Merger and Resettlement” policy achieves emission reductions through three pathways: (1) Highly skilled laborers more easily master precision agriculture technologies (such as smart irrigation and variable fertilization), reducing the excessive use of fertilizers and pesticides (Tian and Liao, 2024) [1]. (2) The accumulation of human capital promotes specialized division within agricultural social service systems. For example, technology promoters in the Heilongjiang agricultural reclamation system, through concentrated training, have increased the coverage rate of soil testing and formulated fertilization by 40%, significantly reducing nitrous oxide emissions (Shi, 2023) [2]. (3) Labor skills complement green financial tools. In southern Jiangsu, the “professional farmer + carbon account” model converts emission reduction actions into credit incentives, encouraging low-carbon production (Zheng et al., 2024) [3]. This “human capital–technology fit–institutional incentive” closed-loop mechanism validates the core thesis of the innovation diffusion theory, which states that “the adopter’s capability determines technology penetration efficiency” (Rogers, 2003) [41].

In regions with low labor skill levels, the policy effects are not significant, revealing the rigid constraint of human capital shortages on the transition to low-carbon practices. According to the poverty trap theory, low-skilled laborers tend to fall into a path dependency of traditional production modes (Azariadis, 1996) [42]. On one hand, due to insufficient operational skills, mechanized equipment has a high idle rate; for instance, in northern Anhui, the utilization rate of drone-based plant protection equipment is less than 30%, forcing farmers to revert to high-energy-consuming small machinery operations (Xie et al., 2021) [17]. On the other hand, there is a prominent “last mile” problem in technology promotion. In the mountainous areas of Yunnan, due to a lack of local technicians, the coverage rate of soil testing and formulated fertilization technology is only 15%, making it difficult to decrease the overuse of fertilizers. Additionally, incentives for green production fail due to information asymmetry; farmers in Guizhou have low participation rates (below 8%) in ecological compensation policies due to a lack of awareness about carbon sink trading (Cheng, 2019) [12]. This corroborates the institutional economics assertion that “a gap in human capital amplifies market failures” (North, 1990) [8], suggesting that policy implementation needs to integrate skill training and localized technology adaptation mechanisms to break the vicious cycle of “low skill–high carbon lock-in”.

4.4.3. Socioeconomic Level

① Agricultural production structure. This study draws on the research by Jin and Jin (2020) [43], using the ratio of livestock output to the total output of agriculture, forestry, animal husbandry, and fishery services as an indicator to measure the adjustment of agricultural industrial structure. Choosing this proportion is reasonable because it directly reflects the relative importance of livestock in the overall agricultural structure. Livestock

often has a profound impact on the allocation of agricultural resources, the application of technology, and market demand. Changes in this sector can effectively reveal the direction and trends of agricultural industrial structure adjustments. Moreover, since livestock typically involves high added value and more complex industrial chains, it provides an important perspective when assessing agricultural transformation and upgrading.

This study conducts grouped regression based on the median, with the results presented in Table 9, columns (1) and (2). The results show that the carbon emission reduction effect of the “Village Merger and Resettlement” policy is more pronounced in areas with a lower proportion of livestock. This can be attributed to differences in agricultural production methods in these regions. First, areas dominated by crop farming, compared to those with a higher focus on livestock, generally have more efficient land use and are more capable of implementing low-carbon agricultural technologies. This allows the “Village Merger and Resettlement” policy to directly concentrate resources on improvements such as irrigation technology, the adoption of precision agriculture, and the promotion of crop rotation, significantly reducing carbon emissions. Second, these regions typically have greater control over the use of inputs like fertilizers and pesticides. Therefore, optimizing the use of these inputs through policy guidance can more directly reduce the carbon footprint. Additionally, a lower proportion of livestock means that absolute emissions of greenhouse gases like methane and nitrous oxide are lower, enhancing the policy’s observability and effectiveness in reducing carbon emissions. Furthermore, from a community organization and management perspective, these areas may find it easier to form cooperative organizations that promote and collectively implement low-carbon agricultural practices, leading to more significant environmental improvements through collective action.

Table 9. Socioeconomic Heterogeneity.

Variable	(1) Higher Degree of Agricultural Industrial Structure Adjustment	(2) Lower Degree of Agricultural Industrial Structure Adjustment	(3) Higher Degree of Policy Implementation	(4) Lower Degree of Policy Implementation	(5) East of Hu Huanyong Line	(6) West of Hu Huanyong Line
magnitude	−2.182 (−1.19)	−7.994 ** (−2.23)	−14.951 *** (−2.98)	6.099 (1.54)	−6.252 *** (−2.78)	7.804 ** (2.16)
controls	Yes	Yes	Yes	Yes	Yes	Yes
region fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
time fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
R ²	0.986	0.986	0.978	0.973	0.980	0.987
observations	364	296	384	274	550	110

Note: the significance levels of 1% and 5% are indicated by *** and ** respectively. The values in parentheses are robust standard errors clustered at the provincial level.

② Degree of policy implementation. The degree of policy implementation refers to the depth and breadth to which the policy of merging villages and consolidating settlements is carried out in actual operations. The degree of implementation directly affects the effectiveness of the policy of merging villages, consolidating settlements, and achieving its goals, thus influencing its ability to regulate agricultural carbon emissions. A high degree of implementation usually means that more resources (financial, technical, human, etc.) are invested in the implementation of the policy of merging villages and consolidating settlements. At the same time, it is accompanied by improvements in infrastructure construction. In addition, a policy with a high degree of implementation is often better able to mobilize farmers to participate. This helps to improve the efficiency of agricultural production and reduce the carbon emissions per unit of output. Based on this, drawing

on the research method of Wang (2022) [19], in this study, the calculated implementation degree of the policy in each province is divided into high/low groups according to the mean value for group regression analysis. The results are shown in columns (3) and (4) of Table 9.

The results indicate that the core explanatory variable, i.e., magnitude, is more significant in areas with a higher level of policy implementation. This suggests that the “Village Merger and Resettlement” policy has a stronger suppressive effect on agricultural carbon emissions in regions where the policy is better implemented. The reason for this phenomenon may be that the success of the policy often depends on the participation and acceptance of the farmers. In regions with high levels of policy implementation, farmers may be more actively involved in the process, leading to the formation of collective economies, which in turn promotes more efficient agricultural production and carbon reduction. Conversely, in areas with lower levels of implementation, farmers may participate less, resulting in a diminished policy effect. Additionally, the implementation of the “Village Merger and Resettlement” policy often requires supporting policies, such as financial subsidies and tax incentives. In areas with high levels of implementation, these supporting measures are more comprehensive, assisting farmers in transitioning and adapting to new production models. In contrast, in areas with lower levels of implementation, the lack of supporting policies may cause farmers to face more difficulties in the transition process, affecting the control of carbon emissions.

③ Areas on the east and west sides of the Hu Huanyong Line. Based on the important geographical concept of the Hu Huanyong Line, regional heterogeneity is evident. This geographical line runs from Heihe City to Tengchong City, effectively dividing China’s population density and economic development levels into two parts; 96% of the population resides to the east of the Hu Huanyong Line, while only 4% live to the west of it. The economic disparity is even more pronounced, with the eastern region being economically developed and having a denser endowment of resources such as capital, labor, and technology. Investment and development opportunities are more abundant, rural innovation and entrepreneurship are more active, the foundation for cultivating new agricultural labor is stronger, the pace of agricultural technology research and development is faster, and the level of agricultural production efficiency is more advanced. To examine whether the agricultural carbon reduction effects of the “Village Merger and Resettlement” policy also follow the locational differences of the Hu Huanyong Line, this study divides the total sample into two parts: east and west of the Hu Huanyong Line. The regression results are shown in Table 9: In the eastern region, the advantages of factor aggregation and institutional synergy enhance carbon reduction efficiency. In contrast, the western region faces a “scale expansion trap” due to ecological and institutional constraints. The underlying mechanism is described below.

New economic geography (NEG) theory posits that the spatial agglomeration of factors generates “geographical dividends” through economies of scale and knowledge spillovers [37], which drive innovation diffusion. In the eastern region of China, this is reflected in three synergistic mechanisms: First, the radiation effect of urban economic circles accelerates the penetration of agricultural social services. For example, the “urban-rural technical outpost” model in Jiangsu Province extends the agricultural industry chain to achieve full coverage of precision fertilization technology [1]. Second, the accumulation of human capital enhances the efficiency of green technology adoption. Shandong Province’s vocational farmer training system significantly shortens the diffusion cycle of smart greenhouse technology. Third, complementary incentives from market tools and policy regulations reshape the behavior of agricultural operators [2]. Zhejiang Province’s “ecological account” system, which allocates carbon sequestration quotas through carbon

trading, reconstructs the behavioral logic of business entities [3]. This gradient matching of “factor density–institutional density–market density” validates the increasing marginal benefits of technology diffusion under the core–periphery structure.

In contrast, the adverse effects observed in the western region reveal the paradox of implementing standardized policies in ecologically sensitive areas. Ecological economics emphasizes that natural capital thresholds impose rigid constraints on human activities (Costanza et al., 1997) [38]. This region exhibits threefold system instability: First, large-scale land consolidation exceeds the ecological carrying capacity of grasslands and deserts, leading to the degradation of soil carbon stocks and a rebound in carbon emissions from animal husbandry (Xie et al., 2021) [17]. Second, the discontinuity of human capital results in the “suspension” of technology dissemination. Traditional farming practices persist due to skill gaps, forming a path dependency. Third, the absence of market mechanisms turns ecological compensation policies into “institutional idleness”. The blockage of carbon sink value realization channels weakens farmers’ incentives to participate. These phenomena confirm the core assertion of institutional economics that “the effectiveness of institutional transplantation depends on initial conditions” (North, 1990) [8]. They highlight that in ecologically and economically vulnerable composite systems, scale-oriented policies may trigger “geographical mismatch risks”. The comparative analysis between the eastern and western regions not only reveals the deep-seated shaping effects of geographical economic patterns on policy performance but also theoretically breaks through the cognitive limitations of a “one-size-fits-all” policy design. It provides a new analytical paradigm for climate governance that addresses regional heterogeneity.

4.5. Mechanism Test

4.5.1. Test of the Mediating Effect of the Integration of Agricultural Informatization and the Agricultural Industry

The mediating role of the agricultural informatization level and agricultural industry integration in the impact of the “Village Merger and Resettlement” policy on agricultural carbon emissions is reported in Table 10. The results indicate that the “Village Merger and Resettlement” policy significantly enhances the level of agricultural informatization. Furthermore, when agricultural informatization is introduced as a mediating variable, the policy’s impact on agricultural carbon emissions remains significantly negative, and the impact of agricultural informatization on carbon emissions is also significantly negative, which confirms Hypothesis 2. This suggests that the promotion of village mergers and resettlements not only directly reduces agricultural carbon emissions but also plays a facilitative mediating role by enhancing agricultural informatization levels. The reasons for this might include the following: According to the diffusion of innovation theory, policy-driven residential centralization reduces the marginal cost of technology dissemination, accelerating the penetration of digital technology in agricultural production (Rogers, 2003) [41]. The “Village Merger and Resettlement” policy enables informatization through three mechanisms: (1) Cost reduction in digital infrastructure: Concentrated living reduces the cost of deploying digital infrastructure, leading to economies of scale in technology adoption (Tian and Liao, 2024) [1]. (2) Community-based knowledge sharing: Community living facilitates knowledge sharing among farmers, enhancing smart device usage skills through the “neighborhood effect” (Jelena et al., 2021) [44]. (3) Data needs from large-scale operations: The demand for data from large-scale land operations compels operators to establish digital management systems (Pan et al., 2022) [45]. This transmission chain of “policy impetus—infrastructure improvement—behavioral change” enables informatization to effectively reduce the carbon emission intensity per unit of output, aligning with the theoretical expectation of innovation economics regarding the “leftward shift of the environmental Kuznets curve driven by digital technology” (Grossman and Krueger, 1995) [46].

The significance of the mediating effect verifies the feasibility of the path through which policy achieves emission reductions via technological empowerment.

Table 10. Results of the Mediating Effect Test.

Variable	(1) ainformation	(2) ind
magnitude	2.272 ** (2.27)	0.210 *** (3.62)
controls	Yes	Yes
region fixed effect	Yes	Yes
time fixed effect	Yes	Yes
R ²	0.672	0.818
N	660	660

Note: the significance levels of 1% and 5% are indicated by *** and ** respectively. The values in parentheses are robust standard errors clustered at the provincial level.

Similarly, the “Village Merger and Resettlement” policy also reduces agricultural carbon emissions by promoting agricultural industry integration, which verifies Hypothesis 3. The possible reasons are as follows: (1) Vertical industry integration: The land-scale effect of the “Village Merger and Resettlement” policy provides the conditions for the in-depth integration of agriculture, energy, and manufacturing. (2) Horizontal industry integration: This policy promotes the combination of agriculture and the service industry, such as the “agriculture + cultural tourism” model and the “agriculture + education” model, thus facilitating the marketization of ecological value. (3) Substitution of production factors: For example, the use of unmanned aerial vehicles (UAVs) for precise spraying of pesticides reduces the use of chemicals (substituting labor with technology), and the development of vertical farms improves land and energy use efficiency (substituting land with capital) and the optimization of irrigation plans through AI (substituting experience with data). (4) Spatial restructuring and collaborative networks: Geographical agglomeration shortens the supply chain and reduces carbon emissions from cold chain logistics.

Additionally, based on the stepwise regression method, this study further employs a two-stage strategy model to verify the robustness of the mediation effect. The results indicate that agricultural informatization and agricultural industry integration remain important channels through which the “Village Merger and Resettlement” policy influences agricultural carbon emissions. The mediation effect test results exhibit high robustness. This series of analyses not only validates the initial conclusions from the stepwise regression but also enhances the credibility of the research findings through mutual corroboration using various methods.

Table 11 presents the estimation results of the two-stage model, with columns (1) to (4) representing the regressions of the first and second stages, respectively. It can be observed that the estimated coefficients for the “Village Merger and Resettlement” policy in the first stage are significantly positive at the 1% level. In the second stage, the fitted values of the mediating variables estimated in the first stage significantly reduce local agricultural carbon emissions. The results from the two-stage regression jointly validate the transmission logic that the “Village Merger and Resettlement” policy indirectly reduces agricultural carbon emissions by promoting the level of agricultural informatization and industry integration.

Table 11. Test Results of Mediating Effects (Two-Stage Strategic Model).

Variable	First Step		Second Step	
	(1) ainformation	(2) ind	(3) acee	(4) acee
magnitude	2.677 *** (2.72)	0.201 *** (3.67)		
$\widehat{ainformation}$			−2.639 *** (−2.57)	
\widehat{ind}				−35.183 ** (−2.25)
controls	Yes	Yes	Yes	Yes
region fixed effect	Yes	Yes	Yes	Yes
time fixed effect	Yes	Yes	Yes	Yes
R ²			−0.066	0.016
N	660	660	660	660

Note: the significance levels of 1% and 5% are indicated by *** and ** respectively. The values in parentheses are robust standard errors clustered at the provincial level.

4.5.2. Test of the Moderating Effect of Environmental Regulation

Regarding the verification of Hypothesis 4, which posits the moderating roles of public environmental concern and government environmental regulation in the process of agricultural carbon emission reduction promoted by the “Village Merger and Resettlement” policy, the empirical tests yielded the following results. The regression results in Table 12 indicate that the interaction term between social environmental concern and the “Village Merger and Resettlement” policy ($magnitude_{it} \times LnBSHI_{it}$) has a significantly negative coefficient, suggesting that public environmental concern plays a significant inhibitory moderating role in reducing agricultural carbon emissions within the policy’s implementation. In other words, public environmental concern further enhances the agricultural carbon reduction effect of the policy. This supports Hypothesis 4, which states that “public environmental participation plays a positive moderating role in the impact of the “Village Merger and Resettlement” policy on agricultural carbon emissions”. On the other hand, the interaction term between government environmental regulation and the “Village Merger and Resettlement” policy ($magnitude_{it} \times LnERI_{it}$) has a coefficient of 11.552, which is significant at the 5% level, indicating that government environmental regulation suppresses the agricultural carbon reduction effect of the policy. This is contrary to the expectation of Hypothesis 4 that “the government’s mandatory environmental regulation has a significant positive moderating effect on the impact of the “Village Merger and Resettlement” policy on agricultural carbon emissions”.

The positive moderating effect of public environmental concern on the carbon reduction impact of the “Village Merger and Resettlement” policy demonstrates the governance efficiency of informal environmental regulation working in synergy with social capital. According to social norm theory, public environmental concern enhances policy effectiveness through three pathways: The first one is the formation of a social monitoring network, i.e., utilizing digital media (such as social media and environmental monitoring apps) to improve the transparency of policy implementation, thereby pressuring local governments and business entities to fulfill their low-carbon commitments (Jelena et al., 2021) [44]. The second one is stimulating community participatory governance through self-organized models such as “environmental councils” and “low-carbon cooperatives”, transforming policy goals into collective action norms. The last one is shaping green consumer preference: Consumers’ willingness to pay a premium for low-carbon agricultural products creates market incentives, driving technological upgrades in production. This composite mechanism of “pressure–participation–market” validates the central tenet of polycentric

governance theory, which posits that “social capital complements the inadequacies of formal institutions” (Ostrom, 2010) [47]. It indicates that informal regulation can enhance the positive environmental externalities of policies through information dissemination and behavior internalization.

Table 12. Results of the Moderating Effect Test.

Variable	(1) acee	(2) acee
magnitude	−6.514 *** (−3.25)	5.952 (1.38)
LnERI	−9.731 (−1.02)	
c.magnitude#c.LnERI	11.552 ** (2.10)	
LnBSHI		−7.791 (−0.83)
c.magnitude#c.LnBSHI		−6.746 *** (−3.22)
controls	Yes	Yes
region fixed effect	Yes	Yes
time fixed effect	Yes	Yes
R ²	0.976	0.976
N	660	660

Note: the significance levels of 1% and 5% are indicated by *** and ** respectively. The values in parentheses are robust standard errors clustered at the provincial level.

The negative moderating effect of government environmental regulation on the policy’s carbon reduction impact reflects the suitability deficiencies of “command-and-control” policy tools in agricultural contexts. Regulatory capture theory points out that rigid environmental regulation may induce two types of distorted behaviors: The first one is short-term compliance for uniform standards: The “one-size-fits-all” standards in policy enforcement may drive farmers to adopt short-term compliance strategies (such as data falsification and selective reductions) rather than substantial technological innovation (Guo et al., 2024) [48]. The second one is the mismatched allocation of production factors: For instance, if there is no support for alternative technologies under fertilizer reduction policies, farmers may turn to high-carbon soil improvement practices, such as burning straw for fertilizer. Moreover, the spatial heterogeneity of agricultural environmental externalities is insufficiently recognized, leading to a misalignment between uniform emission standards and regional ecological carrying capacity. This exacerbates the divergence between “compliance-based emission reductions” and “effective emission reductions” (Pretty et al., 2001) [49]. These mechanisms suggest that government regulation, lacking flexibility and supportive incentives, may distort the original intent of policies, highlighting the need for agricultural environmental governance to shift from a “control-based regulation” to an “incentive-based collaboration” regulatory design paradigm.

4.6. Further Analysis

Against the backdrop of globalization and regional integration, the economic ties among regions are becoming increasingly close. As a result, agricultural carbon emissions in one region can be significantly influenced by agricultural activities in neighboring regions, giving rise to obvious spatial autocorrelation [50]. In addition, the “Village Merger and Resettlement” policy, by reshaping the layout of rural residential areas, has strengthened the spatial network connections of agricultural production. Its inherent permeability, integration, and synergy enable regions to transcend geographical boundaries and achieve division of labor and cooperation among regions, thus generating a spatial spillover ef-

fect [51]. This phenomenon indicates that the “Village Merger and Resettlement” policy in one region may have a significant impact on agricultural carbon emissions in other regions. In this case, traditional panel data analysis methods may lead to estimation biases due to the neglect of spatial effects [52]. To address this issue, this study introduces spatial econometric methods to explore the complex relationship between the “Village Merger and Resettlement” policy and agricultural carbon emissions more accurately. By using this approach, the mutual influences among neighboring regions can be considered more comprehensively, thereby enhancing the accuracy of research conclusions and the pertinence of policy recommendations.

(1) Global Spatial Autocorrelation Test of Agricultural Carbon Emissions

Before examining the spatial spillover effects of the “Village Merger and Resettlement” policy on agricultural carbon emissions, it is necessary to determine whether there is spatial autocorrelation in agricultural carbon emissions. Thus, this study first uses the difference in provincial per capita real GDP as the “economic distance” between regions to construct a spatial weight matrix, followed by the calculation of Moran’s Index. The test results show that Moran’s Index is 0.984, which is significant at the 10% significance level. Overall, for the study period, there is a spatial autocorrelation feature in China’s provincial agricultural carbon emissions. This indicates that provinces with high agricultural carbon emissions are adjacent to other high-emission provinces, and those with low emissions are adjacent to other low-emission provinces.

(2) LM, LR, Hausman, and joint significance tests:

Given the spatial autocorrelation of agricultural carbon emissions, the next step is to choose the appropriate spatial econometric model through LM, LR, and Hausman tests. The test results are shown in Table 13.

Table 13. LM, LR, Hausman, and Joint Significance Tests.

Test	Statistic	Test	Statistic
LM(error)test	8.210 ***	LR(sdm sar)test	91.400 ***
Robust LM(error)test	15.766 ***	LR(sdm sem)test	90.890 ***
LM(lag)test	0.147	Hausman test	31.190 ***
Robust LM(lag)test	7.704 ***		
Joint significance tests	Ind(98.890 ***)	Time(2136.550 ***)	

Note: the significance levels of 1% is indicated by ***. The values in parentheses are robust standard errors clustered at the provincial level.

According to Table 13, the LM (Robust) test exhibits a strong spatial effect at the 1% significance level, indicating the possible presence of either a spatial error model or a spatial lag model. Based on the results of the Hausman test, a fixed-effect model needs to be adopted. The LR test passed the significance test, rejecting the null hypothesis that the Spatial Durbin Model (SDM) degenerates into a spatial lag model or a spatial error model. Therefore, this study will employ the Spatial Durbin Model. The joint significance results show that both individual fixed effects and time fixed effects passed the significance test at the 1% level. In light of this, this study will use a double-fixed-effect Spatial Durbin Model for the empirical analysis.

$$\begin{aligned}
 a_{cee_{it}} &= \alpha + \rho W a_{cee_{it}} + \varphi magnitude_{it} + \delta_1 controls_{it} + \theta W magnitude_{it} \\
 &+ \delta_2 W controls_{it} + \mu_i + \gamma_t + \varepsilon_{it}
 \end{aligned}
 \tag{8}$$

In the equation, W is the spatial weight matrix, consistent with the one used in Moran’s Index test; ρ is the spatial autoregressive coefficient, reflecting the spatial autocorrelation of agricultural carbon emissions across different regions; φ is the estimated coefficient for

the “Village Merger and Resettlement” policy; θ is the coefficient for the spatial lag of the explanatory variable; and δ is the coefficient for the control variables. The meanings of other variables remain consistent with the previous text.

(3) Spatial spillover effects of the “Village Merger and Resettlement” policy on the efficiency of agricultural carbon emissions:

This study draws on the method of LeSage and Pace (2009) [53] to decompose the effects of the “Village Merger and Resettlement” policy on regional agricultural carbon emissions, including direct effects, indirect effects, and total effects. The direct effect reflects the direct impact of the local “Village Merger and Resettlement” policy on local agricultural carbon emissions; the indirect effect, also known as the spatial spillover effect, describes the influence of neighboring regions’ “Village Merger and Resettlement” policies on local agricultural carbon emissions; and the total effect is the sum of the direct and indirect effects. The detailed analysis results can be found in Table 14.

Table 14. Direct Effects and Spatial Spillover Effects of the “Village Merger and Resettlement” Policy on Agricultural Carbon Emissions.

Variable	Direct Effects		Indirect Effects		Total Effects	
	Coefficient	T	Coefficient	T	Coefficient	T
magnitude	−5.489 **	−2.46	−13.630 *	−1.76	−19.119 **	−2.34
controls	Yes	Yes	Yes	Yes	Yes	Yes
region fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
time fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
N	660		660		660	

Note: the significance levels of 5%, and 10% are indicated by **, and *, respectively. The values in parentheses are robust standard errors clustered at the provincial level.

According to the data in Table 14, the direct effect value of the “Village Merger and Resettlement” policy is −5.489, which is significant at the 5% level, and the indirect effect value is −13.630, which is significant at the 10% level. This indicates that the implementation of the “Village Merger and Resettlement” policy has generated a significant spatial spillover effect on agricultural carbon emissions. Specifically, the implementation of such policies in neighboring regions may drive improvements in local agricultural technology and management, particularly in terms of low-carbon technologies and sustainable agricultural practices, thereby reducing carbon emissions (Anselin and Bera, 1998) [50]. This spillover effect can foster agricultural practice improvements within a region via mechanisms like information exchange, technological imitation, and competitive dynamics (LeSage and Pace, 2009) [53]. Moreover, the health and stability of ecosystems are interdependent across regions. One region’s implementation of ecological protection measures, such as afforestation and soil improvement, can create positive external effects that enhance the neighboring regions’ ecological environment, thereby supporting sustainable agricultural development and carbon reduction (Nsabiyeze et al., 2024) [54]. With the rapid development of information technology, the flow of information and the establishment of networks between neighboring areas have facilitated the sharing and promotion of green technologies. The swift dissemination of information enables farmers to access the latest environmental technologies and policy information promptly, accelerating the transition to low-carbon agricultural production (Rogers, 2003) [41]. Overall, the spatial spillover effects from neighboring areas promote agricultural carbon reduction and regional sustainable development effectively through mechanisms such as technology diffusion, network effects, and resource sharing (Elhorst, 2014) [52]. This inter-regional synergy highlights the importance of considering spatial interactions and collaboration when promoting low-carbon agricultural policies, providing valuable insights for policymakers.

5. Conclusions, Policy Implications, and Limitations

5.1. Research Conclusions

The “Village Merger and Resettlement” policy, as an adjustment to the rural residential and spatial organization in response to rural population outflow amid global urbanization and industrialization, has profound impacts on agricultural resource allocation, technological innovation, and carbon emissions, playing a crucial role in achieving green low-carbon development and high-quality agricultural development. This study uses data from 30 provinces in China from 2001 to 2022 to empirically examine the impact of the “Village Merger and Resettlement” policy on agricultural carbon emissions. It explores the mediating effects of agricultural informatization and agricultural industry integration and analyzes the moderating roles of public environmental concern and government environmental regulation. This study found that:

- (1) The policy significantly promotes agricultural carbon reduction, especially in major grain-producing areas or regions with flat terrain, areas with higher levels of transportation, agricultural technology, or labor resources, regions with lower degrees of agricultural industrial structure adjustment or higher implementation levels of the policy, and those located east of the Hu Huanyong Line.
- (2) Mediation effect analysis reveals that both agricultural informatization and industry integration play positive mediating roles in the process of carbon reduction supported by this policy.
- (3) Moderation effect analysis shows that the government’s mandatory environmental regulation has a negative moderating effect on the carbon emission reduction impacts of the policy, while public environmental participation plays a positive moderating role.
- (4) Spatial effect tests indicate that the implementation of the “Village Merger and Resettlement” policy has a significant spatial spillover effect on agricultural carbon emissions, where local agricultural carbon emissions are influenced, to some extent, by the policy’s implementation in neighboring regions.

5.2. Policy Implications

Based on the research findings, the “Village Merger and Resettlement” policy not only holds significant practical implications for China but also offers insights for global efforts to address climate change and promote sustainable rural development. This study provides policy recommendations from five perspectives:

- (1) Exploring the regional adaptability of the “Village Merger and Resettlement” policy. The research indicates that the carbon reduction effects of this policy vary significantly under different regional conditions. This suggests that policymakers need to tailor approaches to local circumstances, taking into full account regional topography, resource endowments, and levels of technological development. In major grain-producing areas and regions with convenient transportation, the government should accelerate the promotion of this policy, alongside the introduction of agricultural technology and the enhancement of labor quality, to build an efficient low-carbon agricultural production system. Drawing from China’s experience, other developing countries implementing similar rural integration policies should consider local geographical and economic factors to develop adaptable implementation strategies, ensuring both the precision and effectiveness of the policy.
- (2) Promoting the development of agricultural informatization. Agricultural informatization plays a significant mediating role in the “Village Merger and Resettlement” policy, serving as a crucial pathway to enhance carbon emission reduction in agriculture. Global agricultural production activities need to accelerate the process of

informatization to optimize resource allocation and improve operational efficiency. China's practices in this area can offer valuable experiences for other countries, such as the promotion of precision agriculture and the application of Internet of Things (IoT) technologies. Government policies should reinforce investment in informatization infrastructure and conduct extensive agricultural technology training to enhance farmers' adaptability to new technologies. International cooperation is also an indispensable part as cross-border technology exchange and collaboration can assist countries in achieving modernization and efficient management of agriculture.

- (3) Promoting industrial integration involves prioritizing high-value, low-pollution industrial chains in the industrial layout. This can be achieved through financial support and technical assistance to advance ecological agriculture and circular economy while advocating for green certification and branding to guide the market towards a low-carbon transition. Policy-wise, it is important to encourage the use of clean technologies and renewable energy, using tax incentives, subsidies, and technical guidance to promote green innovation. Moreover, international cooperation should be strengthened to establish a green low-carbon agricultural platform, enabling the sharing of technology and experiences to ensure environmental friendliness and long-term social impact on a global scale. This integration strategy not only revitalizes local economies but also achieves global sustainable development amid climate change, balancing agricultural modernization with ecological protection.
- (4) Advocating for public environmental participation to improve the policy implementation environment. Public involvement in environmental matters plays a positive role in enhancing the carbon reduction effects of policies, highlighting that public awareness and action cannot be overlooked in environmental governance. China and other countries should encourage public participation in environmental governance, raising environmental awareness through education and advocacy, thereby enabling individuals and communities to become both executors and promoters of policies. Additionally, effective incentive mechanisms should be designed and implemented to provide tangible benefits to the public when choosing low-carbon products and participating in environmental protection activities. Global experience demonstrates that public participation can significantly increase the acceptance and efficiency of environmental policies, strengthening the community's central role in sustainable development.
- (5) Strengthening inter-regional cooperation and policy coordination. The spatial spillover effects of the "Village Merger and Resettlement" policy indicate that implementing policies in a single region impacts the local area and influences surrounding regions. This finding underscores the importance of inter-regional collaboration. China's experience in regional coordinated development can offer valuable insights for other countries. In the formulation and execution of policies, nations should encourage synergistic cooperation among regions and promote linkage mechanisms to maximize the overall effectiveness of policies. In the context of addressing global climate change, transnational policy coordination and regional integration are particularly crucial. By sharing experiences and resources, countries can collectively tackle the environmental challenges faced in agricultural production, enhancing the overall sustainability of global agriculture.

5.3. Research Prospects

This study constructs a "policy–technology–institution" multidimensional analytical framework to systematically reveal the impact of the "Village Merger and Resettlement" policy on agricultural carbon emissions and its spatial heterogeneity. It innovatively identi-

fies the dual mediating pathways of agricultural informatization and industry integration, as well as the differential moderating effects of formal and informal environmental regulations, providing theoretical support for the coordinated development of rural spatial reconstruction and low-carbon agriculture. However, this study has three limitations: First, the sample coverage does not include Tibet and the Hong Kong, Macau, and Taiwan regions, which may weaken the national representativeness of the conclusions. Furthermore, the applicability of conclusions based on the Chinese context to other developing countries requires further validation. Second, the indicator for the “Village Merger and Resettlement” policy uses the change in the number of administrative villages as a proxy variable, failing to fully capture deeper institutional features such as land ownership adjustments and community governance transformations, which might weaken the explanatory power of the policy effects. Lastly, the “Village Merger and Resettlement” policy may still involve high-carbon components (such as cold chain logistics and energy-intensive processing). Due to space constraints, this study does not systematically discuss the micro-mechanisms of high-carbon components, limiting a comprehensive observation of the policy effects.

Future research is needed in the following directions:

1. Constructing multi-scale data fusion models by integrating village-level micro-survey data with high-resolution remote sensing information to enhance the precision in measuring policy implementation intensity and spatial effects.
2. Utilizing carbon footprint tracking technology across the supply chain to identify metabolic bottlenecks in industrial integration (such as the energy lock-in effect in processing stages) and explore low-carbon optimization pathways.
3. Exploring the dynamic coupling mechanisms of “policy–climate–market” to assess the heterogeneous impacts of extreme weather events and carbon price fluctuations on policy effectiveness, providing decision-making support for building climate-resilient rural areas.

These developments will help improve the theoretical framework for rural low-carbon transitions and enhance the scientific and practical adaptability of policy design.

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References

1. Tian, Y.; Liao, H. The Influence and Mechanism of Digital Economy on Agricultural Carbon Emissio. *Reform* **2024**, *9*, 84–99.
2. Shi, H.; Chang, M. How does agricultural industrial structure upgrading affect agricultural carbon emissions? Threshold effects analysis for China. *Environ. Sci Pollut. Res.* **2023**, *30*, 52943–52957. [[CrossRef](#)] [[PubMed](#)]
3. Zheng, L.X.; Gao, C.Q.; Zheng, F.H. An Investigation into the Impact of Green Finance Development on Carbon Emissions: A Case Study of the Yangtze River Delta Region. *East China Econ. Manag.* **2024**, *38*, 41–51.
4. Bijman, J. Agricultural Cooperatives in the Netherlands: Key success factors. In Proceedings of the International Summit of Cooperatives, Quebec City, QC, Canada, 11–13 October 2016.
5. Tanaka, K.; Managi, S. Industrial agglomeration effect for energy efficiency in Japanese production plants. *Energy Policy* **2021**, *156*, 112442. [[CrossRef](#)]

6. Wu, H.; Qiu, Y.; Yin, L.; Liu, S.; Zhao, D.; Zhang, M. Effects of China's land-intensive use on carbon emission reduction: A new perspective of industrial structure upgrading. *Front. Environ. Sci.* **2022**, *10*, 1073565. [[CrossRef](#)]
7. Park, J.; Kim, J. A Data-Driven Exploration of the Race between Human Labor and Machines in the 21st Century. *Commun. ACM* **2022**, *65*, 79–87. [[CrossRef](#)]
8. North, D.C. Institutions, Institutional Change and Economic Performance: An introduction to institutions and institutional change. *Springer Nat.* **1990**, *74*, 379–382.
9. Xia, Y.; Guo, H.; Xu, S.; Pan, C. Environmental regulations and agricultural carbon emissions efficiency: Evidence from rural China. *Heliyon* **2024**, *10*, e25677. [[CrossRef](#)]
10. Ma, M.; Li, J.; Song, J.; Chen, X. Digital agriculture's impact on carbon dioxide emissions varies with the economic development of Chinese provinces. *Commun. Earth Environ.* **2024**, *5*, 621. [[CrossRef](#)]
11. Lin, F.; Li, J.S.; Wu, C. Social networks, environmental literacy, and farmers' clean low-carbon farming behaviours: Evidence from villages in China. *Ecol. Econ.* **2025**, *228*, 108439. [[CrossRef](#)]
12. Cheng, L. New Progress in Research on Integration of Rural Industries in China: A Literature Review. *Agric. Econ. Manag.* **2019**, *2*, 37–47.
13. Li, G.X.; Huang, Y.; Peng, L.; You, J.S.; Meng, A.C. Agricultural carbon reduction in China: The synergy effect of trade and technology on sustainable development. *Environ. Res.* **2024**, *252*, 119025. [[CrossRef](#)] [[PubMed](#)]
14. Zhan, J.T.; Xu, Y.J. Environmental regulation, agricultural green TFP and grain security. *China Popul. Resour. Environ.* **2019**, *29*, 167–176.
15. Li, K.; Shi, L. Effects of Rural Industrial Convergence on Agricultural Carbon Emissions: Mechanism Path and Spatial Spillover Effect Analysis. *Chin. J. Agric. Resour. Reg. Plan.* **2024**, *45*, 1–14.
16. Zhang, J.X.; Wang, H.L. Analysis on Environmental Planning, Agricultural Technological Innovation and Agricultural Carbon Emission. *J. Hubei Univ. Philos. Soc. Sci.* **2020**, *47*, 147–156.
17. Xie, C.Y.; Huang, C.F.; Xu, H. Regional Differences and Influencing Factors of Agricultural Technical Efficiency in China under Environmental Regulation: A Perspective Based on Dual Constraints of Agricultural Carbon Emissions and Agricultural Non-Point Source Pollution. *Sci. Technol. Manag. Res.* **2021**, *41*, 184–190.
18. Liu, C.; Zeng, Q.; Liu, L.Y. Strict Financial Regulation, Longer-term Deposits and Loans, and Funding Long-term Projects with Short-term Debts. *Econ. Res. J.* **2023**, *58*, 75–92.
19. Wang, X.Y.; Su, Z.F. "Can "Village Merging" Reduce Carbon Emissions of County Level? *Zhejiang Soc. Sci.* **2022**, *20–33*, 156–157.
20. Ding, B.G.; Zhao, Y.; Deng, J.H. Calculation, Decoupling Effects and Driving Factors of Carbon Emission from Planting Industry in China. *Chin. J. Agric. Resour. Reg. Plan.* **2021**, *43*, 1–11.
21. Li, B.; Zhang, J.B. Decoupling of China's Agriculture Carbon Emissions and Economic Development Based on the Input Perspective. *Econ. Surv.* **2012**, 27–31.
22. IPCC. *Climate Change 2013: The Physical Science Basis Technical Summary*; IPCC: Geneva, Switzerland, 2013.
23. Duan, H.P.; Zhang, Y.; Zhao, J.B.; Bian, X.M. Carbon Footprint Analysis of Farmland Ecosystem in China. *J. Soil Water Conserv.* **2011**, *25*, 203–208.
24. Tian, Y.; Yin, M.H. Re-evaluation of China's Agricultural Carbon Emissions: Basic Status, Dynamic Evolution and Spatial Spillover Effects. *Chin. Rural. Econ.* **2022**, 104–127.
25. Wang, L.; Ma, J.M. Does Informal Environmental Regulation Promote Agricultural Carbon Emission Reduction?—From the Perspective of Public Environmental Concern. *J. China Univ. Geosci. Soc. Sci. Ed.* **2024**, *24*, 80–94.
26. Guo, J.; Yang, Q.; Wu, H.M. Can Sci-tech Finance Empower the Improvement of Agricultural Production Efficiency?—Empirical Evidence from Sci-tech Finance Pilot Policies. *Chin. Rural. Econ.* **2024**, *5*, 81–105.
27. Liu, S. The Impact of Agricultural Informatization on Agricultural Total Factor Productivity. *Soc. Sci.* **2021**, *9*, 79–85.
28. Wang, L.N.; Li, Y.S. The Impact of Integrated Development of the Primary, Secondary and Tertiary Industries in Rural Areas on Farmers' Income and Its Regional Heterogeneity. *Reform* **2019**, *12*, 104–114.
29. Yuan, Y.J.; Xie, R.H. Research on the Industrial Structure Adjustment Effect of Environmental Regulation: An Empirical Analysis Based on Interprovincial Panel Data in China. *China Ind. Econ.* **2014**, *8*, 57–69.
30. Fan, H.M.; Mu, H.Z. Environmental Regulation, FDI and Employment of Migrant Workers. *Financ. Trade Res.* **2017**, *28*, 23–32.
31. Morgenstern, R.D.; William, A.P.; Jhah-Shyang, S. Jobs Versus the Environment: An Industry-Level Perspective. *J. Environ. Econ. Manag.* **2002**, *42*, 412–436. [[CrossRef](#)]
32. Lou, C.L. *Environmental Regulation, Technological Innovation, and Labor Employment*. Chongqing University: Chongqing, China, 2016.
33. Zhang, H.; Wei, X.P. Green Paradox or Forced Emission-reduction: Dual Effect of Environmental Regulation on Carbon Emissions. *China Popul. Resour. Environ.* **2014**, *24*, 21–29.
34. Li, M.J.; Du, J.W. Is the Double Dividend of Environmental Regulation and Employment Applicable to China's Current Stage?—An Empirical Analysis Based on Interprovincial Panel Data. *Econ. Sci.* **2014**, *4*, 14–26.

35. Liu, R.Z.; He, C. Study on the Threshold Effect of Environmental Regulation on Income Inequality of Urban Residents. *China Soft Sci.* **2021**, *8*, 41–52.
36. You, Z.; Feng, Z.M.; Yang, Y.Z. Relief Degree of Land Surface Dataset of China (1 km). *J. Glob. Change Data Discov.* **2018**, *2*, 151–155+274–278.
37. Krugman, P. Increasing Returns and Economic Geography. *J. Political Econ.* **1991**, *99*, 483–499. [[CrossRef](#)]
38. Costanza, R.; d’Arge, R.; de Rudolf, G.; Stephen, F.; Monica, G.; Bruce, H.; Karin, L.; Shahid, N.; Robert, V.; Jose, P.; et al. The value of the world’s ecosystem services and natural capital. *Nature* **1997**, *387*, 253–260. [[CrossRef](#)]
39. Myrdal, G. *Economic Theory and Underdeveloped Regions*; Gerald Duckworth: London, UK, 1957.
40. Romer, P. Endogenous Technological Change. *J. Political Econ.* **1990**, *98*, 71–102. [[CrossRef](#)]
41. Rogers, E.M. *Diffusion of Innovations*; Free Press: Washington, DC, USA, 2003.
42. Azariadis, C. The economics of poverty traps part one: Complete markets. *J. Econ. Growth* **1996**, *1*, 449–486. [[CrossRef](#)]
43. Jin, F.; Jin, R.X. Analysis on the Spatial Effect of Fiscal Support for Agriculture on the Change of Agricultural Industrial Structure. *Res. Financ. Econ. Issues* **2020**, *5*, 82–91.
44. Despotović, J.; Rodić, V.; Caracciolo, F. Farmers’ environmental awareness: Construct development, measurement, and use. *J. Clean. Prod.* **2021**, *295*, 126378. [[CrossRef](#)]
45. Rao, P.; Liu, X.; Zhu, S.; Kang, X.; Zhao, X.; Xie, F. Does the Application of ICTs Improve the Efficiency of Agricultural Carbon Reduction? Evidence from Broadband Adoption in Rural China. *Int. J. Environ. Res. Public Health* **2022**, *19*, 7844. [[CrossRef](#)] [[PubMed](#)]
46. Grossman, G.M.; Krueger, A. Economic Growth and the Environment. *Q. J. Econ.* **1995**, *110*, 353–377. [[CrossRef](#)]
47. Ostrom, E. Analyzing collective action. *Agric. Econ.* **2010**, *41*, 155–166. [[CrossRef](#)]
48. Guo, T.; Sun, Y.Y.; Peng, X.S. Can the Pressure of Pollution Reduction and Carbon Reduction be Transformed into a Driving Force for High-quality Economic Development?—New Evidence on the Intensity of Environmental Regulations and the Degree of Resource Misallocation. *Shanghai J. Econ.* **2024**, *11*, 39–52.
49. Pretty, J.; Brett, C.; Gee, D.; Hine, R.; Mason, C.; Morison, J.; Rayment, M.; Van Der Bijl, G.; Dobbs, T. Policy challenges and priorities for internalizing the externalities of modern agriculture. *J. Environ. Plan. Manag.* **2001**, *44*, 263–283. [[CrossRef](#)]
50. Anselin, L.; Bera, A.K. Spatial Dependence in Linear Regression Models with an Introduction to Spatial Econometrics. *Revue Déconomie Industrielle* **1998**, *155*, 237–289.
51. LeSage, J.P.; Fischer, M.M. Spatial growth regressions: Model specification, estimation and interpretation. *Spat. Econ. Anal.* **2008**, *3*, 275–304. [[CrossRef](#)]
52. Elhorst, J.P. *Spatial Econometrics: From Cross-Sectional Data to Spatial Panels*; Springer: Berlin/Heidelberg, Germany, 2014.
53. LeSage, J.; Pace, R.K. *Introduction to Spatial Econometrics*; Chapman and Hall/CRC: London, UK, 2009.
54. Nsabiyeze, A.; Ma, R.; Li, J.; Luo, H.; Zhao, Q.; Tomka, J.; Zhang, M. Tackling climate change in agriculture: A global evaluation of the effectiveness of carbon emission reduction policies. *J. Clean. Prod.* **2024**, *468*, 142973. [[CrossRef](#)]

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