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Cover Story

Indonesia's Free Nutritious Meals program (Makan Bergizi Gratis, MBG) is more than a social welfare scheme; it is a bold, nationwide investment in human capital with profound implications for agricultural and rural development. Launched in 2025, this ambitious initiative aims to deliver one nutritious daily meal to millions, primarily targeting schoolchildren from an early age. Its core thesis is simple yet transformative: consistent nutritional support is the bedrock for a more educated, healthy, and productive future generation, directly supporting the national "Golden Indonesia 2045" vision.

The program's achievements are twofold, bridging immediate welfare with long-term structural growth. Foremost, it tackles the persistent challenge of stunting and malnutrition. By guaranteeing a safe, diverse meal during the school day, MBG directly improves dietary diversity and energy intake for vulnerable children. This intervention is critical for cognitive development and educational outcomes, aiming to break the intergenerational cycle of poverty. Early implementation data shows rapid scaling, reaching millions of beneficiaries within months and demonstrating significant political and administrative commitment. Simultaneously, MBG is consciously designed as a catalyst for rural and agricultural economies. A cornerstone of its implementation is the directive for local procurement. The vast network of community kitchens is encouraged to source ingredients from local farmers, fishermen, and small-scale food enterprises. This creates a predictable, large-scale market for fresh produce, providing income stability and stimulating local agri-food systems. The program thus functions as a unique policy instrument, linking social protection directly to agricultural demand, fostering rural entrepreneurship, and encouraging investment in local food supply chains.

The program's rapid rollout has exposed challenges, particularly regarding food safety, supply chain quality, procurement corruption prevention and long-term fiscal sustainability. If these hurdles are overcome, MBG could stand as a global reference for how social protection policies can drive inclusive rural development.

(Yanxiong Wu, Professor, Zhejiang A&F University, China)

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About the Journal

Agricultural & Rural Studies (**A&R**, **ISSN 2959-9784**) is an exclusively digital, open-access journal dedicated to advancing interdisciplinary scholarship at the critical nexus of agricultural sustainability, rural revitalization, and farmer well-being. Published quarterly, **A&R** features a range of content types—including original research, reviews, perspectives, and commentaries—serving as a professional and innovative platform for rigorous academic dialogue and global knowledge dissemination.

Core Features:

(1) **Interdisciplinary Scope:** A&R centers on interdisciplinary and multidisciplinary inquiry, integrating insights from economics, sociology, human geography, and cognate disciplines to address pressing contemporary issues in agriculture, rural development, and farmer-related policies—bridging theoretical frameworks to advance holistic understandings of these dynamic systems.

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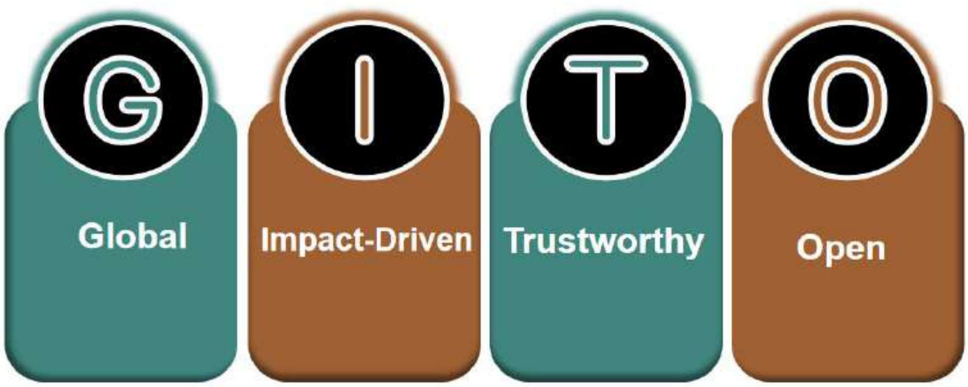

Agricultural & Rural Studies

Article

The Welfare Level of Rice Farmers in the Bengawan Solo Watershed, Indonesia

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Abstract: The welfare of rice farmers in the Bengawan Solo Watershed region is a critical issue, as it reflects the socioeconomic conditions of agrarian communities that depend on the sustainability of natural resources and agricultural productivity. The objective of this research is to analyze how rice farming contributes to household income and overall welfare. This study aims to determine the level of household welfare of rice farmers in the Bengawan Solo Watershed area, Central Java. Sampling was conducted using an unproportional random sampling method on 240 farmers in six districts in Central Java. Data analysis used the Good Service Ratio (GSR), Farmer Household Income Exchange Rate (FHIER), and Farmer Exchange Rate (FER) indicators. The results showed that a GSR value of 0.38 indicates a higher allocation of household expenditure toward non-food needs. Furthermore, an FHIER value of 1.40 indicates that total household income exceeds total household expenditure. However, a FER value of 99.21 indicates that income derived solely from rice farming is insufficient to cover all household expenses. These findings suggest that although rice farming plays an important role in household income, farmer welfare in the Bengawan Solo Watershed remains highly dependent on income diversification and continued productivity improvement, and institutional support.

Keyword: FER; FHIER; GSR; farmer welfare; watershed rice farmers

Check for updates

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1. Introduction

Rice (*Oryza Sativa*) is a major agricultural commodity and serves as a staple food for a large proportion of the global population, particularly in Asia, with Indonesia being one of the primary consumers (Istiyanti et al., 2025). With a population of more than 270 million people, Indonesia is heavily dependent on rice production to meet its staple food needs. Data from the Pusat Data dan Sistem Informasi Pertanian (2022), rice consumption on a household scale as a staple food reaches 81,044 kg/cap per year. Given this high demand, rice farming in Indonesia continues to expand each year (Rifin et al., 2024). However, rice cultivation is highly water-dependent, as irrigation plays a critical role in sustaining production. Water sources are derived from both groundwater and river systems (Prikhodko & Bandurin, 2023).

As an agricultural country, Indonesia has many agricultural systems, one of which is the watershed rice farming system (Ramadhani et al., 2021). Cultivating rice in watersheds offers several advantages, including enhanced agricultural productivity and more efficient utilization of water resources (Liu et al., 2021). The watershed has good morphometric and hydrological characteristics, so it can ensure sufficient water supply for rice growth (Yanti et al., 2021).

With an abundance of water, areas crossed by rivers can be ideal land for growing rice (List et al., 2020; Punnoli et al., 2025). However, farmers in watershed regions remain highly vulnerable to frequent and unpredictable flooding events, exacerbated by climate change (Punnoli et al., 2025). Such floods reduce productivity and result in substantial economic losses, directly affecting farmers' livelihoods by damaging crops, lowering yields, and diminishing household income.

In Indonesia, particularly within the Bengawan Solo Watershed, seasonal flooding remains a recurring and increasingly complex issue, as the agricultural sector, especially food crop production, faces major challenges arising from the impacts of climate change (Susanawati et al., 2022). River overflows during the rainy season, exacerbated by land degradation caused by erosion, sedimentation, and declining soil fertility, have direct adverse impacts on the condition and quality of agricultural land (Soemitro et al., 2021). In addition, suboptimal water resource management in the Bengawan Solo Watershed has led to imbalances in water availability between the rainy and dry seasons (Rosalia et al., 2021). This combination of factors reduces agricultural productivity by delaying rice planting schedules, increasing the risk of crop failure, and decreasing crop yields, which ultimately affects farmers' income levels and the welfare of farming households in the Bengawan Solo Watershed (Priyana et al., 2024).

Beyond production losses, these recurring environmental stresses have significant economic implications for farming households. Reduced yields, higher input costs, and increased production uncertainty collectively contribute to low farm profitability and a declining Farmer Exchange Rate (FER), indicating that farmers' purchasing power fails to keep pace with rising production costs. In flood-prone areas such as the Bengawan Solo Watershed, these pressures intensify household economic vulnerability and limit farmers' capacity to reinvest in agricultural activities or adopt adaptive technologies. While at the national level, the Farmer Exchange Rate (FER) reached 114.14 in 2023, as reported by Statistics Indonesia (BPS); this figure represents an aggregate condition and does not fully capture local disparities. In flood-prone regions like the Bengawan Solo Watershed, the FER is likely to be considerably lower due to persistent environmental shocks (Slamet Widodo et al., 2024).

Despite the growing body of literature on flooding, land degradation, and rice production in the Bengawan Solo Watershed, systematic assessments of farmer welfare that integrate economic performance indicators remain limited. Existing studies predominantly focus on biophysical impacts or short-term income fluctuations, while comparative regional analyses that examine variations in farmer welfare across flood-affected areas are scarce. Moreover, the role of low FER and limited farm profitability as key determinants of farmer welfare has not been comprehensively examined within the context of the Bengawan Solo Watershed. This gap underscores the need for a more integrated and regionally comparative approach to understanding farmer welfare in environmentally vulnerable rice-producing regions.

Farmer welfare is an important indicator because it is closely related to their income level, which determines farmers' ability to meet their living needs and invest in farming (Aleksandrova et al., 2024). Welfare levels are commonly assessed through indicators such as household income, land ownership, farming experience, education level, and production capacity (Ojo et al., 2020). The level of welfare reflects the extent to which farming families are able to meet their living needs.

Various previous studies have addressed the welfare of rice farmers in the Bengawan Solo Watershed, with varying focuses and approaches. This study, therefore, seeks to provide a more comprehensive analysis of farmer welfare, with the aim of providing insight and describing the level of farmer welfare.

2. Materials and Methods

2.1. Location and Time of Research

This study adopts a quantitative descriptive approach to assess the welfare levels of rice farmers in the Bengawan Solo Watershed, Central Java. The focus of the study covers six regencies in Central Java: Wonogiri, Sragen, Karanganyar, Sukoharjo, Klaten, and Boyolali. The research locations were determined purposively, taking into account regional accessibility, the presence of farmer institutions or groups, the availability of natural resources, and the number of farming households. The study was conducted over a three-month period, from June to August 2025, encompassing preparation and coordination, field data collection, and preliminary analysis. Research activities were adjusted to field conditions, with the June–August timeframe serving as the primary reference for implementation.

2.2. Sampling Procedure and Data Collection

This study employed a survey method using direct interviews with respondents through a structured questionnaire. The sampling technique used was disproportionate random sampling, in which the study area and respondents were selected through multiple stages. First, six regencies in Central Java Province located within the Bengawan Solo Watershed were selected based on specific research considerations, namely their status as major rice production centers and their regular exposure to seasonal flooding. Subsequently, within each selected regency, rice farmers were chosen using simple random sampling.

An equal number of 40 rice farmers was randomly selected from each regency, resulting in a total sample size of 240 respondents (Table 1). The determination of an equal sample size across regencies was intended to ensure balanced representation among study areas, rather than reflecting the actual population proportion in each regency. The selection of farmer respondents was based on the following criteria: (1) active farmers who were currently cultivating or had cultivated rice within the past year, (2) farmers residing within the Bengawan Solo Watershed, and (3) farmers with at least one year of farming experience. Farmers who were not actively engaged in rice farming activities during the study period were excluded from the sample.

Table 1. Sampling Procedure and Data Collection.

Research Location	Number of Respondents
Wonogiri	40
Sragen	40
Karanganyar	40
Sukoharjo	40
Klaten	40
Boyolali	40
Total	**240**

Data were collected through direct interviews with farmer respondents, complemented by observations of farmer groups and their activities. The information gathered included farmer characteristics, land ownership status, use of agricultural inputs, household income and expenditures, as well as environmental awareness. These data serve as the basis for evaluating the welfare of farming households in the Bengawan Solo Watershed.

2.3. Analysis Techniques

Analysis techniques in farming refer to the methods or approaches used to assess and understand the conditions, performance, efficiency, and well-being of farmers. These techniques involve measuring various aspects such as income, consumption, education, health, and access to resources. Through such analyses, researchers can contribute to improving the living standards of farming communities (Nandy & Singh, 2020). In analyzing welfare, several analytical tools can be employed, as illustrated in Figure 1.

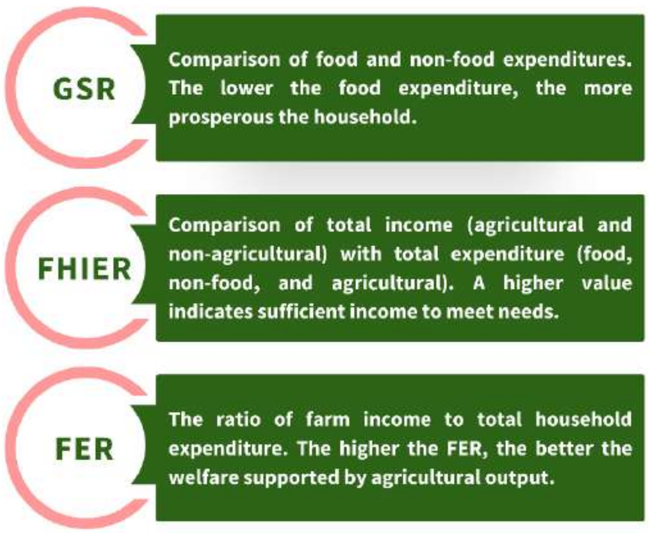

Figure 1. Analysis Techniques.

(1) Good Service Ratio (GSR)

Good service ratio (GSR) is an indicator applied to assess the level of farmers' ability to meet their living needs from farming income (Asante et al., 2025). GSR can be calculated by comparing the food expenditure and the non-food expenditure of farmer households (Rahayu et al., 2023). The GSR is crucial because it reflects the level of farmer welfare. Furthermore, the GSR can be calculated using the following formula:

$$\text{GSR} = \frac{\text{Food Expenditure}}{\text{Non-food Expenditure}} \quad (1)$$

GSR > 1 (Less Prosperous), indicating a heavier economic burden on farming households because food expenditures exceed non-food expenditures.

GSR = 1 (Prosperous), indicating a household balance between food and non-food expenditures.

GSR < 1 (More Prosperous), indicating that farming households spend more on non-food needs than on food needs.

(2) Farmer Household Income Exchange Rate (FHIER)

The Farmer Household Income Exchange Rate (FHIER) is an indicator used to evaluate the welfare level of farming households by comparing household income with household expenditure (Priyadi et al., 2020). Farmer household income and expenditure are crucial in determining the FHIER value. Higher incomes also increase the potential for a farm household's welfare index to increase (Angelica et al., 2025). Then, the FHIER index can be formulated as follows:

$$\text{FHIER} = \frac{\text{Total Income}}{\text{Total Expenditure}} \quad (2)$$

FHIER > 1 (Surplus): Indicates that the farmer's household income is higher than its expenses. An FHIER value > 1 indicates the financial stability of the farmer's household.

FHIER < 1 (Deficit): Indicates that the farmer's household expenses are higher than its income. This indicates that an FHIER value < 1 indicates a financial burden on the farmer's household (Ahdika et al., 2021).

(3) Farmers Exchange Rate (FER)

The Farmers' Exchange Rate (FER) is an indicator used to assess farmers' purchasing power by comparing farm income with total household expenditure. This measure is critical as it directly reflects the welfare of farming households (Ramadhanu et al., 2021). A higher FER value indicates that farm income is sufficient to cover household expenses, whereas a lower FER value suggests economic vulnerability, with farmers struggling to meet basic needs (Pratiwi et al., 2020). The FER is calculated using the following formula:

$$\text{FHIER} = \frac{\text{Total Income}}{\text{Total Expenditure}} \quad (3)$$

FER > 100 (Surplus) indicates that production prices are rising faster than consumption prices, resulting in farmers' income exceeding their expenses.

FER = 100 (Break-even) indicates that farmers' income is balanced with their expenses, meaning they are in a break-even state.

FER < 100 (Deficit) indicates that farmers' consumption is rising higher than production prices, resulting in farmers' income being less than their expenses.

3. Results

3.1. Characteristics of Farmers

Farmer characteristics provide a depiction of the actual conditions and inherent attributes of farmers, which influence farm management practices and the level of prosperity achieved (Bogdan & Kulshreshtha, 2020). These characteristics are commonly classified based on factors such as gender, age, household size, educational attainment, and other socio-demographic variables (Lillo et al., 2025).

Studies in agriculture show that gender has become an important factor that plays a role in agricultural practices and access to resources (Fasakin et al., 2023). Table 2 shows the gender distribution of farmers in the Bengawan Solo watershed, showing that the majority of farmers are men, totaling 200, or 83.33%, while female farmers are only 40, or 16.67%. This distribution indicates that male participation in agricultural activities is significantly more dominant than female participation. The gender distribution of farmers in this study is nearly identical to the results of research conducted by Mwalyagile et al. (2024) in Tanzania, which also reported a higher proportion of male farmers. Male dominance in agriculture is often attributed to the physically demanding nature of farming and men's relatively easier access to land and productive resources, factors that frequently limit women's involvement (Sedegah, 2025).

Table 2. Characteristics of Farmers.

Variable	Frequency	Percentage (%)
Gender		
Male	200	83.33
Female	40	16.67
Total	240	100.00
Age (Year)		
21–42	36	15.00
43–64	133	55.42
65–86	71	29.58
Total	240	100.00
Family Member		
1–3	121	50.42
4–7	118	49.17
8–11	1	0.41
Total	240	100.00
Education Level		
Elementary School	95	39.58
Middle School	45	18.75
High School	71	29.58
College	15	6.25
Not in School	14	5.84
Total	240	100.00
Farming Experience (Year)		
1–24	127	52.92
25–48	86	35.83
49–72	27	11.25
Total	240	100.00
Land Size (m^2)		
235–5,490	185	77.08
5,491–10,746	48	20.00
10,747–16,002	7	2.92
Total	240	100.00
Land Ownership		
Alone	206	85.83
Rent	34	14.17
Sharing	0	0.00
Total	240	100.00

Farmer age is a key factor influencing experience, productivity, and the capacity to manage agricultural activities effectively (Qiao & Liu, 2020). In Table 2, the majority of farmers in the Bengawan Solo Watershed are in the 43–64 age group, 133 people (55.42%), indicating that most farmers are of productive age. Meanwhile, 71 farmers, or 29.58%, are in the 65–56 age group, and only 36, or 15.00%, are in the 21–42 age group. These findings suggest limited participation from the younger generation, with middle-aged and older farmers comprising the majority of the workforce. This study shows that the majority of farmers are in the age category of 40 years or more, comparable to that targeted in the study by Maman et al. (2022), which has similar results. Several factors contribute to the low involvement of younger people in agriculture, including negative perceptions of farming as a labor-intensive and less profitable occupation (Giwu et al., 2024).

Household size is an important factor influencing the economic responsibilities that farmers must bear (Bitana et al., 2024). In Table 2, the majority of farmers have families ranging from 1–3 people (121 farmers, or 50.42%), with 118 farmers (49.17%) having families with 4–7 people. Meanwhile, only one farmer has a family of 8–11 people. These data indicate that the majority of farmers in the Bengawan Solo watershed have small to medium-sized families. The data in this study are almost in line with the research of Istiyanti et al. (2024) found that most farmers in

Kulonprogo have an average family size of 1–3 people. With relatively small household sizes, the economic obligations of farmers remain moderate and aligned with the household's capacity to meet daily needs (Stratton et al., 2020).

One of the important factors influencing farm management is the level of farmer education. The level of education is very useful in increasing agricultural production results (Hasanah et al., 2021). Higher education enhances farmers' ability to access information, adopt technology, and capitalize on business opportunities (Sharma & Bhambri, 2024). From the data presented in Table 2, the majority of respondents in the Bengawan Solo Watershed were at the elementary school level, 95 people (39.58%), making this group the largest. Meanwhile, the lowest number was in the Not in School category, with 14 people (5.83%). This data shows that although some farmers only received a low level of education, the majority had completed elementary to secondary education, with quite a few farmers even reaching high school and university. Farmers who have received a proper education often receive support in the form of understanding of innovation, information, and technology related to agriculture (Oli et al., 2025).

Farming experience is an important aspect that reflects a farmer's skills and knowledge in managing a farm. Greater experience generally enhances farmers' ability to overcome challenges, make informed decisions, and adapt to changing conditions (Habtemariam et al., 2020). Based on Table 2, the majority of farmers in the Bengawan Solo Watershed have experience ranging from 1-24 years, namely 127 people or 52.92%, indicating a dominance of farmers with relatively short to medium experience. Then, there are 86 people or 35.83% who have 25–48 years of experience, and only 27 people or 11.25% have 49–72 years of experience. These results suggest that the majority of farmers possess limited to moderate experience, with relatively few having long-term expertise. This limited experience may restrict their ability to apply advanced farm management strategies, making them more reliant on traditional practices or support from agricultural extension services (To-The et al., 2025).

Land size is a critical determinant of agricultural production capacity. Farmers with larger holdings have greater opportunities to increase yields and income, while those with smaller plots often face operational and economic constraints (Kumar & Moharaj, 2023). From Table 2, the majority of farmers in the Bengawan Solo Watershed own land areas of 235–5,490 m² (185 people; 77.08%), while the fewest own land areas of 10,747–16,002 m² (only 7 people; 2.92%). These findings indicate that most farmers operate on small-scale landholdings, which may restrict productivity and limit household income (Mathinya et al., 2022).

Land ownership status indicates the pattern of land ownership by farmers, whether the land is owned, leased, or held through a profit-sharing system. This pattern influences the farmer's level of independence and the costs they must bear in the farming process (Akber et al., 2024). Based on the data in Table 2, the majority of farmers in the Bengawan Solo Watershed own their own agricultural land, with a total of 206 people or 85.83%. Meanwhile, 34 people, or 14.17% of farmers, manage their land by renting. No farmers use a profit-sharing system, so the land ownership pattern is dominated by farmers who own their own land and a small number who rent. This pattern reflects a predominance of private ownership, which generally provides more stable economic returns compared to rented land, where production costs tend to be higher and income less secure (Geng et al., 2021).

3.2. Cost

3.2.1. Farming Input Costs

Farming input costs represent all expenditures incurred by farmers to procure agricultural production facilities required before and during the rice cultivation process (Ibañez et al., 2024). Farming input costs include several components such as seeds, fertilizers, and pesticides. These components play a direct role in determining the quality and quantity of the harvest (Bailly & Roldan, 2023). Careful analysis of input costs enables farmers to manage expenditures more efficiently, ensuring that each investment contributes to optimal improvements in yield and overall productivity.

Fertilizer is a critical input in rice farming, as it enhances soil fertility and supports plant growth and productivity. Based on Table 3, the total average cost of agricultural production inputs incurred by farmers in the Bengawan Solo watershed area reached IDR 3,205,599. Then, in the seed component, the highest cost was spent on Mapan varieties (05 & 25) at IDR 387,938, while the smallest was Hybrid Rice with a cost of IDR 21,000. For fertilizers, the highest expenditure was on chemical fertilizers with a cost of IDR 1,715,169, while the lowest was on liquid organic fertilizer at IDR 4,770. As for pesticides, the highest cost was allocated to chemical pesticides, worth IDR 279,162, while the smallest was organic pesticides, with a cost of only IDR 750.

Table 3. Farming Input Costs for a Year.

Production Facilities	Costs (IDR)	Percentage (%)
Seed Varieties		
Inpari (32, 35, & 64)	49,092	1.56
Mapan (05 & 25)	387,938	12.35
Ciherang	52,000	1.66
Hibrida	21,000	0.67
Mentik (Wangi & Susu)	60,000	1.91
Logawan	51,000	1.62
PP/P2	227,001	7.23
Mengkongga	36,000	1.18
Segreng	51,000	1.62
Sidenok	90,000	2.87
Situagendit	45,000	1.43
Total Seed Varieties	1,070,031	34.08
Fertilizer		
Chemical Fertilizers	1,715,169	54.64
Animal Manure	16,251	0.52
Liquid Organic Fertilizers	4,770	0.15
Solid Organic Fertilizers	53,001	1.69
Total Fertilizer	1,789,191	57.00
Pesticides		
Chemical Pesticides	279,162	8.89
Organic Pesticides	750	0.03
Total Pesticides	279,912	8.92
Total Farming Inputs Costs	3,139,134	100.00

In general, these findings indicate that farmer expenditures in the Bengawan Solo watershed remain heavily concentrated on chemical fertilizers and selected seed varieties, while spending on organic fertilizers and pesticides remains minimal. This pattern suggests a strong dependence on chemical inputs to sustain agricultural productivity, consistent with the observations of Hasibuan et al. (2022).

3.2.2. Depreciation Cost

Depreciation costs represent the reduction in the value of fixed assets, such as agricultural tools and machinery, over their useful life due to wear, aging, or other technical factors (Schroers et al., 2020). These costs are typically calculated by subtracting the residual value of an asset from its initial value and dividing the result by its economic lifespan, thereby yielding the annual depreciation expense (Arata et al., 2025). The existence of depreciation costs is very important because it can affect the calculation of overall production costs, where the greater the depreciation value, the greater the total farming costs, and ultimately, can reduce the net profits received by farmers (Sampaio et al., 2021).

As shown in Table 4, the depreciation costs of agricultural equipment in the Bengawan Solo Watershed, it can be seen that the largest depreciation is found in sprayers with an average value of IDR 71,312 or approximately 49.08% of the total depreciation cost. Meanwhile, the smallest depreciation is found in other harvesting equipment with an average value of IDR 335 or 0.23%, so their contribution to the total depreciation cost is relatively small. This indicates that sprayers are the equipment that bears the largest depreciation burden, while harrows have almost no significant impact.

Table 4. Equipment Depreciation Costs for a Year.

Types of Equipment	Amount (IDR)	Percentage (%)
Hoe	27,891	19.20
Sickle	30,623	21.08
Sprayer	71,312	49.08
Weigher	1,152	0.79
Shovel	1,104	0.76
Harrow	663	0.46
Tractor	12,223	8.40
Other Harvesting Equipment	335	0.23
Total Depreciation Cost	145,303	100.00

3.2.3. Labor Costs

In agriculture, labor costs constitute a major component of the production cost structure, as nearly every stage of farming requires human or mechanical labor (Vaňová et al., 2024). Labor costs include workers' wages, overtime costs, operational costs for the use of machinery or other agricultural tools, as well as allowances or other facilities provided to workers during the farming business (Frahan et al., 2024).

Table 5 shows that labor costs in the Bengawan Solo Watershed, the highest labor costs are found in harvesting activities, totaling IDR 3,154,362, while the lowest are in post-harvest activities, at only IDR 5,625. This indicates that harvesting is the most labor-intensive stage of rice farming, while post-harvest activities require minimal labor input. In addition, planting and land preparation also represent substantial cost components, with planting expenses being relatively high due to the large workforce required at this stage (Jumpah et al., 2024). Land preparation, by contrast, relies more heavily on machinery to improve efficiency (Li et al., 2024).

Table 5. Labor Costs for a Year.

Description	Non-Family Labor (WH)	Labor Cost (IDR)	Machine (IDR)	Total (IDR)
Land Preparation	0.85	644,250	1,239,375	1,883,625
Planting	8.17	2,235,999	0	2,235999
Weeding	0.30	145,251	1,875	147,126
Harvesting	4.38	2,091,237	1,063,125	3,154,362
Post-Harvest	0.01	5,625	0	5,625
Transportation	0.10	96,501	51,249	147,750
Total Labor Cost	13.81	5,218,863	2,355,624	7,574,487

*WH (Working Hour)

3.2.4. Other Costs

In addition to major inputs such as seeds, fertilizers, labor, and depreciation, farming also incurs other costs that fall into the category of indirect expenses (Mamadiyarov et al., 2023). These costs include indirect expenses, such as administrative costs or other unforeseen expenses (Baraka et al., 2021). Although relatively small in nominal value, these costs still contribute to total production expenses and must be considered to ensure more efficient farm management.

Other costs in farming in the Bengawan Solo Watershed are dominated by expenditures for Indirect Taxes, with an average of IDR 600,000 per year, while the lowest is the cost of Spare Parts Maintenance, with an average of only IDR 117,500 per year (Table 6). These findings suggest that tax obligations, although indirect, represent the most significant additional financial burden for farmers in the Bengawan Solo Watershed, whereas their maintenance costs contribute minimally to overall expenditures. Such costs, though secondary, still raise total production expenses and may reduce farmers' profit margins, thereby lowering overall farming efficiency (Baraka et al., 2021).

Table 6. Other Costs for a Year.

Other Costs	Amount (IDR)
Spare Parts Maintenance	117,500
Indirect Taxes	600,000
Farmers Group Membership Fees	240,000
Internet/Credit/Data	500,000
Other Expenses	260,000
Total Other Costs	1,717,500

3.2.5. Total Costs

In a farming enterprise, total costs represent the cumulative sum of all expenses incurred by farmers throughout the production process (Sultan et al., 2021). In general, costs are categorized into two types: fixed costs and variable costs. Fixed costs refer to expenditures that remain unchanged regardless of the level of production, whereas variable costs encompass expenses that fluctuate in accordance with changes in the level of output.

Based on Table 7, the total expenditures of farmers in the Bengawan Solo Watershed, it can be observed that the overall cost incurred amounts to IDR 12,576,424. The largest portion of the expenses comes from labor costs, totaling IDR 7,574,487, while the smallest portion is attributed to equipment depreciation costs, amounting to IDR 145,303. This indicates that the farming cost structure in the Bengawan Solo Watershed shows a higher concentration of expenses allocated to labor wages, whereas the cost of asset depreciation contributes the least to the total expenditure.

Table 7. Total Costs.

Types of Costs	Amount (IDR)
Total Farming Inputs Costs	3,139,134
Total Depreciation Cost	145,303
Total Labor Costs	7,574,487
Total Other Costs	1,717,500
Total Costs	12,576,424

3.3. Farmer Household Income

Farmer household income encompasses all earnings derived from both agricultural and non-agricultural activities (Hariyanto et al., 2021). These may include revenues from the sale of agricultural products, wages from off-farm employment, or income from secondary businesses (Octavio et al., 2024). The size of a farmer's household income greatly determines the welfare of the farmer's household, because it will affect their ability to meet their daily needs (Aleksandrova et al., 2024).

Table 8 indicates that farmer household income in the Bengawan Solo Watershed, the highest source of income from the agricultural sector comes from rice farming with an average of IDR 35,416,789 (71.05%), while the lowest is from livestock with an average of IDR 1,538,333 (3.09%). Then, in non-agricultural income, the largest source comes from laborers with an average of IDR 7,044,167 (14.13%), while the lowest is from drivers with an average of only IDR 75,000 (0.15%). These findings demonstrate that farming households in the Bengawan Solo Watershed remain heavily dependent on agriculture, particularly rice cultivation, as their primary source of livelihood, as reflected in Figure 2, which shows that agricultural activities account for 74.14% of total household income, compared to 25.86% from non-agricultural sources. This dependence is largely shaped by limited access to non-agricultural employment opportunities, low skill levels outside the farming sector, and strong cultural and hereditary ties to land management (Sumaryanto et al., 2021).

Table 8. Farmer Household Income for a Year.

Type of Income	Amount (IDR)	Percentage (%)
Agriculture		
Rice Farming	35,416,789	71.05
Livestock	1,538,333	3.09
Total Agriculture	36,955,122	74.14
Non-Agriculture		
Laborer	7,044,167	14.13
Trader	2,314,300	4.64
Furniture Maker/Carpenter	1,078,333	2.16
Tailor	125,000	0.25
Teacher	250,000	0.50
Civil Servant	830,000	1.67
Retiree	525,000	1.05
Self-Employed	426,000	0.85
Village Government Employee	222,000	0.45
Driver	75,000	0.15
Total Non-Agriculture	12,889,800	25.86
Total Farmer Household Income	49,844,922	100.00

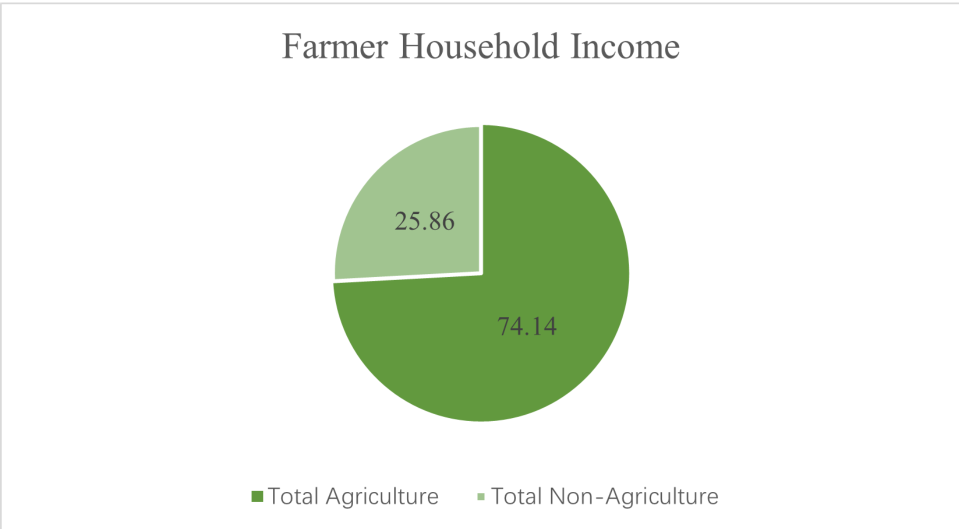

Figure 2. Farmer Household Income.

3.4. Farmer Household Expenditure

Farmer household expenditure refers to the total costs incurred by farming families to meet daily living needs (Hariyanto et al., 2021). In general, expenditure is divided into two main categories, namely, food expenditure, such as rice, side dishes, vegetables, and other consumption needs, and non-food expenditure, which includes education costs, health, transportation, and other social needs (Kaur et al., 2023). The level of household expenditure greatly influences the economic conditions of farmers, because expenditure that is greater than income will suppress purchasing power, savings, and the ability of farmers to develop their farming businesses (Shafi et al., 2021).

As presented in Table 9, farmer household expenditures in Bengawan Solo Watershed are predominantly allocated to non-food needs, with an average of IDR 16,767,301, much larger compared to food category expenditure, which is only IDR 6,353,760. The largest component of the non-food category comes from others, amounting to IDR 3,197,433, while in the food category, the largest component comes from side dishes, amounting to IDR 2,534,868. Meanwhile, the smallest component of non-food expenditure comes from the health category, amounting to IDR 230,448, then the smallest component of food expenditure is the rice category, amounting to IDR 38,448. Overall, the total expenditure of farmer households reaches IDR 35,697,485, which shows that non-food needs have a larger amount compared to food needs, as also illustrated in Figure 3, where non-food expenditures account for 72.52% of total household spending, while food expenditures comprise only 27.48%. Therefore, non-food expenditure is the main factor that influences the economic condition of farmer households. (Table 9)

Table 9. Farmer Household Expenditure for a Year.

Type of Production	Amount (IDR)	Percentage (%)
Food		
Rice	38,448	0.17
Vegie & Fruit	870,396	3.76
Side Dishes	2,534,868	10.96
Spice	1,831,308	7.92
Drink	269,820	1.17
Snack	808,920	3.50
Total Food	6,353,760	27.48
Non-Food		
Lighting and Fuel	3,918,456	16.95
Tax	2,585,532	11.18
Communication	1,095,744	4.74
Family	3,429,036	14.83
Daily necessities	1,176,900	5.09
Health	230,448	1.00
Social	1,133,750	4.90
Others	3,197,433	13.83
Total non-food	16,767,301	72.52
Food & Non-Food Expenditures	23,121,061	100.00
Agricultural & Non-Agricultural Expenditures	12,576,424	
Total Expenditures	35,697,485	

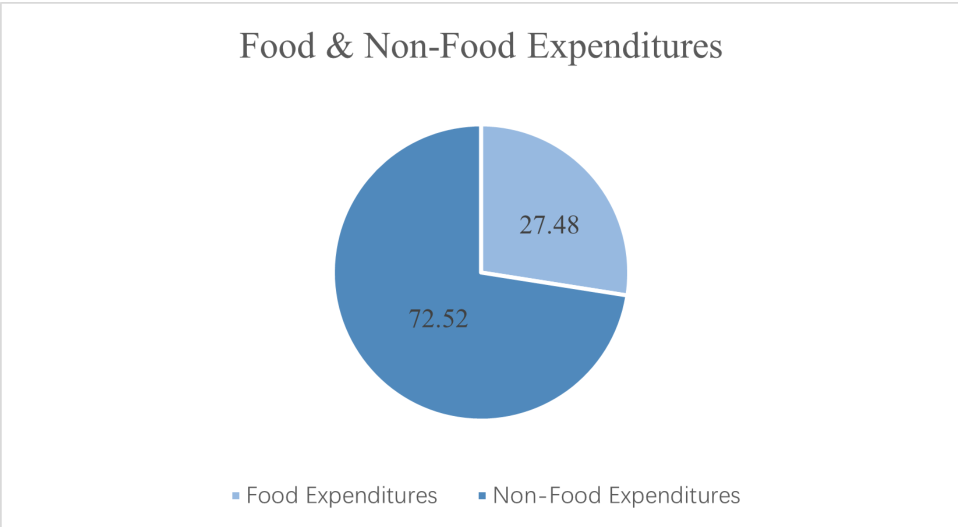

Figure 3. Food and Non-Food Expenditures.

3.5. Standard of Living of Farmer Households Based on Welfare Level

3.5.1. Good Service Ratio (GSR)

GSR, or the Good Service Ratio, is an indicator used to compare food and non-food expenditures in farming households. Food expenditures cover daily necessities, staples, side dishes, snacks, drinks, and more. Non-food expenditures include other costs such as taxes, transportation, healthcare, education, and more.

From the results of the Good Service Ratio (GSR) analysis presented in Table 10, it can be seen that food-related expenditures amount to IDR 6,353,760, while non-food expenditures reach IDR 16,767,301. The GSR calculation for farmers in the Bengawan Solo watershed yielded a value of 0.38. This value indicates that rice farming households in the Bengawan Solo watershed in

Central Java are relatively prosperous. A GSR value below 1 indicates that household income is sufficient not only to cover food consumption but also to allocate a greater share of expenditures toward non-food needs, reflecting a higher level of welfare. These findings contrast with the results reported by Rahayu et al. (2023), who explained that the welfare analysis of red rice farmers in Gunung Kidul, measured using the Good Service Ratio, yielded a value of 1.13, indicating that these farmers fall into the non-prosperous category.

Table 10. Analysis Good Service Ratio.

Description	Amount
Food Expenditure (IDR)	6,353,760
Nod-food Expenditure (IDR)	16,767,301
Good Service Ratio < 1	**0.38**

3.5.2. Farmer Household Income Exchange Rate (FHIER)

The Farmers Household Income and Expenditure Ratio, or FHIER, is an indicator used to compare a farmer's household income to its total expenses. This value reflects the extent to which income is able to cover the farmer's living expenses. The FHIER is obtained by comparing total income and total expenses.

Based on the results of the Farmer Household Income Exchange Rate (FHIER) analysis presented in Table 11, it is observed that the total income of farmers in the Bengawan Solo watershed amounts to IDR 49,844,922, while the total expenditure reaches IDR 35,697,485. The FHIER was calculated at 1.40. Since the value is greater than 1, this indicates that farming households in the Bengawan Solo Watershed earn incomes that exceed their total expenditures. An FHIER above 1 reflects financial stability, demonstrating that households are able to cover their living costs while maintaining a surplus. The analysis in this study is consistent with the findings of Priyadi et al. (2020), who reported an FHIER value of 1.28, indicating that farmers were experiencing a surplus.

Table 11. Analysis of Farmer Income Exchange Rate.

Description	Amount
Total Income (IDR)	49,844,922
Total Expenditure (IDR)	35,697,485
FHIER	**1.40**

3.5.3. Farmers Exchange Rate (FER)

The Farmers Exchange Rate (FER) is an indicator that describes a farmer's ability to cover household needs through farm income. The Farmers' Exchange Rate is the ratio of farm income to total expenses paid by farmers (inputs and consumption), which is used as an indicator of farmer welfare.

Based on Table 12 of the Farmers' Exchange Rate (FER) analysis for farmers in the Bengawan Solo watershed, it is shown that the farming income amounts to IDR 35,416,789, while the total expenditure reaches IDR 35,697,485. The FER was calculated at 99.21. Since this value is below the threshold of 100, it indicates that household consumption exceeds production income, meaning that farmers' earnings from agricultural activities are insufficient to cover total expenses. This condition reflects a low level of welfare, as farming households face a significant income expenditure deficit. In other words, this indicates that the farming activities carried out have not yet generated optimal profits, and therefore, the welfare of the farmers has not been fully achieved. However, the findings of this study are not consistent with those reported by Syaharuddin et al. (2021), in which the standard FER value was 118.76, indicating that farmers in West Nusa Tenggara were experiencing a surplus.

Table 12. Analysis of Farmers' Exchange Rate.

Description	Amount
Farming Income (IDR)	35,416,789
Total Expenditure (IDR)	35,697,485
Farmers Exchange Rate < 100	**99.21**

4. Discussion

The results reveal a complex welfare condition among rice farmer households in the Bengawan Solo Watershed. The Good Service Ratio (GSR) value of 0.38 indicates that the household expenditure is more heavily allocated to non-food needs than food needs. However, this expenditure pattern is not solely supported by income from rice, such as off-farm and non-farm employment, which contribute significantly to activities. This finding suggests that the welfare of rice farmer households in the Bengawan Solo Watershed is highly dependent on income diversification beyond agricultural production. These findings are consistent with the study conducted by Triyono & Berliani Arifianikmah (2024), which found that farmers in Candibinangun Village were categorized as prosperous, with a GSR value of 0.98.

Meanwhile, the Farmer Household Income Exchange Rate (FHIER) among farmers in the Bengawan Solo Watershed was 1.40, indicating that household income is higher than total household expenditure. This suggests that rice farmer households in the Bengawan Solo Watershed are in a surplus condition. The FHIER value also strengthens the evidence that income from various sources, both agricultural and non-agricultural, helps maintain the economic stability of farming households. The findings of this study are consistent with those reported by Triyono and Berliani Arifianikmah (2024), who found an FHIER value of 1.41, showing that farmers in Candibinangun Village achieved a good level of welfare.

However, the results of the Farmers' Exchange Rate (FER) analysis show a value of 99.21, indicating that income derived solely from rice farming is insufficient to cover the total household expenditures of rice farmers in the Bengawan Solo Watershed. In other words, farmers are still experiencing a deficit in the agricultural sector, and reliance solely on agricultural income has not yet guaranteed household welfare. The condition of farmers in the Bengawan Solo Watershed is consistent with the findings of Ramadhanu et al. (2021), which explained that a low FER is often caused by high agricultural production costs, rising input prices, and farmers' dependence on chemical fertilizers and labor.

The apparent contradiction between the positive GSR (0.38) and FHIER (1.40) values and the deficit FER (99.21) reveals a critical vulnerability in the welfare of rice farmer households in the Bengawan Solo Watershed. Although household welfare appears relatively stable when total income is considered, this condition is largely sustained by income diversification, particularly from non-agricultural sources, which account for a substantial share of household income. The FER value below 100 indicates that income derived solely from rice farming remains insufficient to cover household expenditures, highlighting that agricultural activities alone have not yet ensured sustainable household welfare. Consequently, farmers' economic stability is fragile and highly vulnerable to potential disruptions in off-farm and non-farm employment opportunities.

This condition is closely related to structural challenges in the Bengawan Solo Watershed. Previous studies have documented that seasonal flooding, suboptimal water management, and soil degradation have limited rice productivity and increased production risks in this region, thereby reducing the profitability of rice farming. As a result, farmers are compelled to rely on income diversification strategies to maintain household welfare. The low FER observed in this study, therefore, reflects not only farm-level economic inefficiency but also broader environmental and infrastructural constraints that continue to undermine the sustainability of rice-based livelihoods in the Bengawan Solo Watershed.

Furthermore, the expenditure structure of farmers is still dominated by labor costs and chemical inputs, indicating that production efficiency has not yet reached an optimal level. The high use of chemical fertilizers and pesticides also demonstrates the limited application of environmentally friendly agricultural technologies and the lack of farm diversification. This highlights the importance of enhancing farmers' capacity through agricultural extension programs and government support in promoting sustainable agricultural technologies (Nath et al., 2023).

Farmer welfare is also influenced by socio-economic characteristics such as age, education level, farming experience, and land ownership status. The majority of farmers are within the productive age range (43–64 years) and have attained basic to secondary education levels, which can serve as valuable assets in adopting technological innovations and modern farming practices. However, the relatively low participation of younger generations remains a significant challenge for the sustainability of the agricultural sector in the Bengawan Solo Watershed region.

Overall, this study reveals that the welfare of rice farmer households in the Bengawan Solo Watershed is primarily sustained through income diversification rather than agricultural profitability alone. The strong dependence on non-agricultural income sources exposes farming households to significant economic vulnerability, as disruptions in off-farm employment opportunities could rapidly undermine household welfare despite the currently positive GSR and FHIER values. Furthermore, environmental constraints specific to the Bengawan Solo Watershed, such as seasonal flooding, water management challenges, and soil degradation, contribute directly to the low profitability of rice farming, as reflected in the FER value of 99.21. These findings underscore the need for integrated policy interventions that not only improve production cost efficiency and adopt modern farming technologies but also strengthen farmer organizations and promote more resilient livelihood strategies to support sustainable farmer welfare.

This study has several limitations. First, the analysis relies on cross-sectional data, which may not fully capture temporal variations in farmer welfare and income dynamics, particularly in relation to seasonal flooding and climate variability in the Bengawan Solo Watershed. Second, the welfare assessment is limited to three indicators (GSR, FHIER, and FER), which may not fully reflect other social and institutional dimensions of farmer welfare. Future research is encouraged to employ longitudinal data, incorporate additional welfare indicators, and examine the role of institutional support, climate adaptation strategies, and market access in shaping the long-term welfare of rice farmers.

5. Conclusion

Based on the discussion, the welfare of rice farmers in the Bengawan Solo Watershed reflects a complex condition characterized by a strong dependence on non-agricultural income sources rather than agricultural activities alone. The annual household income of rice farmers in the Bengawan Solo Watershed, Central Java, reaches IDR 49,844,922, consisting of IDR 36,955,122 derived from the agricultural sector and IDR 12,889,800 from non-agricultural activities. Meanwhile, total household expenditure amounts to IDR 35,697,485 per year, including food, non-food, agricultural, and non-agricultural expenditures, indicating that household welfare is maintained through a combination of multiple income sources rather than rice farming profitability alone.

This condition indicates a surplus between household income and expenditure. The GSR value of 0.38 shows that food expenditure is lower than non-food expenditure, reflecting a consumption pattern associated with the fulfillment of secondary needs. In addition, the FHIER value of 1.40 indicates that total household income is sufficient to cover overall expenditures. Critically, however, the FER value of 99.21 demonstrates that income derived solely from rice farming is insufficient to meet household expenses, revealing that farmer welfare is heavily dependent on off-farm and non-agricultural income sources. This dependence creates significant economic vulnerability, as any disruption to non-agricultural employment opportunities could rapidly threaten the welfare of rice farmer households in the Bengawan Solo Watershed.

Overall, while farming households are generally able to meet their needs, as confirmed by the GSR and FHIER, the low FER highlights the need for innovation and diversification of income sources. Given the critical role of off-farm income in maintaining household welfare and the environmental challenges specific to the Bengawan Solo Watershed, policy interventions must address both improvements in agricultural productivity and livelihood diversification strategies to ensure sustainable farmer welfare.

Therefore, policy interventions should be specifically directed at addressing the low FER value (99.21), which indicates that income from rice farming alone is insufficient to sustain household welfare. Targeted measures are required to reduce production costs and improve income efficiency, such as input subsidy schemes for fertilizers and seeds, extension services focused on cost-efficient and climate-resilient rice farming practices, and improved access to affordable agricultural credit. In parallel, considering the strong dependence on off-farm income, livelihood diversification strategies should be strengthened through the development of non-rice agricultural activities and rural non-farm employment opportunities. Strengthening farmer organizations and cooperatives is also essential to enhance farmers' bargaining power, market access, and resilience to economic shocks, particularly in the flood-prone Bengawan Solo Watershed. These integrated policy measures are expected to support sustainable livelihoods, improve regional productivity, and enhance food security in the long term.

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Abbreviations

The following abbreviations are used in this manuscript:

GSR	Good Service Ratio
FHIER	Farmer Household Income Exchange Rate
FER	Farmers Exchange Rate
IDR	Indonesian Rupiah

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Agricultural & Rural Studies

Article

Assessment of Impact, Vulnerability, and Farm Households' Adaptation in the Context of Climate Change: A Study on Six Agro-Climatic Zones of Assam, India

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Abstract: This study investigates the impact of climate change on farm households across six agro-climatic zones of Assam, India, characterized by diverse topographies and climate-related challenges. The zones, ranging from flood-prone areas to hilly terrains, experience unique climate-related stresses, including floods, droughts, and soil erosion. To develop region-specific strategies, this research identifies the determinants of adaptive management practices employed by farmers in response to these climate-related challenges. The study reveals that Assam is highly vulnerable to climate change impacts, including erratic rainfall, rising temperatures, and extreme weather events. To mitigate these effects, farmers have adopted various adaptation measures, which are analyzed to understand their effectiveness in coping with climate change in Assam. The research area comprises six districts from each agro-climatic zone. The study found that the majority of farmers remain heavily reliant on the monsoon, as evidenced by the limited attention given to their choices in adopting irrigation facilities, with only 30 percent of the surveyed farmers implementing this strategy. A total of nine factors influencing adaptation strategies were assessed using a binary logistic model (BLM) or regression analysis. More than 86 percent of farmers in the study area reported having experienced climate change over the last 30 years. Furthermore, farmers' awareness and perceptions regarding alterations in rainfall and temperature revealed that a considerable number acknowledged fluctuations in rainfall; however, in relation to temperature, they observed an increase only in the past three years, attributing this rise primarily to increasing relative humidity as a significant factor.

Keywords: adaptive management; climate change; perception on climate change; agriculture

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1. Introduction

Climate change poses significant challenges for agriculture, particularly affecting marginalized and small farmers who rely heavily on farming for their livelihoods. Without appropriate adaptation strategies, the impact of climate change could worsen dramatically (Elum et al., 2016; Elum & Snijder, 2023). Adaptation measures are essential to mitigate the negative effects of climate shifts on agricultural practices (Intergovernmental Panel on Climate Change [IPCC], 2023). India, in particular, faces compounded stress from industrial development and urbanization, which further strains its socio-ecological systems. The "global climate risk index" (2023) ranks India as the 8th most vulnerable country out of 182 to climate hazards (Ministry of Finance, 2024). While both adaptation and mitigation policies are available, adaptation is considered a crucial approach in the agricultural sector. While mitigation efforts are important for reducing the long-term effects of climate change, adaptation strategies are vital for reducing the immediate vulnerabilities faced by farmers and farming communities (Wheeler & von Braun, 2013). Implementing effective adaptation practices can safeguard agricultural production, lessen vulnerabilities, and enhance the resilience of farming systems in the face of changing climatic conditions. Thus, it is crucial for agricultural communities to understand available adaptation options and the challenges they might encounter in implementing them. Several studies have explored climate change adaptation using a multinomial logit (MNL) model to analyze the choices farmers make regarding various adaptation strategies (Adimassu & Kessler, 2016; Begum & Mahanta, 2017; Deressa et al., 2009; Gbetibouo, 2009; Hisali et al., 2011; Marie et al., 2020; Nhemachena & Hassan, 2007). However, this approach may not adequately capture the reality, as many households adopt multiple adaptation strategies simultaneously. Grouping adaptation responses, such as "livelihood diversification by moving to non-farming" or "altering planting decisions by sowing different crop varieties," can complicate the analysis of the factors influencing farmers' decisions. Therefore, we have chosen to employ a Binary Logit model to more effectively identify the specific factors that influence farmers' choices related to each adaptation option. Recent studies have emerged, shedding light on the connection between the agricultural sector and climate change. One segment of this literature examines how climate change affects crop yields in India, while another explores how crop diversity can serve as a strategy for adapting to climate shifts. At a regional level, Upadhyay (2012) analyzed the productivity changes in rice across Assam from 1970 to 2010, utilizing time-series data. In this study, average temperature and annual rainfall were assessed as climate variables, alongside non-climatic factors such as high-yield variety seeds, irrigation coverage, and fertilizer use. The multiple regression results suggest that rising temperatures negatively impact rice productivity, whereas rainfall has a beneficial effect. In another approach, Mandal and Singha (2020) applied the feasible generalized least squares method to a stochastic yield function to evaluate the effects of climate change on the mean yields of five crops—winter, summer, autumn rice, mustard, and potato—using district-level panel data from 1991 to 2013. Their findings indicate that expected extreme temperatures could severely reduce average yields of summer rice and mustard, while typical mean temperatures exhibited a non-linear influence on the yield variability of summer rice, winter rice, and potatoes. Looking at adaptation strategies, Begum and Mahanta (2017) explored how farmers respond to mitigate the adverse effects of climate change, identifying key factors that shape their adaptive choices. Interviews with 230 farmers across three agro-climatic zones in Assam revealed common strategies such as fertilizer application, crop variety adjustments, innovative farming practices, and changes in planting schedules. Their Probit regression analysis identified income levels, non-farming extension services, and access to credit as primary influences on these adaptation decisions.

Different agro-climatic zones often face distinct challenges regarding access to technology, infrastructure, and information. By analyzing the factors that determine these disparities, we can better address the needs of all farmers and provide equitable support. It's vital to study how farmers in Assam's varied agro-climatic zones adapt their management practices in the face of climate change. This understanding is crucial for crafting targeted strategies that enhance food security and sustainable livelihoods. Despite various policy initiatives aimed at fostering farm-level adaptation, the adoption rates remain notably low across different states (Kharumnuid et al., 2018). Bryan et al. (2013) investigate farmers' views on climate change, current adaptation strategies, and the factors that affect farmers' decisions to adapt in Kenya. The findings indicate that households encounter significant obstacles in adapting to climate change. Although many households have implemented minor modifications to their farming methods in response to climate change (notably, altering planting choices), only a few households can afford to make more substantial investments, such as in agroforestry or irrigation, despite a willingness to invest in such initiatives. This highlights the necessity for increased investments in rural and agricultural development to enhance the capacity of households to make strategic, long-term choices that influence their future well-being. Bryant et al. (2000) emphasize agricultural adaptation as a deliberate proactive or reactive response to climate-related changes, influenced by various factors. A notable characteristic of the methodologies employed in research on adaptation within Canadian agriculture is the emphasis on the significant role of human agency. Many individual farmers believe they are well-equipped to adapt to climate due to their extensive "technological" toolkit, which instills confidence in their ability to manage climatic changes. In numerous regions, there is minimal concern regarding climate change, except in cases where specific types of climatic vulnerability are present. Farmers react to biophysical factors, including climate, as they engage with a complex array of human factors. Several of these factors, particularly institutional and political ones, have tended to reduce the risks at the farm level associated with climatic variability and change, yet they may also exacerbate the long-term vulnerability of Canadian agriculture. Despite the technological and management adaptation strategies accessible to producers, Canadian agriculture continues to be susceptible to climatic variability and climate change. Sarkar and Padaria (2015) carried out a study in the Shimla and Kullu districts of Himachal Pradesh, India, aimed at assessing the knowledge and awareness levels of farmers regarding climate change. A total of 100 farmers were interviewed, and information was gathered from various experts to develop future extension strategies. The findings indicated that only 22 percent of respondents were aware of climate change in the region, while 43 percent had knowledge of the various human-induced factors contributing to climate change. The study highlights the low levels of knowledge and awareness among the sample, suggesting the necessity for an intensive extension education program to enhance their capacity and empower them with information. From the existing literature, it is found that there is a pressing need for comprehensive research to identify the factors influencing farmers' adaptive behaviours. This study seeks to bridge that gap by examining the diverse adaptation measures utilized by farmers in both dry and flood-prone areas within Assam's agro-climatic zones, as well as the barriers they face in implementing those practices. The following Figure 1 shows the agro-climatic zones of Assam.

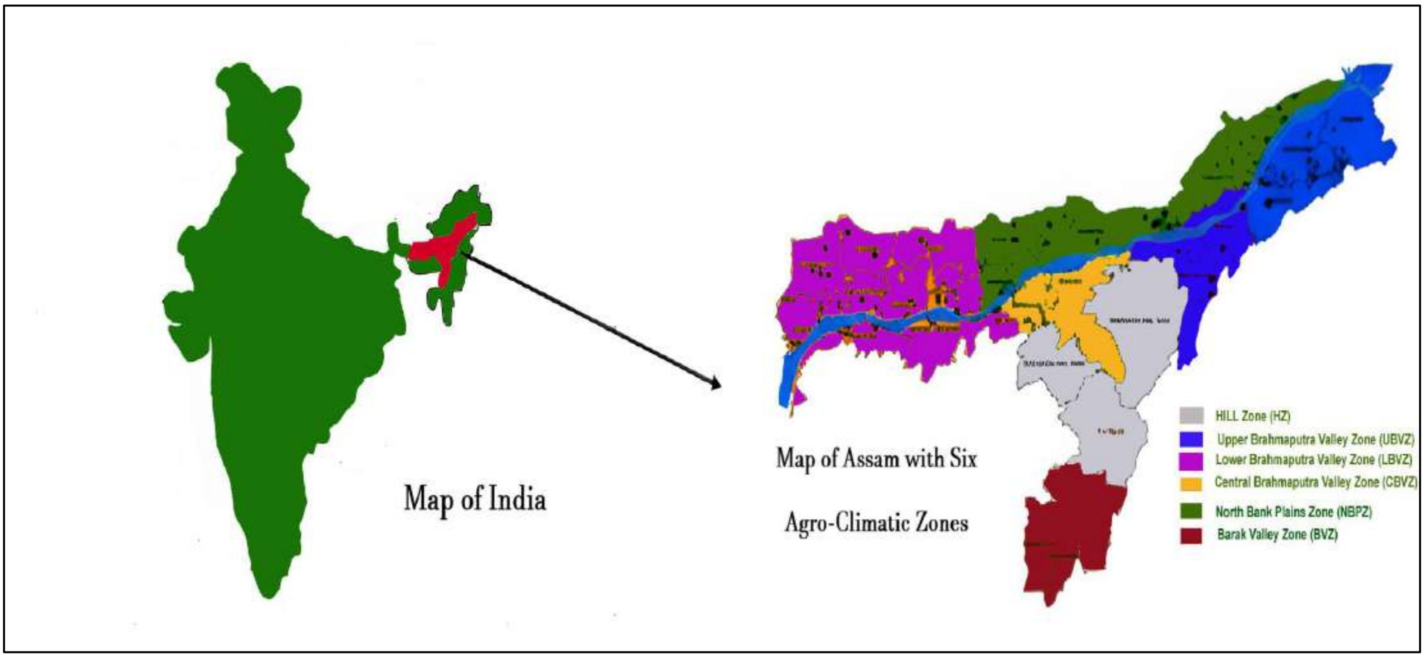

Figure 1. Map of India and Assam with Six Agro-Climatic Zones.

2. Materials and Methods

The data collection took place in the second half of 2024 using a self-structured survey schedule. From the six agro-climatic zones of Assam, namely Hill Zone (HZ), Upper Brahmaputra Valley Zone (UBVZ), Lower Brahmaputra Valley Zone (LBVZ), Central Brahmaputra Valley Zone (CBVZ), Barak Valley Zone (BVZ), and North Bank Plains Zone (NBPZ), six districts have been selected, namely Golaghat, Nagaon, Barpeta, Lakhimpur, Cachar, and Dima Hasao. These areas were chosen due to their agricultural prominence and notable climatic variations after a thorough analysis of secondary data. To explore the adaptability and vulnerabilities of farmers in the face of climate change, we employed a multistage purposive sampling approach. This method involved selecting blocks, villages, and households based on observed rainfall inconsistencies and agricultural climate predispositions.

A total of 2 blocks from each district and 2 villages from each block, i.e., a total of 12 blocks and 24 villages have been selected for the survey, which is based on various aspects like the variability of the crops cultivated, flood-prone & relatively dry areas, as their means of adaptation vary depending on all these aspects. Subsequently, the perception of climate change, determinants of adaptation considering socio-economic factors, and barriers to adaptation are discussed separately. Finally, the study gathered primary data from around 300 agricultural households randomly.

The following Figure 2 shows the sample design by taking households as a unit of analysis.

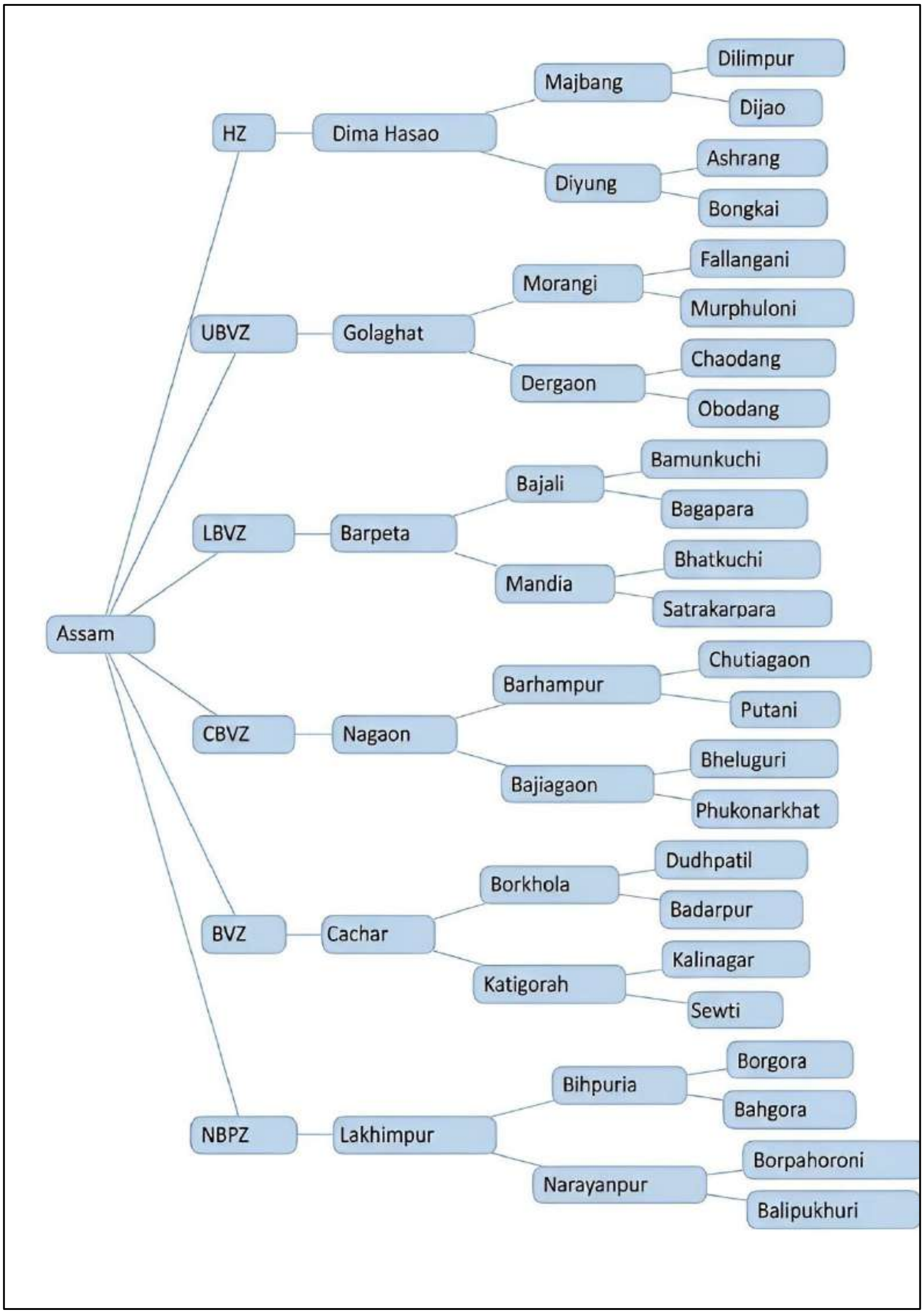

Figure 2. Sample Design.

We focused on farm households engaged in farming activities, whether on their own land or rented land, recognizing these households as the primary decision-makers and actors in agricultural practices. The survey aimed to capture local perceptions and observations regarding climate change mitigation strategies. We also gathered insights into the socio-economic conditions of the farmers, their adaptations, and their access to information about climate change and new agricultural techniques, including climate and agricultural extension services. Additionally, we collected data on four selected crops throughout the seasons of summer, monsoon, post-monsoon, and winter. The survey questionnaire addressed several key mechanisms: (a) self-reported climate change mitigation approaches adopted by farmers; (b) assessments of adaptive strategies in farming practices; (c) the extent of specific challenges farmers faced that could hinder adoption and coping strategies; and (d) demographic information focusing on essential socio-economic factors. For components

(b) and (c), responses were measured on a Likert scale, ranging from strongly disagree to highly agree. The "adaptation" variable was classified as a dependent dummy variable, assigned a value of 1 for farmers who reported taking adaptive measures in response to adverse climate impacts, and a value of 0 for those who did not engage in any adaptive actions. Farmers utilize various strategies to enhance their adaptability to climate change, although these strategies often vary based on their socio-economic characteristics. For example, literate farmers may implement different adaptive measures compared to their illiterate counterparts.

Annual family income, farm size, membership in Self-Help Groups (SHGs), access to credit, farming experience, contact with extension service agents, distance to the market, and awareness of climate change information are all factors that shape how farmers adopt measures to cope with environmental degradation and severe weather patterns linked to climate change (Begum & Mahanta, 2017; Guntukula & Goyari, 2020). Regardless of the methods chosen by each farmer, it's evident that implementing adaptive measures can help mitigate the adverse impacts of climate change on agricultural productivity, household income, and the overall well-being of farmers.

Logistic regression models are widely used in this context because they ensure that the estimated probabilities remain within the range of 0 to 1 (often between these two values). Several researchers have utilized binary logistic regression, yielding consistent findings, such as those from Fosu-Mensah et al. (2012), Adesina and Chianu (2002), Zamasiya et al. (2021), Kgosikoma et al. (2018), and Pathak et al. (2020). The general form of a binary logistic model can be expressed as:

$$Y_i = l(P) = \beta_0 + \beta_1 \sum_{i=1}^{n} X_i + X_i + \varepsilon_i \quad (1)$$

Where Y_i is a specific binary dependent variable (one of the adaptation strategies), β_0 is the constant (intercept) term and 1 is a set of coefficients to be assessed. Further, X represents a set of independent variables, and ε_i is an error term. The positive sign of the coefficients of explanatory variables represents the probability of implementing a specific adaptation strategy to climate change. In contrast, a negative sign indicates a reduced likelihood of adopting adaptations. Now, P can also be expressed as:

$$P_i = 1/1 + e - (\beta_0 + \beta_i x_i) \quad (2)$$

For simplicity, equation 2 can be expressed as:

$$P_i = 1/1 + e - Z_i \quad (3)$$

Where,

P_i: Probability of adaptation of the "i"th respondent;

$e{-}Z_i$: refers to the "irrational number" e raised to the power of Z_i

Z_i: is a function of N-descriptive variables and expressed as:

$$Z_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n x_n + \mu_i \quad (4)$$

Where, β_0 = Constant term $\beta_1, \ldots, \beta_n$ = Regression co-efficient.

Therefore,

$$Z_i = \beta_0 + \beta_1(Age) + \beta_2(Gender) + \beta_3(Edu) + \beta_4(Family\ size) + \beta_5(land\ holding) + \beta_6(Distance\ to\ the\ market) + \beta_7(Farming\ experience) + \beta_8(access\ to\ credit) + \beta_9(Membership\ in\ SHGs) + \beta_{10}(Infor.\ Climate\ change) + \mu \quad (5)$$

Before estimating the logit model for cross-sectional analysis, we first examined the presence of multicollinearity and heteroscedasticity among the chosen explanatory variables. To accomplish this, we conducted both the contingency coefficient test and the variance inflation factor (VIF) test. Additionally, we utilized a correlation matrix to gauge the relationship between the explanatory variables. A correlation coefficient above 0.4 indicates potential collinearity, and a high correlation coefficient (greater than 0.4) suggests the occurrence of multicollinearity (Long & Freese, 2006). The results from the correlation analysis revealed that age correlates with both education and farming experience. Except for the variables related to contact with extension services and training, the VIF values for all other variables were below 10, with collinearity tolerance and eigenvalues remaining below 1, confirming that multicollinearity is not a significant issue in this model. We fitted an Ordinary Least Squares model, omitting the variables related to contact with extension service agents and training from the final model. To mitigate the effects of heteroscedasticity, we estimated a robust model that utilized a robust variance estimator built on a list of equation-level scores alongside a covariance matrix.

Selection of Dependent and Independent Variables

In the Estimated Models to identify the factors influencing adaptation activities, we performed a logit regression where the dependent variable (adaptation measure) was binary, indicating whether a farm household responded "yes" or "no" to having undertaken a specific action. Consequently, we conducted ten logistic regressions for each adaptation measure implemented by farmers in the study area. The selection of dependent variables was guided by insights from field surveys and relevant existing literature. Similarly, a range of factors influences the adaptation options. Based on literature and experiences from the field, this study takes household, farm, and institutional characteristics, including physical and human resources of the household, as independent variables. This study also considers indicators of perception on changing climate, which include three explanatory variables such as the perception of the farmer on climate change, awareness of increasing temperature, awareness of increasing rainfall, and variability of rainfall. This study also recognizes 10 independent variables mentioned in Table 1, which were most suitable in explaining the usage of farm household adaptation choices. However, as mentioned earlier, explanatory variables are chosen based on the field survey and existing literature. The average age of the respondents was 40 years, with each having around 10 years of farming experience. Households typically comprised about 5 members. On average, each household owned between 27 and 30 Bighas of land, and the market was located approximately 11 kilometers away. Additionally, most respondents reported an education level ranging from lower primary to primary.

Table 1. List of selected dependent and independent variables.

Model	Dependent variables	Units of measurement	Independent variables	Description	Measurement	impact	Mean	SD
1	Using different varieties	1 = using different varieties; 0 = if not	Age	Continuous	Years	+ −	40.92	8.61
2	Using early maturing varieties	1 = using early maturing varieties; 0 = if not	Gender	Categorical	1 = male, 0 = female	+	0.77	0.41
3	Adjusting planting dates	1=advance/delayed planting dates; 0= if not	Level of education	Categorical	Six categories included	+	2.66	1.37
4	Irrigation	1= improved irrigation; 0 = if not	Farming experience	Numerical	Years	+	10.5	4.03
5	Crop switching/ mixed cropping	1 = multiple/ mixed cropping; 0 = if not	Family size	Numerical	Number	+	5.27	2.19
6	Crop to livestock	1 = keeping more livestock; 0 = if not	Income Prop of Agri income	Continuous	Ratio	+	15,000	9020.56
7	Non-farming activities	1 = non-farming activities; 0 = if not	Land size (overall land owned)	Continuous	Bigha	+	27.73	13.73
8	Crop insurance	1 = crop insurance; 0 = if not	Credit access	Binary	1 = yes, 0 = other	+	.64	0.32
9	Use of Organic fertilizer	1 =more fertilizer; 0 = if not	Membership in SHGs	Binary	1 = yes, 0 = other	+	10.5	4.03
10	Pest and disease management	1= increased pest and disease management; 0= if not	Distance to market	Continuous	In Km	−	11.78	2.54
(1* = Credit access institutional sources of credit, like, co-operative societies, RRB, Nationalized Banks, milk co-operative societies, Lake Development societies, Plantation Growers' Association and similar in the study area)			Information on climate change	Binary	1 = yes, 0 = other	+	.75	0.42

Source: Compiled from field survey data.

3. Results

3.1. Farmers' Perceptions of Climate Change

Gaining insight into farmers' perceptions of climate variability—specifically regarding temperature, rainfall, and rainfall variability—provides policymakers with valuable information for effective policy design and implementation (Sarkar & Padaria, 2010; 2015). It is particularly crucial to correlate farmers' perceptions with actual climatological data to formulate a policy agenda aimed at sustainable adaptation to climate change. Consequently, comprehending local perceptions regarding the roots, indicators, and impacts of climate change will enhance our understanding of whether farmers are adapting to long-term changes or merely responding to current observations. All respondents were posed a dichotomous question ("yes/no" response) regarding their experiences of regional climate changes over the past 30 years. Following their initial answers, they were queried about their perceived experiences with a range of climatic events typically associated with global climate change effects in India. Respondents could indicate whether they had observed decreases, increases, or no change in the frequency of these events, or they could express uncertainty. In response to the first question, approximately 87.12% of participants reported that they had perceived climatic changes within the last 30 years. Table 2 illustrates that 87.12% of respondents acknowledged climate change, while the remainder either denied such changes or did not comprehend the variations occurring in the study area. This finding aligns with the research conducted by Chaliha et al. (2012) in the Jorhat district of Assam, which indicated that a majority of respondents had recognized climate change.

Table 2. Perception of farmers on climate change (Distribution of responses to perceived changes in specific climatic events, n = 300).

Categories		%	Young	Adults	Elders	χ^2	Illiterate	literate	χ^2	Male	Female	χ^2
Changes in climate		87.12	5.8	74.2	7.12	0.03**	33.9	61.6	0.1	8.8	8.2	0.102
Temperature	Increased	76.18	4.9	66.1	5.18	0.00***	27.9	48.4	0.203	68.8	6.6	0.163
	Decreased	6.62	2.3	2.4	1.92	1.12	3.2	5.9	0.1	4.3	5.8	0.112
	No change	16.11	5.2	4.9	6.01	0.10	8.3	6.9	0.102	9.7	7.2	0.443
Rainfall amount	Increased	81.98	4.7	73.1	4.18	0.00***	20.2	64.1	0.112	74.6	8.9	0.932
	Decreased	7	1.3	0.8	4.9	0.23	0.9	1.3	0.312	4.7	0	0.203
	No change	14.7	4.6	3.9	6.2	0.13	6.8	5.5	0.22	8.1	6.2	0.312
Rainfall variability	Yes	78	7.3	60.4	10.3	0.01**	44.9	17.8	0.021**	55.2	7.5	0.11
	No	8.1	2	2.5	3.6	0.12	3.8	3.4	0.1	4.7	4	0.432
	Don't know	32	11.1	7.8	13.1	0.91	16.7	14.1	0.101	17.6	10	0.342

Source: Author's calculation from raw data. Note: The age clusters are young (> 35), adult (36–64), elder (> 65).

Subsequently, the perceptions of farmers regarding climate change were examined further by categorizing respondents into various age groups, gender classifications, and educational backgrounds. It is likely that different demographic factors influence farmers' perceptions of climate change. Among the total respondents, 87.12% acknowledged climate change, with 78.8% being male-headed households and 61.6% being literate heads of households. Furthermore, the χ^2 analysis indicated a significant difference among the age groups, with 5.8%, 74.5%, and 7.12% of respondents falling into the young, adult, and elder categories, respectively ($p \leq 0.05$). This suggests that respondents in the adult age group had a better understanding of climate change compared to those in the young and elderly categories. As age increases, farmers tend to gain better access to and acquire knowledge from various sources (Mihiretu et al., 2021).

3.2. Adaptation Choices of Selected Farmers in the Study Area

To determine the primary adaptation strategies among the selected farm households, respondents were initially asked if they had made any changes or adjustments in their practices in response to climate change and variability (shifts in climate variables) over the past decade. Subsequently, farm households in the sampled villages were inquired about their main adaptation activities to address climate change. The principal adaptation strategies in the study area are illustrated in Figure 3. Among the reported strategies, mixed cropping emerged as the most prevalent approach (78%), while the use of early maturing seeds, which represent a new variety of crops (70%), is the most commonly practiced adaptation technique. Other frequently employed strategies include adjusting planting dates (60%) and modifying cropping patterns (50%). The majority of farmers in the study villages are utilizing early maturing seed varieties (short-duration seeds) to mitigate climate-related hazards. Specifically, paddy farmers indicated that traditional seed types are unsuitable for the current climate conditions due to the changing crop growing seasons.

Furthermore, varieties that mature early are less vulnerable to shorter cropping seasons and do not necessitate prolonged water availability (Farooq et al., 2011). Consequently, farmers in the sample villages are transitioning to early maturing varieties. Approximately 10 percent of farmers indicated that they are switching to tree crop varieties due to the unavailability of short-duration seeds in a timely manner and the lack of government assistance in supplying such varieties. For subsequent analysis, migration and the shift to tree crop strategies are excluded from these practices as they demonstrate lower acceptance rates. In addition, crop insurance is crucial, with around 42 percent of farmers in the study area adopting it as a strategy to mitigate the negative impacts of climate change. Out of 300 farm households in the study area, 156 utilized organic fertilizers to enhance soil fertility, which contributes to increased crop yields. Although the rural population relies on agriculture for their livelihoods, non-farm income has also become an integral part of rural livelihoods.

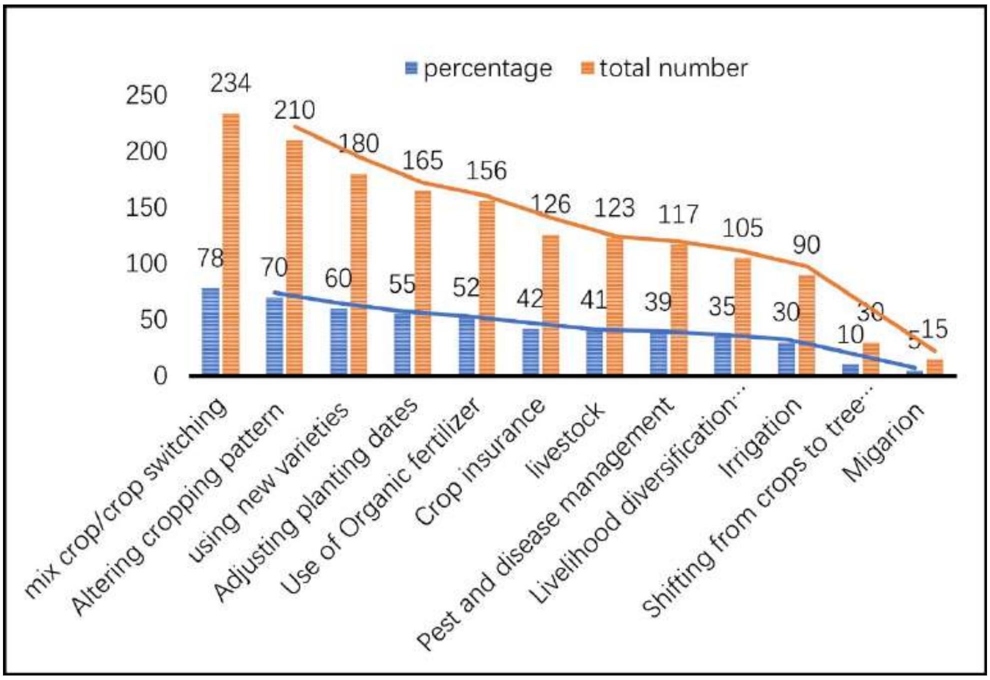

Figure 3. Farm level adaptive practices (n = 300).

The primary motivation for engaging in off-farm activities is that income from non-farm sources is often less susceptible to climate risks compared to agricultural operations. Thus, income diversification is a vital adaptation strategy in response to climate risks. More than 35 percent of farm household members in the sample villages are involved in off-farm income-generating activities to address yield uncertainties associated with climate change. However, due to insufficient credit facilities, they are unable to expand their non-farming ventures. A significant number of farmers remain heavily reliant on the monsoon, as evidenced by the limited attention given to adopting irrigation facilities, with only 30 percent of the selected farmers implementing this strategy. Nevertheless, farm household members also participate in labor work, such as MGNREGA and small businesses. They possess MGNREGA job cards; however, the majority of respondents reported not utilizing these cards because wealthy Zamindars extract the funds. Only 5 percent of the population has been found to migrate to cities such as Guwahati, Hyderabad, and Bangalore, among others, in pursuit of better-paying jobs. Research conducted by Meze-Hausken (2000) and Jha et al. (2018) has also indicated that migration serves as an adaptation strategy in response to global climate change. Furthermore, many farmers are transitioning to livestock farming, as it provides a source of income during dry seasons and periods of drought; they are integrating both practices to mitigate risks. Some marginal farmers are also moving from crop cultivation to livestock. In certain areas of the Lakhimpur and Golaghat districts, this transition is linked to significant sand deposition in agricultural land caused by flooding. Large-scale farmers, particularly those with income from non-farm sectors, are leasing out their land due to the unpredictability of weather conditions. The primary motivation for exiting the agricultural sector is the stable and risk-free income derived from non-farm sources. Determinants of Adaptation Approaches of Selected Farmers in the Study Area: As previously mentioned, farmers' adoption behavior is shaped by a variety of complex variables, including socioeconomic profiles, demographic characteristics, and biophysical factors. Out of the 10 adaptation measures illustrated in Table 1, we conducted logit regression analysis separately for 9 adaptation measures, excluding migration and the transition from crops to tree crops due to significant multicollinearity issues. In Table 3, we present the coefficients and their significance levels for various indicators. The findings indicate that farm income, access to credit, and educational attainment are the primary determinants of adaptation strategies. Conversely, a significant negative correlation has been observed between adaptation measures and variables such as age, family size, and distance to the market. Additionally, the results demonstrate that male farmers are more inclined to adopt irrigation facilities.

Table 3. Binary Logit Models Outcomes Indicating Factors Determining Adaptation Strategies.

Selected Variable	MODEL I Using new variety crop	MODEL II Mix cropping/Crop switching	MODEL III Irrigation	MODEL IV Adjusting planting dates	MODEL V More use of organic fertiliser	MODEL VI Crop to livestock	MODEL VII Crop insurance	MODEL VIII Pest and disease management	MODEL IX Shift to non-farming
CONSTANT	−2.739	−0.980	−2.474	−2.682	−5.049	−0.816	−5.392	−2.379	1.093
	3.410	1.034	1.195	1.239	1.297	1.062	1.658	1.180	1.078
AGE	−0.047**	0.040**	0.043	0.055**	0.022	−0.039*	0.014	0.013	−0.032*
	0.021	0.021	0.021	0.021	0.021	0.018	0.026	0.020	0.018
SEX	0.064	0.011	0.082**	0.031**	0.549	0.041	0.000	0.171	0.065
	0.345	0.352	0.372	0.358	0.372	0.321	0.583	0.354	0.327
EDU	0.234**	0.354***	0.241	0.527***	0.248*	−0.038	0.648***	0.577**	0.084
	0.141	0.155	0.132	0.153	0.143	0.121	0.171	0.143	0.123
INCOME	2.500***	3.100***	9.55	2.420***	1.920	0.000	2.530*	8.600	1.303
	1.090	1.150	1.06	0.000	1.010*	0.000	1.500	1.06	8.910
LAND_HOLDING	0.107**	−0.001	0.019	0.028	0.022	−0.014	0.040**	0.015	−0.015
	0.016	0.017	0.015	0.017	0.017	0.014	0.019	0.016	0.014
FAMILY_SIZE	−0.055	0.194***	−0.171	−0.089	0.013	0.102**	−0.046	0.161**	0.077**
	0.092	0.096	0.090	0.098	0.094	0.080	0.110	0.094	0.080
DTMAR	−0.127**	−0.151**	0.133	−0.208***	−0.032	0.095	−0.067	−0.102	0.130**
	0.064	0.065	0.064	0.069	0.065	0.057	0.083	0.063	0.057
FE	0.037	0.040	0.024	−0.010	0.090*	0.079**	−0.024**	0.056	−0.090**
	0.049	0.052	0.046	0.049	0.052	0.043	0.055	0.048	0.044
CA	0.928***	−0.003	0.452	−0.177	0.836**	0.203	0.544	0.248**	−0.397
	0.352	0.390	0.324	0.363	0.345	0.310	0.393	0.338	0.314
MSHG	0.439	0.515	−0.247	0.621*	0.534	−0.341	−0.644	0.495	0.120**
	0.339	0.343	0.329	0.347	0.354	0.298	0.417	0.334	0.300
INCL	0.335**	0.019	1.294***	0.631*	0.166	0.979***	−0.014	0.581*	−0.482
	0.365	0.357	0.422	0.383	0.395	0.332	0.614	0.371	0.340
Base category -no adaptation	Number of observation = 300			LR χ^2 =168.20 Prob > χ^2= 000				Log likelihood: −143.86	

Source: Author's calculation.
*** p < 0.01, ** p < 0.05, and * p < 0.10.

The findings indicate that farmers possess a wealth of experience related to their agricultural activities. This experience notably boosts the likelihood of adopting organic fertilizers and expanding into livestock farming. However, in terms of other adaptation strategies, the influence of farming experience appears minimal. Additionally, larger family sizes emerge as a significant factor. As family size increases, there is a marked tendency toward utilizing improved crop varieties, enhancing irrigation practices, and increasing fertilizer application (Deressa et al., 2009). Larger-scale farmers typically have better access to resources, allowing them to invest more inputs for improved yields and production, thus adapting to climate change by increasing their use of inputs like fertilizers and irrigation. Our results also indicate that family size positively and significantly impacts the adoption of mixed cropping, pest and disease management, as well as the transition to non-farming activities. By implementing Integrated Pest Management (IPM) strategies, farmers can more effectively manage pests while reducing the adverse effects of chemical pesticides on both the environment and human health. Regarding landholding, it appears to enhance the likelihood of employing various familiar adaptation approaches. The data suggest that as the amount of land owned by farmers increases, so does the probability of cultivating new crop varieties and securing insurance against crop failure, which helps mitigate losses associated with climate variability. In contrast, other adaptive practices reveal insignificant results. Therefore, it is reasonable to conclude that larger landholdings may lead to a reduced inclination toward crop switching or mixed cropping as an adaptation strategy. This observation aligns with previous research, including studies by Bryant et al. (2000), Bryan et al. (2013), and Sarkar and Padaria (2015).

3.3. Barriers to Implementing Coping Strategies for Farmers in the Study Area

Table 4 highlights the challenges identified by farmers that hinder their ability to adopt the climate change coping strategies. The purpose of these results is to provide an overview of the obstacles rather than to evaluate the severity of these constraints. The findings reveal that "Unpredictable weather" stands out as the primary barrier, with 95.7% of respondents recognizing it as a significant impediment to adaptation. This is followed by a lack of credit or financial resources, cited by 63% of farmers, and insufficient farming inputs, such as seeds, reported by 49.7%.

Table 4. The problems faced by the farmers (n = 300).

Difficulty	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Mean
Unpredictable weather	210	68	13	8	1	4.36
	70	22.67	4.3	2.7	0.33	
Lack of credit/money	189	76	28	6	1	4.23
	63	25.3	9.3	2	0.33	
Shortage of land	170	25	90	10	5	4.04
	56.6	8.33	30	3.33	1.7	
Infertile soil	157	100	23	12	7	3.78
	52.3	30	7.7	4	2.3	
No access to information	150	110	30	7	3	3.52
	50	36.66	10	2.33	1	
Insufficient seed	149	98	29	18	5	3.17
	49.7	32.7	9.7	6	1.7	
No Government support	113	8	102	77	0	3.11
	37.7	2.7	34	25.7		
Lack of market Access	108	60	69	58	5	3.03
	36	20	23	19.3	1.7	
Lack of irrigation	103	98	21	78	0	3
	34.3	32.7	7	26		
Insecure property rights	14	6	173	99	8	2.73
	4.7	2	57.7	33	2.66	

Source: Author's calculation from the Field survey, 2024.

In Assam, agricultural production systems primarily depend on the monsoon, which has led to a lack of interest in enhancing irrigation facilities. Additionally, insufficient support from the government poses further challenges to adapting to climate change. In specific areas like Bihpuria and Narayanpur, larger farmers enjoy easy and timely access to seeds from the Mandal level, while marginal and small farmers struggle to obtain seeds promptly from government sources. These smaller farmers often resort to purchasing seeds from the black market at inflated prices, sometimes ending up with lower-quality seeds. To address these barriers, it is crucial for governments to provide institutional support. The obstacles faced by farming households align with findings from Sarkar and Padaria (2015), Pathak et al. (2020), and Guntukula and Goyari (2020). Interestingly, among those who have not adopted the described strategies, the largest hindrance is the belief that adaptation is unnecessary. This notion stems from farmers' perceptions that "we cannot do anything" regarding the shifting weather patterns. For instance, over 75% of farmers have reported experiencing increased temperatures, and more than 80% acknowledge that this contributes to losses in production and revenue due to changes in rainfall. Therefore, bridging the gap between farmers' perceptions and active adaptation strategies is particularly challenging in a region characterized by diverse climatic conditions.

4. Conclusion

This study aimed to explore the awareness of farm households regarding climate change, their adaptation strategies, and the factors influencing these strategies, as well as the obstacles faced by farmers in the region of Assam, utilizing survey data. Most of the farmers are still highly dependent on the monsoon, which is reflected in the fact that their attention to adapting irrigation facilities as an adaptation strategy is insufficient, as only 30 per cent of the selected farmers adopted this strategy. The factors influencing adaptation strategies (a total of nine) were evaluated using a binary logistic model (BLM) or regression analysis. Over 86 percent of farmers in the study area reported experiencing climate change over the past 30 years. Additionally, farmers' awareness and perceptions regarding changes in rainfall and temperature indicated that a significant number of them recognized variations in rainfall; however, concerning temperature, they noted an increase only in the last three years, attributing this rise to increasing relative humidity as a key factor. Moreover, farmers identified the most commonly employed adaptation strategies as: cultivating new crop varieties such as early maturing types, adjusting sowing or planting dates in response to climatic changes, enhancing irrigation facilities, utilizing more organic fertilizers and pesticides, engaging in crop switching or intercropping, participating in non-farm activities, managing pests and diseases, obtaining crop insurance, and livestock farming, among others. The primary challenges to adaptation reported in the study area include unpredictable weather, lack of credit or financial resources, land shortages, insufficient information on climate, and inadequate government funding. Furthermore, the empirical results from the logit regression analysis demonstrated that factors such as age, education level, gender, annual income, landholding size, family size, access to credit, membership in self-help groups (SHGs), and perceptions of climatic variables significantly influence the adaptation actions of farm households in the region. This study recommends that government policies should concentrate on enhancing these critical determinants to support farmers' adaptation efforts and reduce their vulnerability.

The findings help policymakers to better think and plan agricultural policies in terms of adaptation to climate change. Some agricultural policies may exacerbate the impact of climate change, while others may be effective in increasing and securing farmers' incomes. Agricultural policies in terms of adaptation to climate change should integrate at the same time. So it is important to provide them- equitable access to the means of production; Dissemination of technical levers to increase yields per hectare for the greatest number; Sufficiently stable and remunerative levels of agricultural prices; an endogenous growth strategy, initially favoring food sovereignty driven by family farming. Further understanding of the cost of adaptation, the impact of adaptation measures on crop yields, and vulnerability are also important issues that can be considered for future research works.

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Abbreviations

The following abbreviations are used in this manuscript:

HZ	Hill Zone
UBVZ	Upper Brahmaputra Valley Zone
LBVZ	Lower Brahmaputra Valley Zone
CBVZ	Central Brahmaputra Valley Zone
BVZ	Barak Valley Zone
NBPZ	North Bank Plains Zone
IPCC	Intergovernmental panel on Climate Change
SHG	Self-help Group
MGNREGA	Mahatma Gandhi National Rural Employment Guarantee Act

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Agricultural & Rural Studies

Article

Enhancing Rural Households' Resilience in the Face of Climate Change in Nigeria

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Abstract: Resilience to climate shocks is critical for sustaining rural livelihoods, improving agricultural productivity, and fostering long-term development. This study examines the effects of climate change and the resilience capacity of rural households in Nigeria using the General Household Survey (GHS) panel data from 2010/2011 and 2018/2019, covering 2,800 rural households. Descriptive statistics, an ordered probit model, and the Multiple Indicators Multiple Causes (MIMIC) model were applied. Results indicate that 50.3% of households are male-headed, with an average household size of six and a mean age of 49 years, while 41% of household heads have no formal education. Access to agricultural information remains limited, as only 17% received extension services. Households experienced a range of climate-related shocks: 25.21% reported harvest failure due to poor rainfall, 21.64% due to flooding, 10.57% from pest invasion, and 27.36% suffered livestock losses due to illness. Drought experience varies across the geopolitical zones in both waves. The MIMIC results show that a significant proportion of households fall within the low-resilience category, with male-headed households exhibiting relatively higher resilience levels. The ordered probit model further identifies education, dependency ratio, age, marital status, and social capital as major determinants of resilience. The study recommends strengthened fire and flood mitigation strategies, enhanced agricultural adaptation to rainfall variability and pest outbreaks, expanded access to education and extension services, and improved land governance, credit access, and social protection, particularly for women. Strengthening resilience is essential for safeguarding rural communities against the growing impacts of climate change.

Keywords: climate shocks; resilience; rural households; Nigeria

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1. Introduction

Climate change and variability constitute a serious global environmental issue (Nalwanga et al., 2022). The African continent's experiences of fluctuating temperatures, extreme weather events, and poor infrastructure, coupled with the level of poverty, make the continent more vulnerable to the impacts of climate change (Yusuf, 2019). Climate change occurs globally, and its impacts are also felt in developing economies. Nigeria is one of the most vulnerable countries to the impacts of climate change. The country's diverse geography and climate make it susceptible to various climate change impacts (Arowolo et al., 2018). Therefore, Nigeria has the potential to suffer various effects of climate change, some of which have already started manifesting, such as sudden changes in temperature and precipitation occurrences (Haider, 2019). Rain-fed agriculture practice in the country makes it more prone to climate shocks such as flooding and drought (Yusuf et al., 2024).

Climate change is already affecting land in many ways, including by increasing the frequency and intensity of droughts, floods, and storms (Chiriacò & Valentini, 2020). Land use can also impact climate change. For example, deforestation releases carbon dioxide into the atmosphere, while afforestation and reforestation can help to remove carbon dioxide from the atmosphere (Intergovernmental Panel on Climate Change, 2022). Desertification experience, especially in the northern part of Nigeria, has already caused many people and villages to migrate because of a lack of sustainable food production (Arowolo et al., 2018). Desertification from the cumulative effects of deforestation is an existential threat as it has been observed to be moving southwards (Yusuf et al., 2024). Land use can also affect the amount of sunlight reflected in space, which can impact the Earth's temperature. The interaction between climate change and land use is complex, and we still do not know how much. However, land use is a major factor that will influence the future of climate change (Thapa, 2022).

Although desertification and land degradation are acknowledged as complex environmental challenges in Nigeria, their implications for household resilience require explicit integration into the resilience framework. Land tenure security and land governance systems play a central role in shaping the adaptive, absorptive, and transformative capacities of rural households, particularly in regions facing desertification pressures. Secure land rights increase farmers' incentives to invest in soil conservation, agroforestry, irrigation, and climate-smart technologies investments that directly strengthen resilience by enhancing long-term productivity and reducing vulnerability to climate shocks. Conversely, weak tenure systems, highly customary land allocation processes, and gender-biased land access often limit households' ability to respond effectively to drought, flooding, erosion, and loss of soil fertility. In northern Nigeria, where desertification is advancing rapidly, land fragmentation, encroachment, and conflicts between farmers and pastoralists undermine social stability, disrupt livelihoods, and weaken resilience pathways. Governance failures such as poor land registration systems, inadequate enforcement of land policies, and limited community participation further exacerbate climate vulnerability by restricting long-term planning and sustainable land management. Therefore, situating land tenure and governance within the resilience framework is essential, as it clarifies how structural land constraints interact with shocks and adaptive strategies, ultimately influencing household welfare and sustainable rural development in Nigeria.

Shocks refer to sudden and unexpected events that can hurt the well-being of vulnerable populations and are classified into covariates and idiosyncratic shocks. These shocks can disrupt the normal functioning of communities and individuals and may lead to various adverse consequences. They can occur in rural and urban areas and affect people in developed, developing, and underdeveloped countries worldwide. Vulnerable populations are particularly susceptible to the negative consequences of these shocks because they often lack the resources or social safety nets to cope with such disruptions (Food and Agriculture Organization of the United Nations [FAO], 2016). Idiosyncratic shocks occur at the individual level, including loss of family members, protracted illness, and community unrest. Covariate shocks include catastrophic weather events, crop failures, and price declines in commodity export markets, all of which occurred at regional and national levels.

Resilience is seen as the capacity not only to absorb disturbances but also to reorganize while changes are taking place, to retain the same functions, structures, and feedback (Alinovi et al., 2008; Folke, 2006). Therefore, the reorganizational capacity of a household is seen as fundamental in reacting to a shock, especially a climate shock, and adapting to the new situation to get back to a given level of well-being. Moreover, climate resilience implies having good living conditions to withstand hazards or cope with, absorb, and return from shocks such as climate change effects (FAO et al., 2021). An analysis of how a socio-economic unit responds to shocks and risks, such as climate change effects, can serve as an avenue for understanding factors that influence coping and adaptive capacities. Such factors can be adjusted to maximize resilience and minimize vulnerabilities to climate shocks (Odozi et al., 2022). The concept of resilience is of increasing interest to policymakers. However, despite the growing importance of resilience, the concept has not yet been carefully defined or measured (Constas et al., 2014) and is still sometimes confused with the similar but yet different concept of vulnerability (Adger, 2006). Misconceptions of resilience may lead to a limited understanding of coping with or adapting to natural hazards effectively. To avoid such misconceptions, it is necessary to quantify resilience into specific and obtainable objectives (Quinlan et al., 2015).

This study provides more insights into how resilient rural households are to climate shocks and various factors that influence the resilience to climate shocks in rural Nigeria. Determining resilience to climate shocks could help land use and the livelihoods of farming households, improve their farm production, and increase their abilities to bounce back from the effects of climate change to contribute to economic growth and sustainable development. This is also critical for ensuring global food security, nutrition, proper land use, and sustainable natural resource management. This requires both enhancing the capacity of rural people to manage the risks they face and lowering their exposure and vulnerability levels. Therefore, the measures of the household capacity to overcome and recover (resilience) from natural shocks, especially climate change, are very important. The broad objective of this paper is to examine resilience to climate shocks among rural households in Nigeria. The specific objectives are to:

(i) Describe climate-related shocks affecting rural households in Nigeria.

(ii) Examine the level of resilience of rural households to climate shocks.

(iii) Identify factors influencing rural households' resilience to climate shocks in Nigeria.

2. Materials and Methods

2.1. Study Area

The study area is Nigeria. Nigeria lies between 4°–14° N and 3°–14° E, making it north of the equator and east of the Greenwich Meridian located on the West Coast of Africa and occupies approximately 923,768 square kilometers of land and shares borders with Chad and the Atlantic Ocean to the South, Niger Republic to the North, Cameroun to the East, and Benin to the West. The country is made up of 36 States and the Federal Capital Territory. The States and the Federal Capital Territory are divided into 774 Local Government Areas. The spatial distribution of the population is uneven, with the majority (63 percent) of the population living in rural areas and the remaining population living in urban areas (National Bureau of Statistics [NBS], 2019). The population of Nigeria was estimated at 214,587,291 as of February 2022, based on projections of the latest United Nations data reported by Worldometer. The country is divided into six geopolitical regions: North-Central, North-East, North-West, South-East, South-South, and South-West, and four agroecological zones, namely tropic-warm/semiarid, tropic-warm/sub-humid, tropic-warm/humid, and tropic-cool/sub-humid.

2.2 Type and Source of Data

Secondary data was used for this study. The required variables were extracted from the General Household Survey Panel Data (GHS-P) from the Living Standard Measurement Survey-Integrated Survey of Agriculture (LSMS-ISA). Data were repeatedly collected from the same households in 2010–2011, 2012–2013, 2015–2016, and 2018–2019. This survey was conducted by the National Bureau of Statistics, Federal Government of Nigeria (FGN) in collaboration with the Federal Ministry of Agriculture and Rural Development (FMA&RD), the National Food Reserve Agency (NFRA), the Bill and Melinda Gates Foundation (BMGF), and the World Bank (WB; NBS, 2019). The ability to follow the same households over time makes the GHS Panel a new and important tool for studying and understanding the dynamics of resilience. For this study, the 2010–2011 and 2018–2019 waves were used, where relevant information and variables relating more to households' resilience to climate change effects on households were extracted, sorted using STATA 16, and used for the analysis.

2.3. Methods of Data Analysis

Descriptive statistics were used to describe socio-economic characteristics of the rural households' heads and climate-related shocks; the multiple indicators multiple causes (MIMIC) model was used to examine the resilience index; and the ordered probit model was used to identify factors influencing rural households' resilience to climate shocks.

Several established resilience measurement scales, such as the BRACED index, the Self-Reliance Capacity (SRC) framework, and other composite tools, were set aside in this study due to conceptual and methodological limitations that make them unsuitable for the Nigerian rural context and incompatible with the econometric approach adopted. Although these frameworks have been applied in humanitarian and development settings, they often rely on context-specific indicators that lack theoretical coherence when transferred across countries or livelihood systems. More critically, they tend to conflate resilience, vulnerability, and adaptive capacity, thereby obscuring the analytical distinctions needed for robust empirical estimation.

A consistent challenge with these scales is their ambiguous indicator structure, which blends exposure, sensitivity, and adaptive capacity into single composite scores. This blurring of boundaries limits their usefulness in longitudinal analysis, especially when evaluating resilience trajectories using panel data such as the General Household Survey (GHS-Panel) for 2010/2011 and 2018/2019. Such conceptual overlap also complicates their integration with multidimensional and econometric methods, including the Multiple Indicators Multiple Causes (MIMIC) model, Principal Component Analysis (PCA), and the Coping Strategies Index (CSI), which require clear theoretical constructs and well-defined latent variables.

In contrast, this study adopts a theoretically grounded and empirically flexible resilience index derived through the MIMIC model, complemented by principal component analysis (PCA) to validate indicator weighting and structure. This approach allows for the decomposition of resilience into well-established pillars such as access to assets, adaptive capacity, income stability, exposure to shocks, reliance on social networks, access to basic services, and food security conditions. Importantly, the MIMIC framework simultaneously incorporates causal variables (e.g., education, land size, credit access, cooperative membership, climate shocks) and reflective indicators, ensuring internal consistency.

A central methodological concern guiding this decision is whether resilience metrics can capture socially differentiated dimensions of resilience among rural households. Resilience is inherently shaped by social and demographic factors such as gender, age, marital status, household size, land ownership, livelihood strategies, wealth status, and access to communication and social networks. Further inequalities in access to housing facilities, water, sanitation, waste disposal systems, and agricultural inputs influence how households prepare for, absorb, and recover from climate shocks. Frameworks like BRACED and SRC often overlook these nuanced structural determinants, which are crucial for understanding household heterogeneity.

By constructing a multidimensional index tailored to the Nigerian rural context and validated across two survey waves, this study provides a more precise assessment of resilience changes over time. The adopted methods ensure conceptual clarity, strengthen empirical validity, and provide robust statistical grounding for subsequent analyses using ordered probit, fuzzy logit, and marginal effects estimation. This integrated approach enables a deeper understanding of how climate shocks affect household welfare and how resilience capacities evolve within socially differentiated groups.

2.4. Objectives of the Research Study

Objective 1: Describe the climate-related shocks affecting rural households in Nigeria. Descriptive statistic was used to describe the climate shocks, such as floods, drought, and loss of land, identified in the study area.

Objective 2: Examine the level of resilience of rural households to climate shocks.

This objective was achieved using principal component analysis (PCA) and multiple indicators multiple causes (MIMIC) model at the different stages, which are:

(1) First stage: Principal Component Analysis (PCA) was used to determine the index of each of the pillars of resilience capacity of the rural household (d'Errico & Di Giuseppe, 2016). New variables are constructed as weighted averages of the original variables. The matrix of scores was referred to as the matrix *Y*. The basic equation of PCA is, in matrix notation, given by:

$$Y = W'X \tag{1}$$

$$y_{ij} = w_{1i}x_{1j} + w_{2i}x_{2j} + \dots + w_{pi}x_{pj} \tag{2}$$

Where *W* is a matrix of coefficients of variables *x* determined by PCA.

(2) Second stage: The levels of resilience to climate shock were determined using the Multiple Indicators Multiple Causes (MIMIC) model to estimate the resilience capacity index among the households following d'Errico and Di Giuseppe (2016). The MIMIC model is a causal model with one underlying latent variable, multiple indicators, and causes. In the linear MIMIC model, both the relationship between the latent variable and its causes and the relationship between the indicators and the latent variable are linear in the parameters. The MIMIC model is estimated using a Maximum Likelihood (ML) estimator. The latent variable Resilience is jointly estimated by its causes and indicators. The classical linear MIMIC model is specified as follows:

$$y_1 = \beta_0 + \beta_1\eta + \varepsilon_1 \tag{3}$$

$$y_2 = \beta_0 + \beta_2\eta + \varepsilon_2 \tag{4}$$

$$y_3 = \beta_0 + \beta_3\eta + \varepsilon_3 \tag{5}$$

$$y_n = \beta_0 + \beta_n\eta + \varepsilon_n \tag{6}$$

Equation (3–6) shows the relationship between the pillars (indicators) $y_1 \dots y_n$ depending on the number of pillars in use and the resilience capacity index (η), where β and ε are coefficients and error terms, respectively.

$$\eta = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \dots + \alpha k x k + v \tag{7}$$

Equation (7) shows the relationship between the resilience capacity index (η) and the independent variables (causes $x_1 \dots x_n$) derived from the pillars through principal component analysis. It can also be specified as:

$$RL_h = f(P_1, P_2, \dots, P_n) \tag{8}$$

Where RL_h = Resilience capacity of the household h to climate change; $P_1, P_2, \dots, P_n$ = Pillars of Resilience.

$$RL_h = \beta_0 + \beta_1 P_1 + \beta_2 P_2 + \beta_3 P_3 + \beta_4 P_4 + \beta_5 P_5 + \beta_6 P_6 + \beta_7 P_7 + \varepsilon_i \tag{9}$$

Where P_1, P_2, P_3, P_4, P_5, P_6, and P_7 are the seven pillars of resilience (see Table 1).

Table 1. Seven Pillars and Variables.

Pillars	Indicators
Access to Basic Services (ABS)	Access to electricity (Yes =1, No = 0) Access to improved water facility (Yes = 1, No = 0) Access to toilet facility (Yes = 1, No = 0) Distance to water source (km) Access to health facilities (Yes = 1, No = 0)
Assets	Land ownership (Yes =1, No=0) Number of crops planted Number of livestock owned House condition index
Income and Food Access (IFA)	Income from main job (Yes =1, No=0) Income from other jobs (Yes =1, No=0) Total food expenditure (₦)
Social safety nets (SSN)	Assistance from government (Yes =1, No=0) Assistance from Charities or from NGOs (Yes =1, No=0) Assistance from private entities (Yes =1, No=0) Remittances received (Yes=1, No=0)
Adaptive capacity (AC)	Education of household head (number of years of formal education) Dependency ratio (number of children and aged members relative to the total household size) Household Head engaged in farming (Yes=1, No=0) Household Head engaged in wage employment (Yes =1, No=0) Household head with any form of job (Yes =1, No=0)
Access to Agricultural Input and Technology (AIT)	Access to Seed, (Yes =1, No=0) Access to Fertilizer, (Yes =1, No=0) Access to herbicide, (Yes =1, No=0) Access to Extension Services (Yes =1, No=0) Access to farm machines (Yes =1, No=0)
Sensitivity/Perceptions to climate change (How often the experience of climate shocks)	Drought experience, (Yes =1, No=0) Rainfall variability experience, (Yes =1, No=0) Livestock diseases experience, (Yes =1, No=0) Crop failure due to climate variability causes, (Yes =1, No=0) Price shocks, (Yes =1, No=0) Water shortages experience (Yes =1, No=0)

Source: computed, 2023 GHS 2010/2011 and 2018/2019.

These variables determine the latent resilience capacity. They are treated as exogenous predictors that contribute to building household resilience. They originate from the FAO's RIMA-II pillars but serve only as determinants, not indicators, in the MIMIC structure.

(a) In the formative model, the hypothesis is that resilience (η) is influenced by the pillars. Formative indicators are assumed to be correlated and to be measured. In the reflective part, the model's reflective indicator errors (ε) are correlated and assumed to contain measurement errors. The MIMIC model permits simultaneous estimation of the measurement model and the incorporation of causal variables in the structural model for the latent variable resilience, which is linearly determined (apart from random errors, ε) by formative indicators or pillars, and resilience determines the observed reflective indicators (apart from random errors, ε; d'Errico & Di Giuseppe, 2016).

(b) Reflective Indicators (Measurement Model)

These variables manifest or reflect the latent resilience capacity. They represent observable outcomes that are expected to improve as household resilience increases.

Reflective Indicators include: food consumption score (FCS), coping strategy index (reversed), income stability, ability to recover from previous shocks, and perceived well-being score. These indicators reflect the unobserved resilience capacity and form the measurement equation:

$$RCI_{it} = f(IFA_i\,, ABS_i, AST_i,\ SSN_i, AC_i\ ,AIT_i\ ,S_i) \tag{10}$$

$$\begin{bmatrix} Climate\ Shocks\ index \\ Climate\ Variables\ index \end{bmatrix} = \Lambda_{1,}\ \Lambda_2 \times (RCI) + (\varepsilon_1,\varepsilon_2) \tag{11}$$

Climate Shocks index was equated to 1, and the equation was linearized to solve for resilience index (η).

The basic causes of the structural model used in the modeling process of the MIMIC model are ABS, AST, SSN, IFA, S, AC, and AIT, in other words:

$$(RCI) = \left(\beta_{1,}\ \ \beta_{2,}\ \right) \times \begin{bmatrix} ABS & & AST \\ SSN & S & AC \\ IFA & & AIT \end{bmatrix} + (\varepsilon_1) \tag{12}$$

(3) Third stage: in this analysis, the level of resilience was classified into three categories (see Table 2) using Markov chain analysis into least resilience, less resilience and most resilient as used by Ayantoye et al. (2011) and Obayelu and Akpan (2021).

Table 2. Markov Transition Matrix for Resilience.

	Period t			
	Level of Resilience	Least resilient (P_1)	Less resilient (P_2)	Most resilient (P_3)
Period t−1	Least resilient	P_{11}	P_{12}	P_{13}
	Less resilient	P_{21}	P_{22}	P_{23}
	Most resilient	P_{31}	P_{32}	P_{33}

Source: Author's computation 2023 GHS 2010/2011 and 2018/2019.

In this study, resilience capacity is specified as a latent variable (RCI) that is jointly determined by formative causes and measured through reflective indicators, consistent with the Multiple Indicators Multiple Causes (MIMIC) framework. To avoid conceptual ambiguity, the seven resilience pillars are not treated simultaneously as both indicators and causes. Instead, their associated variables are explicitly divided into formative causes (structural model) and reflective indicators (measurement model).

Objective 3: Identify factors influencing rural households' resilience to climate shocks.

The ordered probit regression model was used to identify and analyze the factors of households 'resilience to climate change-induced shocks. Resilience in this measurement involved ordered outcomes. This is with the basic hypothesis that a given natural shock will have a differential impact on households' resilience. Following Tesso et al. (2012) and Adepoju et al. (2011).

$$Y^x = X^1{}_j\beta + U_{Ij} \tag{13}$$

$$Y = 0\ if\ Y^x \leq 0 \tag{14}$$

$$Y = 1 \text{ if } 0 \leq Y^x \leq 1 \quad (15)$$

$$Y = 2 \text{ if } 1 \leq Y^x \leq 2 \quad (16)$$

Y^* is the level of resilience and involves an ordered outcome, that is:
Y = 0 is given to the least resilient households
Y = 1 is given to less resilient households
Y = 2 is given to the most resilient households
The Xij are the explanatory variables.
The independent variables included in the model are:
X_1 = Age of household head (Years),
X_2 = Income in Naira,
X_3 = Livestock owned (yes = 1, otherwise = 0),
X_4 = Marital status (married = 1, otherwise = 0),
X_5 = Dependency ratio,
X_6 = Access to credit (yes = 1, otherwise = 0),
X_7 = Social capital (number of institutional involvement),
X_8 = Levels of education (no formal education = 0, primary = 1, secondary = 2, tertiary = 3),
X_9 = Household head job (agriculture = 1, otherwise = 0),
X_{10} = Household Food consumption in Naira,
X_{11} = Remittance in Naira,
X_{12} = Access to extension services (yes = 1, otherwise = 0),
X_{13} = Household size (number), X_{14} = Farm size (hectare)
β's are parameters estimated and Uij is the disturbance term.

3. Results

Socioeconomic Characteristics of Rural Households

Descriptive statistics in Table 3 showed that 50.3% are males, while 49.7% are females. This indicates that there are more male-headed households than female-headed households among rural households in Nigeria. This result is in line with Olaosebikan et al. (2023) and Ibitola et al. (2019), who also found that there were more male than female household heads in rural households. The distribution of the age indicates that 26% of the households' heads are below 25 years old, 64% are between 26 and 50 years old, 8% fall within the 51–75 age range, and less than 2% are in the 76–100 age category. The mean age is 49 years, implying that most household heads are still within the active age and productive life stages. The result of this study supports the findings of Olajide and Omonona (2019) and Fasakin et al. (2022), who found that most household heads in rural communities are in their productive age range of 40 to 60 years. It means that household heads are of age and mature enough to make decisions and take responsibility in the homes, even in the face of climate shocks. The marital status of the married reveals that 25% are monogamous, while 11% are polygamous. Less than 1% are divorced or separated, while 2% are widowed. 62% are never married. They are still single and have not given birth, or are single parents without the context of cultural or legal marriages among rural households. This means that the never-married are more than the married. Household size indicates that 49% of rural households have household sizes between 1 and 5, while 41% have 6 to 10 household sizes. 10% have 11–15, and less than 1% have a household size greater than 15 family members. The mean household size is found to be 6. Large household size could contribute to an increase in family labor, which could reduce the cost of farm production and increase productivity. This is relevant to the findings of Itunnu (2022), who discovered that an increase in family size would lead to an increase in labor available to cultivate the land, and this shows the relationship between farm size and household size**.** Level of Education shows that about 41% of the rural households have no formal education, while about 26% attain primary education level, about 20% have secondary education, and 14% have tertiary education. It shows that the majority of rural households have no formal education. It implies that many rural households might be unable to apply educational knowledge to improve their economic performance, which could have affected their productivity. This is relevant to the findings of Adetunji (2015), who discovered that rural households have low formal educational attainment, and a lot of people in rural areas have no formal education.

Table 3. Socio-economic characteristics of the rural households.

Socio-economic Characteristics	Frequencies	Percentage (%)	Resilience index
Sex			
Male	1408	50.29	0.0817
Female	1392	49.71	−0.0069
	2800	100	
Age			
<25	722	25.79	0.0329
26–50 Mean = 49	1794	64.07	0.0433
51–75	232	8.29	0.0637
75–100	52	1.86	0.7048
	2800	100	
Marital status			
Married (monogamous)	701	25.04	0.1401
Married (polygamous)	296	10.57	−0.0545
Divorced	6	0.21	−1.5555
Separated	3	0.11	−0.5915
Widowed	67	2.39	0.1652
Never married	1727	61.68	0.0135
	2800	100	
Household size			
1–5	1375	49.11	0.0443
6–10 mean = 6	1135	40.54	0.0522
11–15	271	9.68	−0.0351
16–20	19	0.68	−0.2851
	2800	100	
Level of Education			
No formal education	1140	40.71	0.0229
Primary level	716	25.57	0.0408
Secondary level	552	19.72	0.3677
Tertiary education	392	14.00	−0.2827
	2800	100	

Source: Author's computation 2023 GHS 2010/2011 and 2018/2019.

4. Discussions

4.1 Descriptive Statistics of Climate Shocks in Rural Nigeria

The percentages at which each climate shock occurred in the year 2010/2011 as shown in Table 4 are 1.21% of the destruction of harvest by fire, 5.32% of dwellings damaged/demolished, 25.21% of poor rain that caused harvest failure, 21.64% of flooding that caused harvest failure, 10.57% of pest invasion that caused harvest failure or storage loss, 6.5% of loss of property due to fire or flood, 2.18% of loss of land and 27.36% of death of livestock due to illness. Table 4 also shows the percentages of each climate shock occurred in 2018/2019 are 8.21% of the destruction of harvest by fire, 22.39% of dwelling damaged/demolished, 19.43% of poor rain that caused harvest failure, 31.43% of flooding that caused harvest failure, 6.68% of pest invasion that caused harvest failure or storage loss, 0.04% of loss of property due to fire or flood, 0.04% of loss of land and 11.79% of death of livestock due to illness. Table 5 indicates variations in drought experience in each of the six geopolitical zones in the two waves.

Table 4. Tabulation of climate shocks.

Climate Shocks	2010/2011		2018/2019	
	Freq.	Percent	Freq.	Percent.
Destruction of harvest by fire	34	1.21	230	8.21
Dwelling damaged/demolished	149	5.32	627	22.39
Poor rains that caused harvest failure	706	25.21	544	19.43
Flooding that caused harvest failure	606	21.64	880	31.43
Pest invasion that caused harvest failure or storage loss	296	10.57	187	6.68
Loss of property due to fire or flood	182	6.50	1	0.04
Loss of land	61	2.18	1	0.04
Death of livestock due to illness	766	27.36	330	11.79
	2800	100	2800	100.00

Source: Author's computation 2023 GHS 2010/2011 and 2018/2019.

Table 5. Drought experience across the six zones in 2010/2011 and 2018/2019.

Drought	North-central	Northeast	Northwest	Southeast	South-south	South west	Total
2010/2011	13	20	31	1	10	4	79
	(16.46)	(25.32)	(39.24)	(1.27)	(12.66)	(5.06)	(100.00)
2018/2019	61	71	69	64	60	25	350
	(17.43)	(20.29)	(19.71)	(18.29)	(17.14)	(7.14)	(100.00)

Source: Author's computation 2023 GHS (2010/2011 and 2018/2019); () parenthesis are percentages.

In 2010/2011, the Northwest had the highest (39.24%) drought experience, followed by the Northeast (25.32%), Northcentral (16.46%), South-south (12.66%), Southwest (5.06%), and Southeast (1.27%). In 2018/2019, the Northeast had the highest 20.29% drought, while the north central had 17.43%. The Northwest had 19.71%, the Southeast 18.29%, the south-south 17.14%, and the Southwest 7.14%. Drought experiences have greatly increased within ten years. Climate shocks significantly impacted the livelihood activities of rural households in the study areas. For example, the destruction of harvests by fire, flooding, or pests reduced food security and income for households, while the loss of property, such as the death of livestock, degraded the asset base of households, which could reduce the ability of the households to cope with the negative effects of climate change. Moreover, poor rain that caused harvest failures also increased household dependence on food aid and other forms of support. Dwelling damage, demolition, and loss of land also affected households' ability to access basic infrastructure such as healthcare, education, and transportation. Overall, these climate shocks exacerbated the vulnerability and reduced resilience capacity of rural households in the study areas, put additional stress on their livelihoods, and affected their ability to cope with future climate shocks.

4.2. Levels of Resilience and MIMIC Model Estimates of the Correlates of Resilience

This section explains the factors that determine the resilience capacity index among households. These factors are often referred to as pillars of resilience. The seven pillars of resilience are used in this study (see Table 6). These are access to basic services, adaptive capacity, assets, access to agricultural input technology, income and food access, safety nets, and stability over time. An index was generated for each pillar through observable variables of each of the seven pillars of resilience using principal component analysis. The eight climate shocks identified in the study areas created the climate shocks index. Lastly, climate change indicators of rainfall and temperature were also indexed using PCA. The MIMIC model, estimated using the Maximum Likelihood (ML) estimator, was used to determine the levels of resilience. The levels of resilience capacity index generated were classified into the least, less, and most resilient rural households based on the mean of the resilience index generated (see Table 7). The mean of RCI is 0.0376. Households whose resilience index is below one-third or equal to one-third of the mean are classified as least resilient (≤ 0.0125). Less resilient households are the households whose resilience index is greater than one-third but less than two-thirds of the mean ($> 0.0125 < 0.0251$), while households whose resilience index is equal to or greater than two-thirds ($\geq$ 0.0251) are classified as most resilient. The classification is adopted and used by Adepoju et al. (2011). The resilience index examined using the MIMIC model showed that 52.96 % were least resilient, 34.68 % less resilient, and 12.36 % most resilient to climate shocks in the study area in the pooled data. The Multiple Indicators

Multiple Causes model also determines resilience determinants. The chi-square statistics show 1% significance, and that the result of the MIMIC model is a good fit. Among the seven selected pillars of resilience that formed the resilience capacity index of rural households, the results of the findings indicate that income and food access, social safety nets, agricultural input and technology, and stability measures have significant effects on the resilience capacity of the rural households to climate change effects compare with access to basic services, adaptive capacity, and assets of the rural household heads.

Table 6. Structural Equation Mimic Model (Maximum Like hoods estimation).

Resilience Capacity Index	Coefficient	Std. error	P>z
Access to Basic Services	−0.021 (−0.720)	0.020	0.289
Adaptive Capacity	0.018 (0.089)	0.019	0.342
Assets	−0.008 (0.420)	0.030	0.792
Income and Food Access	−0.095 (1.400) ***	0.030	0.001
Social Safety Nets	0.134 (−1.600) ***	0.019	0.000
Access to Agricultural Input Technology	−0.103 (−0.850) ***	0.027	0.000
Stability over time	−0.080 (−0.290) ***	0.025	0.001
Measurement model			
Climate Shocks < −Resilience	1		
Climate Variables < −Resilience	0.122 (0.140) ***	0.019	0.000
No of Observations	2800		
Chi square	442.44		
Prob. > chi^2	0.0000		
RMSEA	0.039		
Probability RMSEA < 0.05	0.972		
CFI	0.952		
TLI	0.927		

Source: Author's computation GHS (2010/211 and 2018/2019). () parenthesis is standard deviations.
*** Level of significant at 1% ** 5% * 10%.

Table 7. The Levels of Resilience.

Levels of resilience	Freq	Percentage
Least resilient	1,483	52.96
Less resilient	971	34.68
Most resilient	346	12.36
Total	2,800	100

Source: Author's computation 2023 GHS (2010/2011 and 2018/2019).

Evidence of metric and scalar invariance demonstrates that differences in the resilience index reflect true substantive differences, not measurement artefacts.

4.2.1. Common-Method Bias Diagnostics

To address potential inflation of relationships due to common-method variance, two procedures were applied:

- Harman's single-factor test: No single factor accounted for the majority of variance, indicating that common method bias was not a major threat.
- Single-factor latent method construct: Including a method factor in the model did not significantly improve fit, further confirming robustness.

4.2.2. Structural Validity and Model Adequacy

Finally, the MIMIC model was assessed using comparative model-fit indices reported in Table 6 (CFI, TLI, RMSEA, Chi square). All values fell within acceptable thresholds, providing additional support for the adequacy of the latent structure. Embedding these validation steps ensures that the latent resilience index is psychometrically reliable, conceptually coherent, empirically distinct across pillars, comparable across gender and ecological regions, free from major common-method bias, and suitable for econometric analyses such as ordered probit, fuzzy logit, MIMIC structural estimation, and subgroup comparisons.

4.3. Factors Influencing Resilience to Climate Shocks Among Rural Households

This section discusses the ordered probit regression model of the factors influencing resilience to climate shocks among rural households (see Table 8). The dependent variable is resilience categories into least resilience when the resilience index is 0, less resilience when the resilience is 1, and most resilience when the resilience is 2. The explanatory variables included are sex of the household head, age, age squared, marital status, social capital, livestock owned by the household, household size, access to credit, remittance, dependency ratio, levels of education of the household head, access to extension, farm size, household head income, household food consumption, and household head job. The Probability of the chi-square ($P > chi^2 = 0.0000$) and pseudo-R-squared of 0.2741 indicate that the model is a good fit.

Table 8. Factors influencing Resilience to climate shocks among rural households.

Variables	Coef. / t-value	dy/dx; r=0	dy/dx; r=1	dy/dx; r=2
Sex: Female	−0.085 (−1.68) *	0.021(1.420)	−0.012 (−1.410)	−0.008 (−1.420)
Age	0.007 (3.95) ***	0.007 (4.950) ***	−0.004 (−4.900) ***	−0.003 (−4.810) ***
Age squared	0.00037 (6.76) ***	−0.000 (−6.890) ***	0.000 (6.750) ***	0.000 (6.520) ***
Marital status	0.035 (2.56) **	0.005 (1.200)	−0.003 (−1.190)	−0.002 (−1.190)
Social capital	−0.036 (−4.67) ***	0.014 (6.020) ***	−0.008 (−5.940) ***	−0.006 (−5.760)
Livestock owned	−0.017 (−20.04) ***	0.05 (25.580) ***	−0.003 (22.670) ***	−0.002 (14.520) ***
Household size	−0.049 (−6.26) ***	0.014 (6.340) ***	−0.008 (−6.240) ***	−0.006 (−6.030) ***
Access to credit	−0.251 (−3.66) ***	0.074 (3.800) ***	−0.004 (−3.770) ***	−0.030 (−3.750) ***
Remittance	5.978 (0.950)	−1.837 (−0.070)	1.093 (0.070)	0.744 (0.070)
Dependency ratio	0.043 (3.23) ***	−0.013 (−3.430) ***	0.008 (3.420) ***	0.005 (3.370) ***
Levels of education				
Primary	0.336 (5.29) ****	−0.097 (−5.280) ***	0.062 (5.170) ***	0.035 (5.170) ***
Secondary	0.454 (5.88) ***	−0.130 (−5.780) ***	0.080 (6.060) ***	0.050 (4.980) ***
Tertiary	0.505 (6.16) ***	−0.149 (−6.380) ***	0.089 (6.810) ***	0.060 (5.300) ***
Access to Extension	0.419 (6.44) ***	−0.115 (−6.190) ***	0.068 (6.080) ***	0.046 (5.920) ***
Farm size	0.018 (0.13)	0.013 (0.340)	−0.008(−0.340)	−0.005(−0.340)
Income	0.000 (-0.03)	0.000 (0.030)	−0.000(−0.030)	−0.000(−0.030)
HH Food consumption	−2.678 (−22.56) ***	0.784 (23.770) ***	−0.466 (15.240) ***	−0.317 (23.140) ***
Household head job	−0.007 (−5.79) ***	0.000 (6.190) ***	−0.001 (−6.100) ***	−0.001 (−5.890) ***
Pseudo r-squared 0.274		The number of obs. 2800		

Author's computation 2023 GHS 2010/2011 and 2018/2019. Note: dy/dx for factor levels is the discrete change from the base level.
*** p < .01, ** p < .05, * p < .1.

4.3.1. Least Resilient Level, (r = 0)

From Table 8, the sex of the household is negative using males as the baseline, with resilience at a 10% significance level. This implies that female gender resilience capacity decreases by 0.24 units compared with male counterparts. This confirms the result of the resilience index in Table 1 that the male resilience index is higher than that of the female, which also means male-headed households could be more resilient than female-headed households. The male gender is more resilient than the female. The finding of Olaosebikan et al. (2023) also stated that males are more resilient than their female counterparts. Age and the square of age are significant at 1% where the age square has a negative coefficient. This means that a 0.007 unit increase in age of a rural household increases the least resilience capacity of that household head, while 0.0001 unit of age squared decreases the resilience level of the household head. It means resilience increases with age. Also, marital status, social capital, livestock owned by the household, household size, and access to credit are significant at 1% and have a positive relationship with resilience at least resilient level. This means that household heads who are married, have good social capital, own livestock with a considerable household size, and have access to credit, are more resilient and able to cope with climate shocks to some extent.

Levels of education, either primary, secondary, or tertiary, have a negative interaction with the level of resilience, and this could either decrease or increase resilience capacity based on the application of knowledge acquired to climate shocks. Most household heads in rural areas have no formal education, and those who have acquired knowledge through education are not applying the knowledge to climate shock challenges, so their resilience capacity decreases with their levels of education. Access to extension should increase resilience, but it is negative with resilience. This means that resilience is reduced by the inability of households to have access to extension services, especially land use for farm operations. Resilience increases with household food consumption and the household head's job. 0.784 unit increases in household food consumption could lead to a unit increase in the level of resilience capacity of the household. At the same time, 0.002 unit increases in household head job or household head sources of income could increase a unit level of a household's resilience.

4.3.2. Less Resilient Level, (r = 1)

The significant variables at 1% that have a negative influence on resilience to climate shocks are age, marital status, social capital, livestock owned, household size, and access to credit. This implies that rural households could be regarded as less resilient if there is a reduction in age and the household size. That means household heads are less resilient to climate stress when they are younger, and they have low household sizes to cater to. The age coefficient becomes negative while its squared term turns positive, producing a U-shaped relationship. This pattern may signal the influence of health shocks, declining labor productivity, and increased vulnerability among aging rural populations. In such cases, the quadratic term captures a real non-linear deterioration rather than statistical noise. Age effects show non-linear declines in resilience among older households, motivating health interventions and cash transfers for the elderly. Substantively, this finding has policy relevance. A documented late-life decline would justify targeted interventions such as rural health insurance, mobile clinics, old-age cash-transfer schemes, chronic-disease screening, and strengthened community support systems for elderly farmers. Identifying whether ageing depresses resilience because of physical limitations, income loss, or reduced social capital would help refine these interventions and ensure they reach the affected demographic groups effectively.

However, marital status, social capital, livestock ownership, and access to credit, which have positive interactions with the least resilient, now have negative relationships with less resilient capacity levels. This indicates the dynamics of resilience as it is not static. Moreover, it could be explained that households that are married (monogamous), widowed, and never married are less resilient with a higher resilience index than married (polygamous) and separated households, as indicated in Table 1. The reasons could be that households that are married (polygamous) and separated have more burdens to take care of or add more pressure on resources available to cope with shocks than households of other marital statuses, and therefore, their ability to withstand climate shocks decreases. At lower resilient levels, social capital, access to credit, and the number of livestock owned tend to decrease. This result explains why households could transit from one resilience level to another at different times.

The significant factors at 1% that have a positive relationship with less resilient households include age squared, dependency ratio, levels of education (primary, secondary, and tertiary), and access to extension. Age squared means older age. It means that older household heads might be less resilient due to experiences acquired while facing life difficulties over the years, and the accumulation of assets over the years to cope and overcome shocks. Moreover, the positive relationship indicates that resilience is positively influenced by a 0.008 unit increase in dependency ratio, 0.062unit increase in primary education, 0.08unit increase in secondary education, 0.089unit increase in tertiary education, and 0.68unit increase in access to extension services. Hence, a unit increase in dependency ratio, levels of education, and access to extension services increases resilience at the less resilient level.

4.3.3. Most resilient level, (r = 2)

Resilience is dynamic and changes over time (d'Errico & Di Giuseppe, 2016). This is why rural households transit from one level or category of resilience to another over time. The significant variables that determine resilience at each level vary from one level to another. The significant variables that have a negative influence on the most resilient category of the rural households at 1% are age, social capital, livestock owned, household size, access to credit, household food consumption, and household head job while age squared, dependency ratio, levels of education and access to extension have a positive relationship with resilience and are also significant at 1%. The negative coefficient on age alongside a positive and significant coefficient on age squared suggests a non-linear (U-shaped) relationship between age and household resilience. This pattern typically implies that resilience declines at younger middle-ages but begins to rise again at older ages or vice versa, depending on the turning point. This may indicate that health shocks, declining labor capacity, or increased dependency burdens are eroding resilience among older households. Such evidence would strengthen the case for targeted policy interventions, including age-sensitive social protection measures, community-based health programs, and conditional or unconditional cash transfer schemes aimed at enhancing the resilience and welfare of older rural households.

Rural households could transition from least resilient to most resilient if there is a unit decrease in age, social capital, livestock owned, household size, access to credit, household food consumption, and household head job, while their resilience capacity improves with increased levels of education, access to extension, and dependency ratio. This implies that rural household heads who fall into the most resilient category are old and not young, with improved levels of educational attainment over the years. The study's result is relevant to previous studies, such as Raghunathan et al. (2022), who stated that resilience meant that people in the educational environment continued to function, albeit differently. UNESCO (2021) emphasized that strengthening education systems ensures people can overcome adversity easily and are resilient to the risks they face. In times of adversity, education retains high public value, reaches populations on a large scale, and serves as a critical hub for information sharing. A strong education system can potentially improve individual community and institutional resilience. Therefore, education is a very important factor that influences the resilience capacity of the rural household. Levels of education could indicate the level of acquired knowledge over the years, which could also influence other indicators of resilience capacity levels, such as social capital, access to credit, access to extension, number of household members to have, and livestock owned in a time-variant.

The Variance Inflation Factor (VIF) values presented in Table 9 indicate that multicollinearity is not a concern in the model. All variables exhibit VIF values well below the conventional threshold of 10, and even below the more conservative threshold of 5. The highest VIF in the table is 2.26 for age, followed closely by marital status (2.23), both of which remain substantially low and acceptable. All other variables, including sex, age squared, household size, access to credit, cooperative membership, and farm size, have VIF values close to 1, suggesting minimal correlation with other explanatory variables. The mean VIF of 1.27 further confirms the absence of multicollinearity. Therefore, the explanatory variables included in the regression model are sufficiently independent, and the parameter estimates can be considered reliable.

Table 9. Result of variance inflation factor.

variables	vif	1/vif
Sex	1.06	0.946
age	2.26	0.441
Age squared	1.06	0.957
Marital status	2.23	0.448
Monogamous	1.06	0.947
Polygamous	1.25	0.976
Divorced	1.05	0.948
Separated	1.08	0.923
Widowed	1.10	0.911
Never married	1.19	0.837
Household size	1.23	0.813
Access to credit	1.05	0.948
Membership of cooperative	1.05	0.957
Farm size	1.06	0.947
Mean VIF	1.27	

Source: Author's computation 2023 GHS 2010/2011 and 2018/2019.

5. Conclusion

Determining resilience to climate shocks is crucial for enhancing the livelihoods of rural households, improving agricultural productivity, and strengthening their capacity to recover from the adverse effects of climate change, thereby contributing to economic growth and sustainable development. Climate shocks demonstrate the urgent need for effective adaptation strategies to mitigate and manage the risks associated with climate change-induced shocks. Implementing measures to reduce the risk of fires and floods is essential, such as fire safety measures and constructing flood-resistant buildings. Additionally, actions to enhance agricultural resilience to poor rainfall and pest invasions should be prioritized to ensure food security, reduce harvest losses, and reduce loss of land. Appropriate veterinary care and disease prevention measures can help reduce livestock mortality rates. Formal education should be enhanced among rural households to strengthen their resilience capacity to overcome the negative impacts of climate change. Educating married households, primarily middle-aged households, should be intensified. Efforts on agricultural extension services should also be intensified to enforce land use policy to improve access to land, especially among women, and to promote land governance among rural households. Gender inequality should be addressed to build resilience to climate change. Giving women more access to resources, property rights, especially land use, and decision-making power, even to utilize land by themselves, can help to ensure that they are not disproportionately affected by the adverse effects of climate change.

Substantial social capital can help rural households cope with the negative impacts of climate change by providing them with support and resources. The study's findings also recommend that policies and interventions that aim to increase income and food access, strengthen social safety nets, improve agricultural input and technology, and promote stability measures would be most effective in helping rural households become more resilient to climate change. Age effects show non-linear declines in resilience among older households, motivating health interventions and cash transfers for the elderly. Policies and interventions should also be tailored to the specific needs of the communities and the specific climate change effects they face. It is also crucial to address climate challenges through policies and actions that prioritize resilience and sustainable development.

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Abbreviations

The following abbreviations are used in this manuscript:

BMGF	Bill and Melinda Gates Foundation
BRACED	Building Resilience Adapting to Climate Extremes and Disasters
FMA&RD	Federal Ministry of Agriculture and Rural Development
GHS-P	General Household Survey Panel Data
LSMS-ISA	Living Standard Measurement Survey-Integrated Survey of Agriculture
MIMIC	Multiple Indicator Multiple Causes
NBS	Nigerian Bureau of Statistics
NFRA	National Food Reserve Agency
PCA	Principal Component Analysis
SRC	Self-Reliance Capacity
WB	World Bank

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Article

Mechanism and Effect of Digital Economy on Green Utilization Efficiency of Cultivated Land—Taking the Jiangsu-Zhejiang-Anhui Region as an Example

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Abstract: At present, under the dual strategic demands of digital economic development and green transformation of cultivated land, the Jiangsu-Zhejiang-Anhui region, as a key area simultaneously facing the pressure of cultivated land quality degradation and the heavy responsibility of food security, has made the deep integration of digital technology and cultivated land utilization an urgent issue. This study takes 40 prefecture-level cities in Jiangsu, Zhejiang, and Anhui as subjects and uses panel data from 2013 to 2023. The Super-SBM model and entropy method are employed, combined with approaches such as the instrumental variable method, spatial econometric models, and the Tobit econometric model, to empirically examine the impact of the digital economy on the green utilization efficiency of cultivated land and analyze its spatial heterogeneity characteristics. Overall, the findings indicate that (a) the study develops an integrated framework across driving, input, output, and emission dimensions; (b) the digital economy significantly enhances the green utilization efficiency of cultivated land, and this effect remains robust after addressing endogeneity and conducting multiple sensitivity checks; (c) the promotional impact exhibits pronounced spatial heterogeneity, showing a clear inter-provincial gradient (Zhejiang > Jiangsu > Anhui) and significant divergence among cities within provinces. The digital economy development enhances the green utilization efficiency of cultivated land through multiple pathways. It is imperative to implement differentiated policies and establish a coordinated development framework for the three provinces to foster the synergistic development of the digital economy and green agriculture.

Keywords: digital economy development; green utilization efficiency of cultivated land; Super-SBM model; Tobit model; Jiangsu-Zhejiang-Anhui region

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1. Introduction

Presently, the wave of informatization is sweeping across the globe, with the widespread application of digital technologies giving rise to the digital economy. Digital economy constitutes a series of economic activities that utilize digitalized knowledge and information as key production factors, employ modern information networks as vital conduits, and leverage the effective application of information and communications technology as a significant driver for enhancing efficiency and optimizing economic structures (J. Sun, 2023). At the 2024 Global Digital Economy Conference, the Global Digital Economy White Paper released by the China Academy of Information and Communications Technology (CAICT) revealed that the digital economy has become the new engine driving the global wave of technological revolution and industrial transformation. Countries around the world are accelerating the development of key areas in the digital economy, actively seizing development opportunities in digital technology and industries, industrial digitalization, and data elements. Developing the digital economy is a strategic choice to seize the new opportunities presented by the latest round of technological revolution and industrial transformation, and holds significant strategic importance for national development (People's Daily, 2021). In recent years, with the increasing prevalence of information technologies (Wolfert et al., 2017), the digital economy—as a new driving force and business model—has continuously integrated with rural industries. It has gradually become a significant force in promoting the comprehensive revitalization of rural areas and achieving high-quality development (Q. Zhang & Pan, 2025). Presently, the protection and utilization of cultivated land in China face numerous challenges, with prominent issues including declining soil quality, severe soil erosion, and excessive use of chemical fertilizers and pesticides (K. Jiang et al., 2025). To promote high-quality agricultural development, the Ministry of Agriculture and Rural Affairs has issued comprehensive guidelines to enhance the application of smart agriculture, including improving the cultivated land quality monitoring network. Integrating digital economy development with the green utilization efficiency of cultivated land has become an essential component of achieving national food security and sustainable agricultural development strategies.

The green utilization efficiency of cultivated land is a multi-dimensional and dynamically evolving concept, mainly highlighting the characteristics of "greening" and "low-carbonization." Greening focuses on reducing inputs of polluting factors such as pesticides, fertilizers, and agricultural films, alongside mitigating non-point source pollution, while low-carbonization stresses carbon emission reduction and enhanced carbon sink functions (Fu et al., 2024). Green utilization efficiency of cultivated land emphasizes the environmental externalities of farmland utilization systems, aiming to achieve the maximum output of economic, social, and ecological benefits with the minimum input of resources (Xie et al., 2018). From a theoretical perspective, the concept aligns with the principles of ecological economics and sustainable intensification, which advocate for optimizing resource use while minimizing environmental impacts (Tilman et al., 2011). Analyzing this from a life-cycle perspective involves considering three stages: input, production, and output. During the input stage, optimizing the allocation of factors for cultivated land utilization through precise management and other methods, thereby reducing unnecessary inputs (Gebbers & Adamchuk, 2010). The production stage focuses on reducing unexpected outputs such as carbon emissions and non-point source pollution. The output stage prioritizes enhancing grain yields and agricultural output value to increase expected outputs (Zhou & Han, 2024).

Numerous scholars have explored how digital economy development influences agricultural production. Some, through case studies, propose that digital technologies progressively permeate agricultural processes, creating novel production methods and economic models that drive agricultural transformation and upgrading (H. Yin et al., 2020). For instance, Du Jianjun et al. argue that the dissemination of digital technologies facilitates land transfers, thereby promoting large-scale agricultural operations (Du et al., 2023). These scaled entities adopt green technologies, ultimately enhancing agricultural green total factor productivity (Basso & Antle, 2020). Others define digital literacy and digital skills as farmers' "digital capital," positing that this capital provides comprehensive information, thereby enhancing farmers' awareness of green and low-carbon transformation and facilitating their decision-making in this regard (Huang & Nie, 2023). Other scholars propose that digital factors can integrate profoundly with traditional production factors, significantly enhancing input-output efficiency by substituting for and interacting with other factors, thereby boosting green total factor productivity (Han et al., 2022; Klerkx et al., 2019). Furthermore, other literature examines the impact of digital technologies on agricultural and rural development from diverse angles, such as the effects of "Internet Plus" on agriculture (Z. Zhang & Mao, 2020), agricultural production services within the digital economy (Chu, 2020), and digital agriculture models (X. Wang & Zhang, 2014). In summary, existing literature has yielded substantial findings on how digital economy development influences agricultural production. However, research on the impact of digital economy development on the green utilization of cultivated land remains limited (Y. Liu et al., 2018). While some scholars have examined the effects of the rural digital economy on green cultivated land utilization, the underlying mechanisms and spatial heterogeneity between digital economy development and green utilization of cultivated land in the three provinces of Jiangsu, Zhejiang, and Anhui—located in the primary grain-producing region of the middle and lower Yangtze River plain—require further exploration. Therefore, against the backdrop of rapid digital economy development and strong national support for green agricultural development and rural revitalization, how Jiangsu, Zhejiang, and Anhui provinces can enhance the digital economy's role in promoting green farmland utilization—thereby achieving synergistic development between digitalization and agriculture—constitutes a critical scientific question requiring urgent exploration for advancing agricultural modernization in this region.

As pivotal provinces in the middle and lower reaches of the Yangtze River, Jiangsu, Zhejiang, and Anhui possess large populations with substantial grain demands. Their favorable topography, advantageous geographical positioning, and advanced production technologies have propelled rapid agricultural modernization, with the digital economy emerging as a core pillar for rural development. Therefore, examining the impact of digital economy development on the efficiency of green utilization of cultivated land in the Jiangsu-Zhejiang-Anhui region, clarifying the spatial heterogeneity of these effects, and exploring tailored enhancement pathways holds significant importance for high-quality agricultural development. Meanwhile, to visually illustrate the differentiated characteristics, this study selects the cities of Ningbo and Huzhou in Zhejiang Province, which exhibit distinct development paths, as typical cases for comparative analysis. Ningbo, leveraging its solid digital industry foundation, achieved a safe utilization rate of 97.42% for contaminated cultivated land and a supply proportion of over 60% for green, high-quality agricultural products in 2022, demonstrating a higher level of green output in cultivated land use. In contrast, Huzhou, as a region predominantly driven by traditional agriculture, shows a significantly higher share of primary industry value-added compared to Ningbo. Moreover, the added value of its core digital economy accounts for only about 6.2% of its regional GDP, indicating a relatively limited level of integration between the digital economy and agricultural production. These observable spatial disparities visually reveal the non-uniformity of the enabling effects of the digital economy development.

In light of this, this paper constructs an indicator system comprising a digital economy development index and a green utilization efficiency index for cultivated land, based on data from 40 prefecture-level cities across Jiangsu, Zhejiang, and Anhui provinces spanning 2013–2023. Employing the Super-SBM model and Tobit econometric model, it quantifies the impact and spatial heterogeneity of digital economy development on empowering green utilization efficiency of cultivated land. And proposes policy recommendations for enhancing green utilization efficiency through digital economy development, aiming to provide practical guidance for high-quality agricultural development in Jiangsu, Zhejiang, and Anhui.

2. Theoretical Analysis

This study constructs a systematic analytical framework encompassing the driving layer, input side, output side, and emission side to elucidate the multi-pathway mechanism through which the digital economy enhances the green utilization efficiency of cultivated land (Figure 1). The core of this mechanism lies in the fact that the digital economy, through optimizing factor allocation, smartening the production process, and greening the value chain, systematically resolves the core constraints in traditional agricultural production, such as information asymmetry, resource misallocation, and negative environmental externalities. This drives the transformation of cultivated land towards a sustainable development model characterized by precision, intensification, and low-carbon practices.

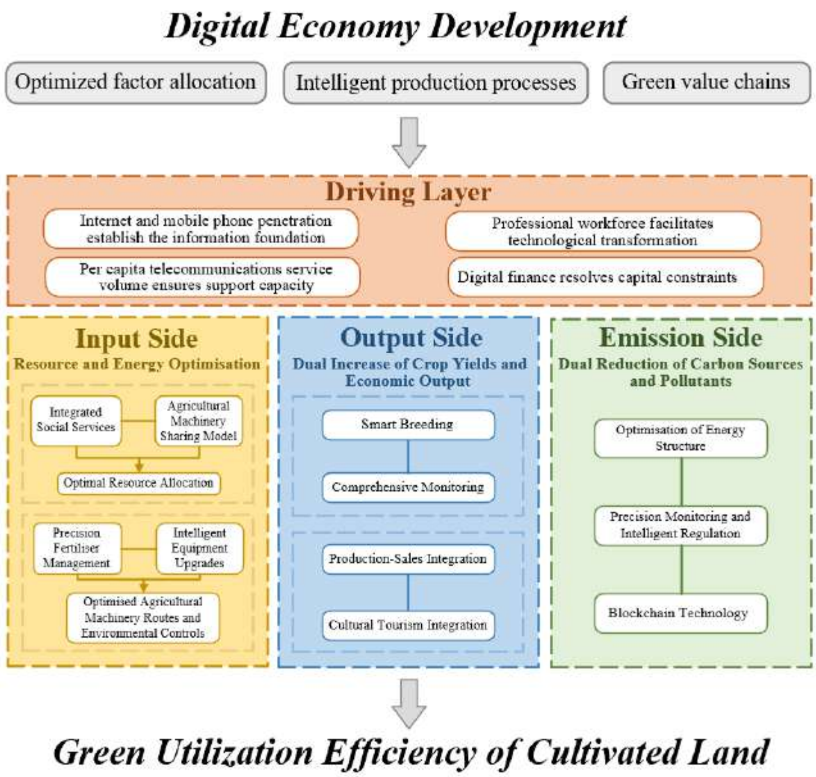

Figure 1. Theoretical framework of the research.

2.1. Driving Layer

Establishing a Multi-dimensional Foundational Support System. The digital economy's driving force for green agriculture stems from its construction of a multi-tiered, robustly supportive foundational system. Firstly, the comprehensive coverage of digital infrastructure, such as the internet and mobile telephony, forms a crucial "information base." This enables real-time collection and high-speed transmission of vast datasets on cultivated land, climate, crops, and markets, thereby facilitating subsequent intelligent decision-making (Amara et al., 2024). Secondly, digital technology professionals are pivotal in activating this foundation. Beyond technological R&D, they actively promote industry-technology integration, applying cutting-edge algorithms and models to specific agricultural scenarios to resolve production challenges (Yao et al., 2025; Y. Li et al., 2025). Thirdly, the increase in per capita telecommunications services signifies a comprehensive leap in digital service capabilities, ensuring seamless connectivity from cloud computing to terminal applications while enhancing the stability and penetration of the entire system. Fourthly, digital finance precisely targets the funding constraints encountered in the agricultural green transition. Through innovative tools such as big data credit assessment, supply chain finance, and green credit, digital finance can identify and support new business entities genuinely engaged in green production. This addresses their financing challenges stemming from high initial investment and long return cycles, injecting capital vitality into the adoption and application of green technologies (An et al., 2025).

2.2. Input Side

Achieving precise and intensive allocation of production factors. On the input side, the digital economy profoundly reshapes traditional production factors through two primary pathways.

(1) Factor restructuring and efficiency enhancement pathway. This pathway aims to reduce redundancy and waste in factor inputs through optimized resource allocation. Firstly, the digital economy transforms data into a new production factor (F. Wang et al., 2023), significantly reducing information asymmetry (C. Yang et al., 2024). Big data platforms integrate land transfer information, agricultural machinery service demands, and agricultural product price forecasts, enabling efficient matching between supply and demand. This facilitates the concentration of cultivated land resources towards more efficient operators, achieving spatial optimization. Online platforms consolidate dispersed agricultural machinery resources, enabling cross-regional and cross-operator deployment. This not only substantially increases the utilization rate of fixed assets like large agricultural machinery but also prevents duplicate investment and resource idleness, representing a fundamentally digitalized, asset-light operation and resource optimization approach (Jones & Tonetti, 2020). Furthermore, digital platforms integrate full-chain socialized services—including sowing, crop protection, and harvesting—enabling smallholder farmers to access professional support through service procurement. This effectively reduces household labor intensity and costs while alleviating pressures from an ageing agricultural workforce and part-time farming practices (Rana et al., 2024).

(2) Technology-enabled pathways for green transformation. This approach focuses on precision management throughout production processes, directly reducing resource consumption and environmental impacts at source. Its core lies in the precise control of inputs such as fertilizers and pesticides (Ci, 2022; Delgado et al., 2019). Through Internet of Things sensors deployed in fields, the system monitors soil moisture, nutrient levels, and crop pests and diseases situation in real time. Integrating crop growth models, it generates variable fertilization and prescription spraying decisions executed by intelligent equipment. This minimizes indiscriminate pesticide use and excessive fertilization, controlling agricultural non-point source pollution at its source while safeguarding yields. This precision agriculture framework robustly underpins the advancement and adoption of intelligent equipment, such as unmanned tractors and automated irrigation systems (Tian et al., 2014; Y. Yang & Wang, 2025). These devices serve not only as execution terminals for precision agriculture but also as conduits for energy-saving technology diffusion (Ge et al., 2025). At a deeper level, digital technologies achieve energy conservation and reduced consumption by optimizing machinery routes and environmental controls. Leveraging the BeiDou navigation system and algorithmic optimization, it plans the shortest, least repetitive operational routes for agricultural machinery, reducing empty-run mileage and non-productive energy consumption. Intelligent irrigation systems, meanwhile, deliver a precise water supply based on real-time meteorological data and evaporation rates, preventing water wastage. Collectively, these measures significantly reduce direct energy consumption and carbon emissions in agricultural production (Q. Jiang et al., 2022; Y.-f. Zhang et al., 2023).

2.3. Output Side

Achieving dual objectives of "Enhancing Quality and Efficiency" and "Adding Value." Following factor optimization at the input end, the digital economy gives rise to a "dual increase" effect at the output side, simultaneously elevating agricultural production efficiency and the market value of agricultural products. Firstly, it enhances agricultural production efficiency and quality. Digital technologies, integrated with intelligent breeding and comprehensive monitoring (L. Yin & Zhang, 2023), fundamentally strengthen the output foundation. Genome sequencing and big data-driven selection accelerate the breeding of high-yielding, stress-resistant, and premium new varieties (Y. Zhang et al., 2025). Comprehensive monitoring via drone remote sensing and satellite imagery enables macro-level oversight and early warning of crop growth and pest or disease outbreaks, guiding field management to systematically enhance yield per unit area and quality. This safeguards basic agricultural supply and ensures product safety. Secondly, expanding the value and industrial boundaries of agricultural products. In post-harvest stages, the digital economy significantly enhances the premium potential of agricultural goods. E-commerce platforms overcome geographical barriers, enabling premium produce to reach consumers nationwide and globally. This reduces multiple intermediate links, allowing producers to capture greater profits (Fang & Shen, 2025; Xiong et al., 2023; C. Zhang & Liu, 2023). Traceability systems built on blockchain and IoT provide tamper-proof digital credentials for agricultural products, visually conveying green and safety information from production processes to consumers. These build trust and secure brand premiums (M. Liu et al., 2025; Sheng et al., 2024). Furthermore, the digital economy significantly expands economic boundaries through the integration of agriculture, culture, and tourism (K. Guo & Ma, 2025; Z. Jiang, 2024). Digital media such as live streaming and short videos can comprehensively showcase and market pastoral landscapes, agricultural culture, and rural homestays, attracting consumers to offline experiences. This promotes the integration of agriculture with tourism, culture, and other industries, forming distinctive rural industrial chains that generate additional economic growth points for villages (R. Sun, 2025).

2.4. Emissions Side

Establishing a comprehensive environmental governance system spanning "source-process-end." At the emissions end, the digital economy drives a "dual reduction" framework of concurrent carbon and pollution reduction, with mechanisms spanning the entire pollution generation process. Firstly, at the energy structure level, digitalized energy management systems enable the intelligent scheduling of the photovoltaic, energy storage, and traditional energy sources within farms. This optimizes energy consumption patterns, increases the share of clean energy, and directly reduces carbon emissions from mechanical power (L. Jiang et al., 2025). Secondly, its role is most critical in pollution control. The aforementioned precision fertilization and pesticide application, alongside intelligent management at the input stage, inherently constitute the most effective method for reducing non-point source pollution at its source, minimizing runoff and leaching of nutrients such as nitrogen and phosphorus, as well as chemical substances (L. Zhang et al., 2025). Moreover, sensor networks and AI image recognition enable continuous, precise monitoring and intelligent regulation of discharge points and waterways. Upon detecting anomalies, immediate alerts pinpoint pollution sources, facilitating rapid response and strengthening containment of pollution spread (Oladele, 2025; Hou et al., 2025). Finally, at the institutional incentive level, blockchain technology establishes a trustworthy environmental data recording platform. Every environmental action can be recorded, certified, and converted into digital assets (Villafranca et al., 2025). This immutable, traceable nature reinforces environmental accountability constraints. Simultaneously, market-based trading mechanisms provide direct economic incentives for emission reduction activities, shifting green production from being "morally driven" to "profit-driven," thereby establishing a long-term governance mechanism.

In summary, enhancing the green utilization efficiency of cultivated land through the digital economy is not achieved by improving a single technology or isolated process, but rather through a multi-dimensional and full-chain process of coordinated evolution. The driving layer forms the foundation, the input side represents the core pathway, the output side manifests economic benefits, and the emissions side signifies environmental outcomes. Through organic linkage and synergistic enhancement across all stages, this mechanism systematically advances the transformation of cultivated land utilization towards green and intensive practices, laying a solid foundation for high-quality agricultural development.

It should be further emphasized that the actual operation of this systemic mechanism does not unfold within a homogeneous spatial context. The enabling effect of the digital economy on the green utilization efficiency of cultivated land does not manifest uniformly across all regions. Its spatial heterogeneity stems from disparities in regional digital infrastructure endowments, industrial structure characteristics, and institutional environments. Fundamentally, this reflects divergent manifestations of foundational elements at the driving layer, core functional pathways at the input end, and value realization mechanisms at the output and emissions end under varying regional conditions. In terms of supporting conditions, significant gradient differences exist across Jiangsu, Zhejiang, and Anhui in digital infrastructure, depth of technological integration, financial inclusion, and talent concentration. This leads to marked divergence in the pathways and effects through which the digital economy influences arable land utilization efficiency via mechanisms such as factor optimization, intelligent production, and green value-added. In most cities of Zhejiang and parts of Jiangsu, robust digital foundations and seamless industry-academia-research conversion enable systematic embedding of digital technologies throughout the entire arable land utilization process. This facilitates precise input management, optimized agricultural machinery operations, and traceability systems, effectively achieving green empowerment. Conversely, in most cities of Anhui and certain transition-phase regions, insufficient digital penetration and disjointed transitions between traditional industries and emerging sectors constrain technological optimization. This may even result in weak or negative short-term empowerment effects.

Based on this, the paper proposes a targeted research hypothesis: the positive promotional effect of digital economy development on the green utilization efficiency of cultivated land exhibits significant spatial heterogeneity. At the inter-provincial level, provinces with superior digital economic foundations and deeper industrial integration demonstrate stronger promotional effects. At the intra-provincial level, cities with a high degree of agricultural structural modernization and robust digital development foundations are better positioned to fully leverage the green enabling value of the digital economy than cities characterized by a higher proportion of traditional agriculture and lagging digital infrastructure.

3. Overview of Study Areas and Data Sources

3.1. Overview of the Study Area

This study selects Jiangsu, Zhejiang, and Anhui provinces as its research area. Situated within the Yangtze River Delta world-class urban cluster, this region exhibits pioneering and exemplary effects nationally in terms of socio-economic development and resource-environment utilization patterns. In recent years, its digital economy has experienced rapid growth, becoming a core engine driving regional high-quality development. According to the 2023 China Digital Economy Development Report, Jiangsu and Zhejiang both rank among the top tier in digital economy development. Zhejiang's digital economy value-added has consistently exceeded 50% of its GDP for multiple consecutive years. In 2022, Jiangsu's core digital industries accounted for approximately 11% of its GDP. Anhui, emerging as a rapidly catching-up province, has consistently ranked among the nation's leaders in digital economic growth rates. The robust yet differentiated digital economy development across these three provinces provides a crucial foundation for this study's examination of the spatial heterogeneity in the impact of digital economy development on the green utilization efficiency of cultivated land.

Concurrently, Jiangsu, Zhejiang, and Anhui face acute pressures on cultivated land resources and pronounced land-population tensions. Together, they support nearly a quarter of China's economic output despite occupying less than 4% of the nation's total land area. The Yangtze River Delta urban cluster, bound by the river, has undergone sustained integration and rapid economic growth. Since the Reform and Opening up, urban construction land in the region has expanded rapidly, leading to extensive conversion of agricultural land for non-agricultural purposes (Y. Sun et al., 2024). Against the backdrop of ensuring food security and sustainable agricultural development, effectively enhancing the green utilization efficiency of cultivated land has become a critical issue for the modernization of agriculture in Jiangsu, Zhejiang, and Anhui. Consequently, examining the impact of digital economy development on the green utilization efficiency of cultivated land holds significant importance.

3.2. Data Sources and Explanation

This study covers the period from 2013 to 2023. Data used to measure each city's digital economy development index and green utilization efficiency index of cultivated land are sourced from the 2014–2024 Jiangsu Statistical Yearbook, Zhejiang Statistical Yearbook, Anhui Statistical Yearbook, and the EPS Statistical Data Retrieval and Forecasting Platform (https://www.epsnet.com.cn/index.html). Missing individual data points were supplemented using interpolation methods. Vector data for spatial distribution mapping was sourced from the National Centre for Basic Geographic Information (https://www.ngcc.cn/).

4. Variable Selection and Model Specification

4.1. Variable Configuration

4.1.1. Dependent Variables

The dependent variable is the green utilization efficiency of cultivated land (GUECL). Integrating the conceptual framework of GUECL with life-cycle spatial convergence analysis, and drawing upon existing research (M. Li et al., 2024; Lu et al., 2025; Lyu et al., 2023; Wu et al., 2021), the production phase incorporates traditional input factors selected from resource and power dimensions: cultivated land resources, fixed assets, chemical inputs, labor, mechanical power, and energy consumption. In the output phase, positive externalities were selected from the socio-economic dimension, with cultivated land economic output and crop yield serving as desired output indicators; negative externalities were selected from the carbon source and pollution emission dimensions, with cultivated land carbon emissions and non-point source pollution representing unexpected outputs. Specific details are presented in Table 1.

Table 1. Evaluation index system for green utilization efficiency of cultivated land

Category	**Indicator Name**	**Variable**	**Indicator Variable**	**Unit**
Production Input Stage	Resource Input	Cultivated Land Resources	Area sown to food crops	1,000 ha
		Fixed Assets	Agricultural fixed asset investment	10,000 yuan
		Chemical products	Pesticide, fertilizer and agricultural film usage	t
		Labor	Agricultural workers	10,000 people
	Power input	Mechanical Power	Total agricultural machinery power	10,000 kilowatts
		Energy consumption	Agricultural diesel consumption	t
Expected Output Stage	Socio-economic	Economic output from cultivated land	Agricultural output value	10,000 yuan
		Crop yield from cultivated land	Grain production	10,000 t
Unexpected Output Phase	Carbon	Carbon emissions from cultivated land	Total carbon emissions from fertilizers, pesticides, agricultural films, machinery, irrigation, and tillage [a]	kg CO_2
	Pollutant Emissions	Groundwater pollution from cultivated land	Loss of nitrogen and phosphorus from chemical fertilizers, inefficient utilization of pesticides, total residual agricultural film [b]	t

Note: Relevant coefficients reference corresponding data for the Southern Humid Plains Region from the First National Pollutant Source Census: Agricultural Pollutant Source Fertilizer Loss Coefficient Manual; the First National Pollutant Source Census: Agricultural Plastic Mulch Residue Coefficient Manual; and the First National Pollutant Source Census: Pesticide Loss Coefficient Manual. The calculation process accounts for the impact of regional natural geographical variations.

[a] $E = \sum E_i = \sum (G_i \times \delta_i)$ and E_i denote carbon emissions from the i-th carbon source. G_i and δ_i represent the respective carbon source quantities and emission coefficients, which are: fertilizers 0.8956 kg/kg, pesticides 4.3941 kg/kg, agricultural film 5.18 kg/kg, agricultural machinery 0.18 kg/kW, irrigation 266.48 kg/hm², ploughing: 312.60 kg/km²; coefficient sources: Oak Ridge National Laboratory (USA), Institute of Agricultural Resources and Environmental Sciences at Nanjing Agricultural University, and other websites.

[b] Fertilizer nitrogen loss = fertilizer application × 80% × nitrogen loss coefficient; Fertilizer phosphorus loss = fertilizer application × 20% × phosphorus loss coefficient; pesticide loss = pesticide application × pesticide loss coefficient; agricultural film residue = agricultural film application × film residue coefficient.

Data Envelopment Analysis (DEA) focuses on evaluating the input-output efficiency of multiple decision-making units (DMUs; Hu & He, 2000), offering advantages such as handling numerous input and output indicators, reducing subjective judgments, and providing directions for efficiency improvements. However, traditional DEA models may yield multiple DMUs as equally efficient, a phenomenon that limits the model's ability to distinguish efficiency in the green utilization of cultivated land in practical applications. To address this issue, this paper introduces the Super-SBM model (Tone, 2002), which permits efficiency values exceeding 1. This model is extensively applied in evaluating farmland utilization efficiency, significantly enhancing the model's precision in identifying and ranking highly efficient decision units. The calculation formula is:

$$M\ \Phi = \frac{1/m \sum_{i=1}^{m} \frac{\overline{x}}{x_{ik}}}{1 + 1/(e_1+e_2) \left(\sum_{s=1}^{r_1} \frac{\overline{y^d}}{y_{sk}^d} + \sum_{q=1}^{r_2} \frac{\overline{y^u}}{y_{qk}^u} \right)} \quad (1)$$

$$\text{Subject to } \overline{x} \geq \sum_{j=1,\neq k}^{n} x_{ij}\lambda_{j,} i = 1, 2, \ldots, m; \quad (2)$$

$$\overline{Y^d} \leq \sum_{j=1,\neq k}^{n} y_{sj}^d \lambda_j, s = 1, 2, \ldots, e_1; \quad (3)$$

$$\overline{Y^d} \leq \sum_{j=1,\neq k}^{n} y_{qj}^u \lambda_j, q = 1, 2, \ldots, e_2; \quad (4)$$

$$\Lambda_j \geq 0, j = 1, 2, \ldots, n, j \neq 0; \quad (5)$$

$$\overline{X} \geq x_k, i = 1, 2, \ldots, m; \quad (6)$$

$$\overline{Y^d} \leq y_k^d, s = 1, 2, \ldots, e_1; \quad (7)$$

$$\overline{Y^u} \leq y_k^u, q = 1, 2, \ldots, e_2 \quad (8)$$

In the formula: n denotes the number of DUMs; m represents the inputs for each DUM; e_1 denotes expected outputs, e_2 denotes non-expected outputs. $x \in E^m, y^d \in E^{e_2}$; Matrix $X = [x_1 \ldots x_n] \in E^{mn}, Y^d = [y_1^d \ldots y_n^d] \in E^{e_1 n}, Y^u = [y_1^u \ldots y_n^u] \in E^{e_2 n}$.

4.1.2. Explanatory Variables

The explanatory variable is digital economy development (DED). Following the methodology of Zhao et al. (2020) and considering data availability at the prefecture-level city tier, this study measures the digital economy development level across Jiangsu, Zhejiang, and Anhui prefecture-level cities through two dimensions: internet development and digital finance penetration. For digital financial inclusion, the China Digital Inclusive Finance Index (F. Guo et al., 2020), jointly developed by Peking University's Digital Finance Research Centre and Ant Group, is employed. This study standardizes data from the following five indicators using the entropy method before applying dimensionality reduction to comprehensively evaluate digital economy development (Table 2).

Table 2. Indicator System for the Digital Economy Development.

Primary Indicator	Secondary Indicator	Measurement Indicator	Weighting
Level of digital economy development	Internet penetration rate	Number of broadband internet users per 100 persons	0.260
	Number of internet industry personnel	Proportion of personnel in computer services and software	0.210
	Mobile telephone penetration rate	Number of mobile telephone users per 100 persons	0.203
	Internet-related output	Telecommunications services volume per capita	0.216
	Digital financial inclusion development	China Digital Financial Inclusion Index	0.111

4.1.3. Control Variables

To control for the potential influence of other factors on the efficiency of green utilization of cultivated land, this study selected the rural revitalization index, level of economic development, and intensity of agricultural fiscal support as control variables. This choice synthesizes the selection of control variables from relevant literature (T. Jiang et al., 2024; Y. Li et al., 2025; Lu et al., 2025;

Lyu et al., 2023;) while considering data availability. The measurement methods for these variables are detailed in Table 3.

Table 3. Design of Relevant Variables and Indicators.

Variable Type	Variable Name	Variable Abbreviation	Variable Description
Dependent variable	Green utilization efficiency of cultivated land	GUECL	Super-SBM model estimated efficiency value
Core explanatory variable	Digital economy development	DED	Peking University China Digital Inclusive Finance Index
Control variable	Rural Revitalization Index,	RRI	Calculated per Xu Xue and Wang Yongyu's methodology (Xu & Wang, 2022)
	Level of Economic Development	ED	Per capita income of villagers
	Strength of Agricultural Fiscal Support	AFS	The proportion of investment in agricultural fixed assets relative to total investment

4.1.4. Mechanism Verification Variable

To thoroughly validate the theoretical framework's mechanism whereby the digital economy influences the green utilization efficiency of arable land through four dimensions—the driving layer, input side, output side, and emission side—this paper constructs two sets of variables for mechanism testing based on the benchmark model.

(1) Four-Dimensional Proxy Variables

Based on the theoretical analytical framework and data availability, the following indicators (Table 4) were selected as proxy variables for the four dimensions, to be used in subsequent semi-unrelated (SUR) regression analysis.

Table 4. Four-Dimensional Proxy Variable Indicator Design Table.

Theoretical Dimension	Variable Name	Variable Symbol	Measurement Method
Driving Layer	Digital Financial Inclusion Level	DFI	Peking University Digital Inclusive Finance Index
Input Side	Chemical Input Intensity	CII	Pesticide, Fertilizer, and Agricultural Film Use per Unit Area (tons/1,000 ha)
Output Side	Agricultural Output Benefit	AOB	Agricultural output value per unit area (¥10,000/1,000 ha)
Emission En	Carbon Emission Intensity of Cultivated Land	CEI	Carbon emissions per unit area of cultivated land ($kgCO_2$/1,000 ha)

(2) Slack Variables

To identify specific pathways through which the digital economy improves inefficient aspects of cultivated land utilization at the micro level, this study analyzes slack values calculated using the Super-SBM model. These slack values measure the degree of inefficiency relative to the production frontier for each decision unit, with higher values indicating greater potential for improvement. The selected slack variables are presented in Table 5.

Table 5. Slack Variable Indicator Design Table.

Slack Variable	Variable Symbol	Corresponding Original Indicator
Chemical Input Slack	CIS	Pesticide, Fertilizer, and Agricultural Film Usage
Energy Consumption Slack	EUS	Agricultural Diesel Usage
Economic Output Slack	EOS	Agricultural Output Value
Cultivated Land Carbon Emissions Slack	CES	Total Cultivated Land Carbon Emissions

4.2. Model Setting

4.2.1. Benchmark Model

As the efficiency scores generated by the Super-SBM model are always positive, the dependent variable data exhibit a truncated form. When handling truncated data, the assumptions of continuity and normality inherent in the OLS method are invalid. Therefore, this study employs the Tobit model (Wu et al., 2021), which is well-suited for treating constrained dependent variables. The model specification is as follows:

$$y_{it} = \beta_0 + \beta_1 x_{it} + \beta_j \sum c_{it} + \varepsilon_{it} \tag{9}$$

In the equation: y denotes the green utilization efficiency index of cultivated land; x denotes the digital economy development index; c denotes the control variable; β_1 denotes the marginal utility of digital economy development level on green utilization efficiency of cultivated land when other control variables remain constant; β_j denotes the marginal effect of control variable j on green utilization efficiency of cultivated land when the core explanatory variable and other control variables remain constant; ε_{it} denotes the random error term; i and t denote prefecture-level city and year, respectively.

4.2.2. Endogeneity Treatment Model

Considering the potential endogeneity issues in the model arising from bidirectional causality or omitted variables, this paper employs the instrumental variable (IV) method for estimation and correction. The number of landline telephones per hundred people and the number of post offices per million people in each city in 1984 are selected as instrumental variables for the level of digital economy development. These historical variables satisfy the relevance and exogeneity requirements and have been extended into a panel format. The following two-stage regression model is constructed:

First stage:

$$x_{it} = \gamma_0 + \gamma_1 Z_{it} + \sum_j \gamma_j c_{jit} + \mu_i + v_t + \epsilon_{it} \tag{10}$$

Second stage:

$$y_{it} = \beta_0 + \beta_1 \hat{x}_{it} + \sum_j \beta_j c_{jit} + \mu_i + v_t + \xi_{it} \tag{11}$$

In the equation: y_{it} denotes the green utilization efficiency index of cultivated land; x_{it} denotes the digital economy development index; $\hat{x}_{it}$ denotes the predicted value of the digital economy development level obtained from the first-stage regression; Z_{it} denotes the instrumental variable, representing the telecommunications infrastructure level of each city in 1984; c_{jit} denotes the j-th control variable; μ_i and v_t denote individual fixed effects and time fixed effects, respectively; ϵ_{it} and ξ_{it} denote random error terms; i and t represent prefecture-level city and year, respectively.

4.2.3. Spatial Econometric Model

To examine whether the impact of digital economy development on the green utilization efficiency of cultivated land exhibits spatial spillover effects, this study introduces spatial econometric analysis based on the benchmark regression. First, the Global Moran's I index is employed to test the spatial autocorrelation of the efficiency values. The formula is as follows:

$$I = \frac{n \sum_{i-1}^{n} \sum_{j-1}^{n} \omega_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i-1}^{n} \sum_{j-1}^{n} \omega_{ij} \sum_{i=1}^{n} (x_i - \bar{x})^2} \tag{12}$$

In the formula: n represents the number of cities, x_i and x_j denote the observed values, and ω_{ij} is an element of the spatial weight matrix W.Given the close ties between regional governance and the economy, this study employs an administrative adjacency spatial weight matrix for the calculation.

Additionally, since the dependent variable (green utilization efficiency of cultivated land) is a non-negative value measured by the Super-SBM model, the data exhibit a truncated distribution. Therefore, a panel Tobit model capable of effectively handling limited dependent variables is adopted, with a spatial lag term embedded into it. The following spatial lag panel Tobit model is ultimately constructed:

$$y_{it} = \rho(W_y)_{it} + \beta_1 x_{it} + \beta_2 (W_x)_{it} + \beta_j \sum c_{it} + \varepsilon_{it} \tag{13}$$

In the formula: y_{it} represents the green utilization efficiency index of cultivated land; x_{it} represents the digital economy development index; $(W_y)_{it}$ and $(W_x)_{it}$ denote the corresponding spatial lag terms, used to capture spatial spillover effects; c_{it} refers to the control variables; β_j indicates the marginal effect of control variable *j* on the green utilization efficiency of cultivated land when other variables remain unchanged; ε_{it} is the random error term; *i* and *t* denote prefecture-level city and year, respectively.

5. Results Analysis

5.1. Benchmark Regression Results

To examine the impact of Digital Economy Development on the Green Utilization Efficiency of Cultivated Land, this study employs a Tobit model for benchmark regression. The estimation results are presented in Table 6. Column (1), which does not include control variables, shows that the coefficient for digital economy development is 0.338 and significant at the 1% level, preliminarily indicating a positive promoting effect of the digital economy on the green utilization efficiency of cultivated land. In Column (2), after further incorporating control variables such as the Rural Revitalization Index, education level, and agricultural operation scale, the coefficient for digital economy development increases to 0.537 and remains highly significant at the 1% level. This suggests that the promoting effect remains robust after controlling for related factors, confirming the mechanism through which the digital economy systematically enhances the green utilization efficiency of cultivated land via optimized factor allocation, intelligent production processes, and greening of the cultivated land value chain.

The estimation results for the control variables do not pass the significance tests, indicating that they do not exhibit stable independent effects under the current model specification. However, controlling for these variables aids in more accurately identifying the net effect of the digital economy on the green utilization efficiency of cultivated land.

Table 6. Estimation of the total effect of digital economy development on empowering green utilization efficiency of cultivated land

Variable	(1) GUECL	(2) GUECL
DED	0.338^{***}(3.72)	0.537^{***}(5.00)
In_ RRI		1.018(0.37)
In_ ED		−1.305(−0.47)
AFS		−0.089(−0.59)
Constant term	0.823^{***}(16.83)	0.633^{***}(8.65)
N	440	440

Note: The statistics in parentheses represent coefficient estimates.
*, **, *** denote significance at the 10%, 5%, and 1% levels respectively.

5.2. Endogeneity Test

This study employs the instrumental variables approach for testing and correction, selecting the number of landline telephones per hundred people and the number of post offices per million people in each city in 1984 as instrumental variables for the level of digital economy development. These historical variables satisfy the relevance and exogeneity requirements and have been extended into a panel format. Table 7 reports the estimation results of the instrumental variables approach (IV-Tobit) along with the corresponding diagnostic tests.

Table 7. Instrumental Variable Estimation Results

Variable	Benchmark Tobit Model	IV-Tobit Model
DED	0.458***(6.22)	0.458***(6.22)
In_ RRI	2.684(0.70)	2.684(0.70)
In_ ED	−2.829(−0.74)	−2.829(−0.74)
AFS	−0.171(−0.99)	−0.171(−0.99)
Constant term	0.717***(17.58)	0.717***(17.58)
N	440	440
First-stage F-statistic		0.458***(6.22)
Over-identification test p-value		2.684(0.70)
Endogeneity Wald test p-value		−2.829(−0.74)

Note: The statistics in parentheses represent coefficient estimates.
*, **, *** denote significance at the 10%, 5%, and 1% levels respectively.

The test results show that the F-statistic in the first-stage regression (89.41) is well above the critical value, indicating sufficient correlation between the instrumental variables and the endogenous variable. The p-value of the over-identification test is 0.9999, supporting that the instrumental variables satisfy the exclusion restriction. The p-value of the endogeneity Wald test is 0.0001, rejecting the null hypothesis of exogeneity for the core explanatory variable at the 1% level, confirming the existence of endogeneity. After controlling for endogeneity, the estimated coefficient for digital economy development rises significantly from 0.458 to 1.348, while remaining statistically significant at the 1% level, indicating that the benchmark regression underestimated the true promoting effect of the digital economy on the green utilization efficiency of cultivated land due to endogeneity bias.

5.3. Heterogeneity Analysis

5.3.1. Regional Heterogeneity

Given the significant disparities in economic foundations, industrial structures, and digital development levels among Jiangsu, Zhejiang, and Anhui provinces, this study further conducts regional heterogeneity analysis to investigate provincial and intra-provincial urban variations in the impact of digital economy development on the green utilization efficiency of cultivated land.

(1) Inter-provincial Regional Heterogeneity.

To better identify regional differences in the impact, grouped regressions were performed for Jiangsu, Zhejiang, and Anhui provinces separately, with estimation results reported in Table 8. From an overall perspective, the digital economy shows a significant positive impact on the green utilization efficiency of cultivated land in the combined sample of the three provinces (coefficient = 0.537, significant at the 1% level), confirming its universal enabling effect. Examining the results by province further reveals a clear gradient of differentiated characteristics.

Table 8. Estimation results of the regional heterogeneity of green utilization efficiency of cultivated land enabled by the development of the digital economy

Variable	Different partitions			
	(1) Jiangsu, Zhejiang, and Anhui	(2) Jiangsu	(3) Zhejiang	(4) Anhui
DED	0.537***(5.00)	0.473**(2.46)	0.889**(2.49)	0.179*(1.79)
In_ RRI	1.018(0.37)	7.503**(2.08)	−10.412(−1.53)	0.659(0.24)
In_ ED	−1.305(−0.47)	−7.816**(−2.18)	9.715(1.43)	−0.847(−0.31)
AFS	−0.089(−0.59)	−0.148(−1.64)	−0.739***(−5.24)	0.241**(2.44)
Constant term	0.633***(8.65)	0.672***(5.45)	0.630***(3.29)	0.849***(12.81)
N	440	143	121	176

Note: The statistics in parentheses represent coefficient estimates.
*, **, *** denote significance at the 10%, 5%, and 1% levels respectively.

The promoting effect is most prominent in Zhejiang Province, with a coefficient of 0.889, significant at the 5% level. This is mainly attributed to its advanced digital infrastructure, dynamic digital industry ecosystem, and efficient agricultural digital application systems, which enable digital technologies to be deeply integrated into the entire chain of green cultivated land production. Jiangsu Province also exhibits a stable positive effect, with a coefficient of 0.473 (significant at the 5% level), reflecting its phased achievements in promoting the synergy between manufacturing digitalization and agricultural green transformation. In Anhui Province, the impact coefficient of the digital economy is relatively small (0.179), showing marginal significance at the 10% level, indicating that its digital economy development has begun to exert a preliminary promoting effect on the green utilization efficiency of cultivated land. This result may be attributed to the rapid construction of digital infrastructure and the promotion of characteristic models such as agricultural e-commerce in recent years. However, due to insufficient depth in the integration of digital technologies with agricultural production and limited overall penetration of green technologies, its enabling intensity remains significantly lower than that of Jiangsu and Zhejiang provinces. The differentiated performance of control variables across the models further highlights the complexity of the influencing mechanisms related to rural revitalization priorities, human capital structure, and agricultural operation scale in the three provinces.

(2) Intra-provincial heterogeneity.

From the perspective of cities within provinces, the differences in the impact of digital economy development on the green utilization efficiency of cultivated land become more pronounced. Even within the same province, the effects vary significantly across cities (Figure 2). Figure 3 further reveals through temporal trends that this heterogeneity persists in dynamic evolution.

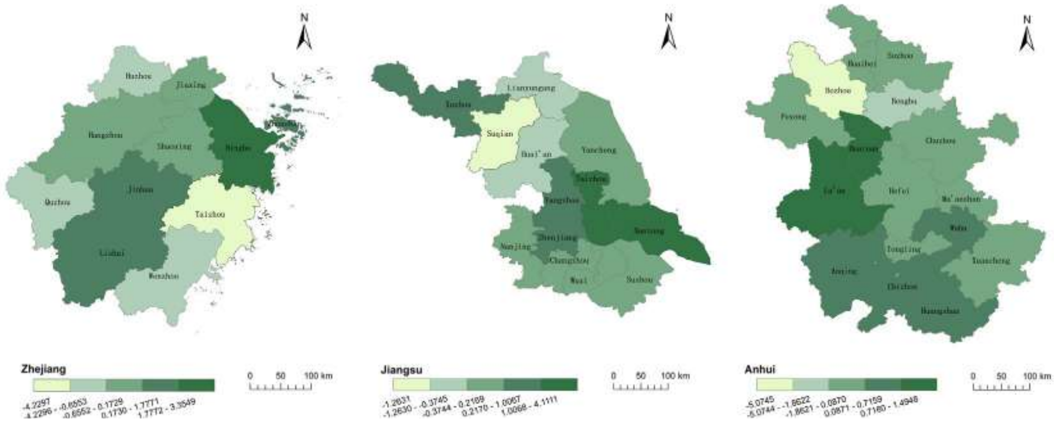

Figure 2. Spatial distribution of the degree of green utilization efficiency of cultivated land enabled by the digital economy development within the three provinces.

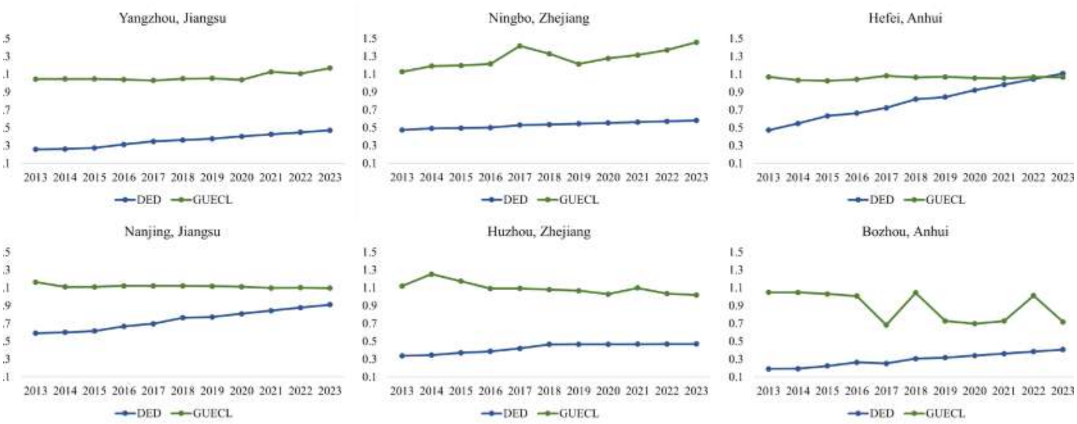

Figure 3. Synergistic Evolution Trend of Digital Economy Level and Green Utilization Efficiency of Cultivated Land in Representative Cities.

In Jiangsu Province, some cities exhibit significant positive effects. For example, Yangzhou City promotes the application of agricultural Internet of Things (IoT), smart irrigation, and precision fertilization systems, and has established a regional agricultural product quality and safety traceability platform, directly empowering agricultural production and management through digital technologies. As a result, the green utilization efficiency of its cultivated land increased from 1.05 in 2014 to 1.17 in 2023. Cities such as Nantong and Taizhou also show positive influences. However, transitional cities like Nanjing and Wuxi display insignificant or even negative effects, which stem from the disconnect between the phase-out of traditional high-energy-consuming industries and the cultivation of digital-green industries, with short-term transition pains suppressing the enabling effect.

In Zhejiang Province, most cities demonstrate significant positive effects. The development of the digital economy in cities like Ningbo and Jinhua has effectively promoted the green utilization efficiency of cultivated land. Ningbo is a particularly notable case. Leveraging its dual advantages in port economy and digital industries, the city has vigorously advanced agricultural digital transformation. By building smart agricultural management platforms and promoting precision farming technologies, it has effectively optimized the allocation of cultivated land resources and integrated green production technologies. Consequently, the green utilization efficiency of cultivated land increased significantly from 1.128 in 2013 to 1.458 in 2023. In contrast, cities like Huzhou show negative effects, which may be attributed to the high proportion of traditional agriculture and insufficient penetration of digital technologies.

Within Anhui Province, the divergence among cities is even more pronounced. Hefei, Tongling, Anqing, and Lu'an exhibit significant positive effects, while Wuhu, Ma'anshan, and Bozhou show significant negative impacts. This reflects considerable gaps across cities within the province in terms of digital infrastructure, technology application, and policy coordination.

5.3.2. Temporal Heterogeneity

To explore the dynamic characteristics of the impact of digital economy development on the green utilization efficiency of cultivated land, this study analyzes time-series data from 2013 to 2023. The regression coefficients for different years are shown in Figure 4. From an overall trend perspective, the influence of digital economy development on the green utilization efficiency of cultivated land exhibits significant temporal heterogeneity, showing a pattern of first rising, then falling, and then rising again, with certain periodic fluctuations. From 2013 to 2015, the regression coefficients increased notably, indicating that the promoting effect of the digital economy on the green utilization efficiency of cultivated land continued to strengthen during this period. This was mainly due to the initial application of digital technologies in the agricultural sector, which promoted the transformation of agricultural production methods toward greener and smarter practices.

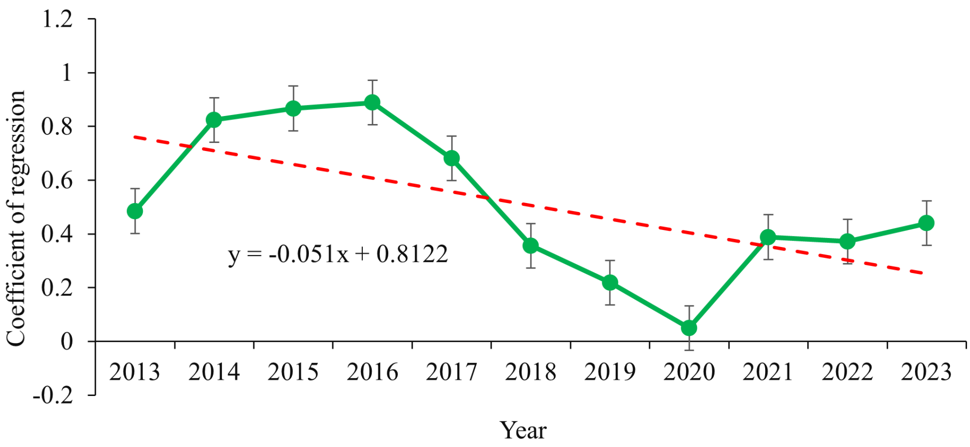

Figure 4. Temporal differentiation of the degree of green utilization efficiency of cultivated land empowered by the digital economy development.

From 2016 to 2020, the coefficients showed an overall downward trend, reaching their lowest point in 2020. On the one hand, this was related to the digital economy entering a stage of deepening integration, where marginal effects gradually weakened; on the other hand, the impact of the COVID-19 pandemic in 2020 disrupted the construction of digital infrastructure and the offline promotion of technologies. In response to economic pressures, some regions temporarily relaxed green development constraints, which significantly reduced the enabling effect of the digital economy on the green utilization efficiency of cultivated land, forming a special low point in the time series. From 2021 to 2023, the promoting effect of the digital economy on the green utilization efficiency of cultivated land strengthened once again, showing an overall recovery and positive trend.

5.4. Mechanism Tests

5.4.1. Mechanism Tests Based on SUR

To systematically verify the pathways proposed in the theoretical framework, this study employs the Seemingly Unrelated Regression (SUR) framework to separately examine the independent effects of four dimensions—driving layer, input side, output side, and emission side—on the green utilization efficiency of cultivated land. Variables in each dimension have been standardized to ensure comparability of the estimated effects. The estimation results are reported in Table 9.

Table 9. SUR Regression Results of the Impacts of Four Dimensions on Green Utilization Efficiency of Cultivated Land

Variable	GUECL	GUECL	GUECL	GUECL
DFI	0.028*(1.90)			
CII		−0.032**(−2.50)		
AOB			0.059***(3.92)	
CEI				0.020(1.56)
In_ RRI	3.585(0.91)	4.218(1.07)	3.427(0.88)	4.210(1.06)
In_ ED	−3.758(−0.95)	−4.293(−1.09)	−3.663(−0.94)	−4.336(−1.10)
AFS	−0.252(−1.37)	−0.243(−1.35)	−0.075(−0.42)	−0.150(−0.83)
Constant term	0.901***(33.00)	0.935***(36.49)	0.870***(31.04)	0.912***35.27)
N	440	440	440	440

Note: The statistics in parentheses represent coefficient estimates.
*, **, *** denote significance at the 10%, 5%, and 1% levels respectively.

According to the estimation results in Table 9, the impacts of the four dimensions exhibit clear differentiation. For every one-standard-deviation increase in the Digital Financial Inclusion index (DFI), the green utilization efficiency of cultivated land improves by 0.0281 units, an effect that is significant at the 10% statistical level. This finding provides empirical support for the theoretical proposition that digital finance drives agricultural green transformation by alleviating financing constraints. The coefficient for Chemical Input Intensity (CII) is significantly negative at the 5% level, indicating that for every one-standard-deviation reduction in this variable, the green utilization efficiency of cultivated land increases by 0.0324 units. This aligns fully with theoretical expectations and confirms that reducing chemical inputs is a crucial pathway for achieving pollution reduction at the source and enhancing the green performance of cultivated land use.

Agricultural Output Benefit (AOB) exhibits the strongest positive effect, with its coefficient highly significant at the 1% level. Specifically, a one-standard-deviation improvement in agricultural output benefit leads to a 0.0593-unit increase in the green utilization efficiency of cultivated land. This result not only highlights the central role of economic returns in green agricultural development but also confirms that “improving quality and efficiency” constitutes the fundamental driving force for transforming cultivated land use patterns at the current stage. In contrast, the impact of Cultivated Land Carbon Emission Intensity (CEI) does not pass conventional significance tests, and its positive coefficient diverges from the theoretical expectation of low-carbon transition. This outcome may suggest that, within the regions and development stages covered by the sample, the relationship between carbon emissions and the green utilization efficiency of cultivated land is not a simple linear negative correlation; its effect may be moderated by technological transition thresholds, lagged effects, or complex nonlinear mechanisms.

5.4.2. Micro-level Pathway Analysis Based on Slack Variables

To identify the pathways through which the digital economy operates in specific production processes, this study examines the impact of digital economy development on four key slack variables, confirming the mechanism by which it enhances the green utilization efficiency of cultivated land through reducing micro-level inefficiencies. The results are presented in Table 10.

Table 10. Tobit regression results for the impact of the digital economy on slack variables

Variable	CIS	EUS	EOS	CES
DED	−12.824***(−6.35)	−7.531 **(−2.57)	−12.133***(−3.60)	−12.112***(−6.57)
In_ RRI	−9.108(−0.15)	42.388(0.38)	−186.972(−1.48)	−52.121(−0.90)
In_ ED	12.374(0.20)	−33.158(−0.30)	193.832(1.54)	54.867(0.95)
AFS	5.341**(2.07)	8.495*(1.90)	9.007*(1.89)	4.527*(1.83)
Constant term	3.230***(4.42)	−0.033 (−0.03)	1.244(0.95)	3.248***(4.81)
N	440	440	440	440

Note: The statistics in parentheses represent coefficient estimates.
*, **, *** denote significance at the 10%, 5%, and 1% levels respectively.

The results in Table 10 show that the development of the digital economy has a significantly negative impact on slack variables across all dimensions. For every one-unit increase in the level of digital economy development, the slack values for the driving layer, input side, output side, and emission side decrease by 12.824, 7.531, 12.133, and 12.112 units, respectively, all of which are significant at the 5% or 1% level. This indicates that the digital economy, by improving digital financial support, promoting precision agriculture technologies, optimizing production-sales linkages, and strengthening carbon emission management, effectively alleviates financing constraints, reduces redundancy in chemical inputs, suppresses output conversion losses, and compresses inefficient carbon emission space. These findings echo the significant effects of the respective dimensional variables on efficiency as presented in Section 5.4.1, and further reveal, from the perspective of reducing micro-level inefficiencies, the specific pathways through which the digital economy improves cultivated land use processes and enhances green efficiency.

5.5. Analysis of Spatial Spillover Effects

To examine the spatial mechanisms through which digital economy development affects the green utilization efficiency of cultivated land, and based on the model specification outlined earlier, this study first conducted a test of spatial autocorrelation. Table 11 reports the Global Moran's I results for GUECL in the Yangtze River Delta region from 2013 to 2023. The test shows that the index is positive for all years, rising steadily from 0.187 in 2013 to 0.242 in 2023, indicating an overall upward trend. This suggests that during the study period, the regional GUECL exhibits significant positive spatial autocorrelation, with the degree of spatial clustering increasing over time. High-efficiency areas and low-efficiency areas each tend to cluster spatially, highlighting the growing synergy of regional green development.

Table 11. Global Moran's I Test Results for Green Utilization Efficiency of Cultivated Land

Year	Moran's I	Year	Moran's I
2013	0.187**(2.16)	2019	0.216**(2.47)
2014	0.179**(2.09)	2020	0.222**(2.53)
2015	0.192**(2.21)	2021	0.229***(2.61)
2016	0.200**(2.30)	2022	0.235***(2.68)
2017	0.213**(2.43)	2023	0.242***(2.75)
2018	0.209**(2.38)		

Note: The statistics in parentheses represent coefficient estimates.
*, **, *** denote significance at the 10%, 5%, and 1% levels respectively.

After confirming the presence of spatial correlation, this study further estimates a spatial lag panel Tobit model, with regression results reported in Table 12. The results show that the coefficient for local digital economy development is 0.3287 and significant at the 1% level, which robustly reaffirms the direct enabling effect of the digital economy on improving local green utilization efficiency of cultivated land. It is noteworthy that the coefficient for the spatially lagged term of digital economy development (W_DED) is 0.2154 and significantly positive at the 1% level. This indicates that the digital economy development in neighboring cities also exerts a significant positive spatial spillover effect on the local region, suggesting that digital technologies, knowledge, and associated green management models can diffuse effectively across adjacent areas, forming a regionally linked enabling pattern.

Table 12. Regression Results of the Spatial Econometric Model.

Variable	GUECL
W_GUECL	0.589^{***} (6.74)
DED	0.329^{***} (5.78)
W_DED	0.215^{***} (2.75)
Constant term	0.413^{***} (6.50)
N	440

Note: The statistics in parentheses represent coefficient estimates.
*, **, *** denote significance at the 10%, 5%, and 1% levels respectively.

Furthermore, the spatially lagged term of green utilization efficiency of cultivated land itself (W_GUECL) displays a coefficient as high as 0.5892, which is highly significant at the 1% level. This result reveals a strong spatial linkage and synergistic effect in the enhancement of green efficiency within the region. The magnitude of this influence far exceeds both the direct and indirect effects of the digital economy, indicating that integrated practices such as cross-border ecological co-governance and industrial coordination among neighboring areas constitute the core driving force for regional green transformation as a whole.

In summary, the spatial econometric analysis demonstrates that the impact of digital economy development on the green utilization efficiency of cultivated land possesses a significant spatial dimension. It manifests not only as a direct local effect but also generates positive regional spillovers. Moreover, the strong spatial synergy of green efficiency itself highlights the profound implications and substantial potential of breaking down administrative boundaries and promoting cross-regional coordination of green development policies and actions in the context of integrated development of the Yangtze River Delta.

5.6. Robustness Checks

To ensure the robustness and reliability of the research findings, this study conducts robustness checks on the benchmark regression results through multiple approaches, including replacing control variables, winsorisation, subsample analysis, and changing the estimation model.

First, at the level of control variables, the benchmark model is re-estimated by replacing "rural per capita income" with "per capita GDP." Second, to exclude potential interference from outliers, all continuous variables in the full sample are winsorized at the top and bottom 1%. Third, considering possible structural changes during the study period, the full sample is divided into two subperiods—2013–2017 and 2018–2023—for separate regressions. Finally, to examine potential bias introduced by the model specification, a panel fixed-effects model is further employed for estimation. The results of each test are presented in Table 13, and the core conclusions remain valid throughout.

Table 13. Regression results of robustness test.

Model	(1) GUECL	(2) GUECL	(3) GUECL	(4) GUECL	(5) GUECL	(6) GUECL
	Benchmark Tobit Regression	**Replace Control**	**1% Winsorization**	**Subsample: 2013–2017**	**Subsample: 2018–2023**	**FE Model**
DED	0.537^{***}(5.00)	0.775^{***}(5.24)	0.606^{***}(5.69)	0.555^{***}(2.96)	0.568^{***}(3.79)	0.649^{**}(2.17)
In_ RRI	1.018(0.37)	−0.122(−1.11)	1.293(0.50)	4.588(1.33)	−0.268(−0.08)	0.644(0.16)
In_ GDP		-0.152^{**}(−2.31)				
In_ ED	−1.305(−0.47)		−1.619(−0.62)	−4.756(−1.38)	0.086(0.03)	−1.053(−0.26)
AFS	−0.089(−0.59)	−0.082(−0.54)	-0.674^{***}(−2.89)	-0.899^{*}(−1.76)	0.177(1.25)	−0.050(−0.15)
Constant term	0.633^{***}(8.65)	0.438^{***}(3.86)	0.612^{***}(8.48)	0.709^{***}(7.14)	0.635^{***}(6.96)	0.539^{***}(2.71)
N	440	440	440	440	440	440

Note: The statistics in parentheses represent coefficient estimates.
*, **, *** denote significance at the 10%, 5%, and 1% levels respectively.

Thus, whether modifications are made in terms of variable measurement, sample scope, or model specification, the positive promoting effect of digital economy development on the green utilization efficiency of cultivated land remains consistent, which fully confirms the robustness and reliability of the core findings of this study.

6. Results and Discussion

6.1. Results

With the state's increasing support for developing the digital economy and the growing prominence of cultivated land issues, leveraging digital economic growth to promote the green utilization of cultivated land and thereby accelerate agricultural development represents both an effective means of achieving rural revitalization and an urgent practical challenge requiring resolution. This study employs panel data from 40 prefecture-level cities across Jiangsu, Zhejiang, and Anhui provinces spanning 2013–2023. Utilizing the Super-SBM model and other methodologies, it quantitatively analyses the impact of digital economy development on the efficiency of green cultivated land utilization, alongside the spatial heterogeneity of these effects. Key findings are as follows:

(1) An integrated analytical framework encompassing the driving layer, input end, output end, and emission end has been constructed, revealing multidimensional synergistic enabling pathways. Unlike existing studies that predominantly focus on singular technologies or stages, this framework elucidates, from a systemic perspective, the interconnected mechanisms through which the digital economy optimizes factor allocation, enhances production process intelligence, and promotes the greening of the value chain. These mechanisms have been empirically validated through Seemingly Unrelated Regression (SUR) and slack variable analysis, providing a new theoretical paradigm for understanding the complexities of agricultural green transformation.

(2) The study confirms that the digital economy exerts a robust promoting effect on the green utilization efficiency of cultivated land, with city-level analyses offering new evidence for precise policymaking. This conclusion holds after controlling for endogeneity and remains valid across a series of robustness checks, including variable substitution and winsorization. Unlike most research conducted at the macro level, this paper focuses on the city-level scale, uncovering significant variations in effects across individual cities. These findings indicate that a uniform policy approach may be ineffective and provide direct micro-level evidence for local governments to formulate differentiated and targeted digital agriculture policies.

(3) The study reveals that the enabling effect of the digital economy exhibits complex spatial heterogeneity, with its intensity profoundly dependent on regional foundational conditions. At the inter-provincial level, the impact follows a gradient pattern, with Zhejiang outperforming Jiangsu, and Jiangsu outperforming Anhui. Significant differentiation is also observed among cities within each province. Notably, the relatively weak promoting effect in Anhui contrasts with the view held in some studies that the digital economy yields universal and homogeneous benefits. This suggests that in regions with inadequate digital infrastructure and integration depth, mere expansion in scale may not effectively translate into green benefits. This finding underscores the constraining role of the digital divide in agricultural transformation and highlights the priority of strengthening digital foundations and deepening sectoral integration.

6.2. Discussion

Given the role of digital economy development in enhancing the green utilization efficiency of cultivated land, coupled with the spatial heterogeneity of its impact across Jiangsu, Zhejiang, and Anhui provinces, the following policy recommendations are proposed:

(1) First, target provincial differences by implementing precise and tailored strategies. For Anhui Province, policies should focus on strengthening the digital foundation and expanding the application of technology. In counties and cities primarily engaged in grain production and regions specialized in cash crops such as tea and medicinal herbs, priority should be given to deploying infrastructure such as farmland IoT and remote sensing monitoring. Additionally, targeted subsidies for applicable technologies like smart irrigation and drone-based plant protection should be provided, while systematic skills training should be conducted for new agricultural entities such as family farms and cooperatives to effectively lower the threshold for technology adoption. For Jiangsu Province, efforts should be directed toward promoting industrial transition and enhancing transformation efficiency. In cities like Nanjing and Wuxi, which are in the midst of industrial transformation, special funds could be established to support the green transformation of agriculture-related industries and workforce skills upgrading. In areas with a strong foundation in digital agriculture, such as Nantong and Taizhou, support should be given to establish provincial-level comprehensive smart agriculture demonstration zones, creating replicable and scalable technological and management models. For Zhejiang Province, the focus should be on innovation leadership

and regional service outreach. Support should be provided to cities like Hangzhou and Ningbo for breakthroughs and integrated demonstrations of cutting-edge technologies such as agricultural artificial intelligence and low-carbon models. At the same time, a provincial-level agricultural digital service platform should be developed to provide data, technology, and market information services for the province and surrounding regions, actively leveraging its role in regional radiation and driving influence.

(2) Build cross-provincial collaboration mechanisms to amplify regional overall effectiveness. Under the framework of integrated development in the Yangtze River Delta, establish a digital agriculture coordination mechanism to jointly build and open a regional agricultural data platform. Priority should be given to promoting the standardization and sharing of data across the three provinces, with particular emphasis on supporting Anhui Province in deploying data collection terminals in major grain-producing counties to enhance its foundational data capabilities. Concurrently, establish joint research and demonstration projects, leveraging Zhejiang's research strengths, Jiangsu's manufacturing enterprises, and Anhui's typical agricultural regions to conduct technology adaptation and application validation, accelerating the promotion of advanced applicable technologies in areas with weaker foundations.

(3) Improve a universal policy support system to solidify the foundation for long-term development. On the incentive side, reform the assessment systems of local governments and relevant departments by incorporating key indicators such as the green utilization efficiency of cultivated land and the adoption rate of digital technologies into evaluations. On the capacity-building side, implement targeted training programs for digital agricultural technicians, relying on agricultural universities and leading enterprises to effectively enhance support for grassroots technology implementation.

Due to data limitations, this study operates at the meso-level of prefecture-level cities. Future research should expand data coverage to examine county-level impact effects, enhancing data accuracy and specificity. This will facilitate the formulation of more practical policy recommendations to support green agricultural development.

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Data Availability Statement: This study covers the period from 2013 to 2023. Data used to measure each city's digital economy development index and green utilization efficiency index of cultivated land are sourced from the 2014–2024 Jiangsu Statistical Yearbook (http://tj.jiangsu.gov.cn/col/col86296/index.html), Zhejiang Statistical Yearbook (http://tjj.zj.gov.cn/col/col1525563/index.html), Anhui Statistical Yearbook (https://tjj.ah.gov.cn/ssah/qwfbjd/tjnj/index.html), and the EPS Statistical Data Retrieval and Forecasting Platform (https://www.epsnet.com.cn/index.html). Missing individual data points were supplemented using interpolation methods. Vector data for spatial distribution mapping was sourced from the National Centre for Basic Geographic Information (https://www.ngcc.cn/).

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Abbreviations

The following abbreviations are used in this manuscript:

GUECL	Green utilization efficiency of cultivated land
DED	Digital economy development
CIS	Chemical Input Slack
EUS	Energy Consumption Slack
EOS	Economic Output Slack
CES	Cultivated Land Carbon Emissions Slack
RRI	Rural Revitalization Index,
ED	Level of Economic Development
AFS	Strength of Agricultural Fiscal Support
DFI	Digital Financial Inclusion Level

CII	Chemical Input Intensity
AOB	Agricultural Output Benefit
CEI	Carbon Emission Intensity of Cultivated Land

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Article

Farmers Perceived Effectiveness of Agricultural Extension Services for Climate Smart Agricultural Practices: Insights from a Selected Coastal Area of Bangladesh

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Abstract: Coastal Bangladesh is highly vulnerable to climate change. Although Agricultural Extension Services (AESs) play a crucial role in promoting Climate Smart Agriculture (CSA) to enhance farmers' adaptive capacity, farmers' perceptions of their effectiveness remain poorly understood. This study employed a convergent parallel mixed-methods approach to assess farmers' perceptions of AES effectiveness in Koyra Upazila, Khulna District. Quantitative and qualitative data were collected concurrently from 9 March to 26 April 2025 using a semi-structured questionnaire survey administered to 190 farmers, complemented by focus group discussions (FGDs). The Perceived Effectiveness Index (PEI), one-way ANOVA, and multiple regression analysis were used to examine perceived effectiveness and its determinants. Findings reveal that 76.8% of farmers perceived AESs as moderately to highly effective in supporting CSA adoption. Introduction of stress-tolerant crop varieties (PEI = 678), stakeholder involvement in decision-making (PEI = 638), and climate-related training (PEI = 614) were rated most effective. Conversely, credit facilities (PEI = 280), ICT use (PEI = 292), and infrastructure support (PEI = 306) were perceived as least effective. ANOVA results show significant variation in perceived effectiveness by age and farming experience. Regression analysis (R^2 = 0.311) identified age, training, and CSA adoption as positive predictors, while climate impact perception, farm size, and adoption barriers negatively influenced perception. Despite moderate success, substantial gaps exist in service delivery, especially regarding financial support, value addition of agricultural products, infrastructure development, fair market access, and digital support. Enhancing AES effectiveness requires greater integration of localized training, farmer participation, and access to enabling resources.

Keywords: climate smart agriculture; agricultural extension services; coastal Bangladesh; perceived effectiveness; climate change adaptation

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1. Introduction

Agricultural productivity is increasingly constrained by the impacts of climate change, particularly in developing regions where food insecurity remains widespread (M. T. Islam & Nursey-Bray, 2017; Kundu et al., 2020). According to the Intergovernmental Panel on Climate Change (IPCC, 2023), climate change is already adversely affecting food production in many regions of the world, with negative impacts outweighing positive ones, especially in developing countries that are more vulnerable to climatic shocks. Moreover, it is projected that by 2050, the population of developing countries will increase by an additional 2.4 billion, particularly in South Asia and further intensifying the pressure on agricultural systems (Fróna et al., 2019).

Bangladesh is widely recognized as one of the most climate-vulnerable countries in the world due to its geographic location, low-lying topography, and high population density (Murshed et al., 2021). Among its most exposed regions are the coastal areas, which cover approximately 32% of the national landmass and are home to nearly 28% of the country's population (M. R. Islam, 2004). These coastal zones are increasingly affected by a range of climate-induced hazards, including tropical cyclones, storm surges, saline water intrusion, sea-level rise, and irregular rainfall patterns (Ahmed et al., 2021; Mitra et al., 2023). Agriculture and climate change have played a reciprocal relationship that is evident in Bangladesh. On one hand, key climatic variables-such as temperature, rainfall variability, humidity, and seasonal shifts-directly affect crop yields, planting calendars, and soil fertility (Bruinsma, 2003). On the other hand, agriculture itself is a significant contributor to greenhouse gas (GHG) emissions, mainly through methane emissions from rice paddies and livestock, and nitrous oxide from synthetic fertilizer use (MacDicken, 2015). This dual relationship underscores the urgency of adopting Climate-Smart Agriculture (CSA) practices that can simultaneously reduce emissions and strengthen farmers' adaptive capacity. At the same time, global evidence suggests that transforming food systems, expanding renewable energy, promoting sustainable production methods, and enhancing carbon sequestration are essential pathways to achieving carbon neutrality and long-term agricultural sustainability (Wang et al., 2021; 2023).

CSA practices refer to an integrated farming technique designed to increase agricultural productivity, enhance resilience to climate change, and reduce greenhouse gas emissions, thereby addressing food security challenges (Lou et al., 2024; Mnukwa et al., 2025). CSA adoption involves the use of technologies and practices that increase productivity and adaptive capacity (Abedin & Shaw, 2014) and aligns strongly with global carbon-neutrality goals, given that food systems and energy together contribute more than 90% of global emissions (Wang et al., 2021). The CSA approach encompasses practices such as improved crop management, sustainable farming methods, agroforestry, integrated pest management, organic pesticides/bio-fertilizer, balanced use of agrochemicals, rainwater harvesting, and the use of climate-resilient crop varieties, all aimed at improving soil health, water use efficiency, and carbon sequestration (Billah et al., 2025; Borychowski et al., 2022; Zheng et al., 2024). Advancing CSA adoption requires targeted efforts to bolster the adaptive and resilience capacities of stakeholders, thereby facilitating the transition to climate-resilient agricultural systems and contributing to national food security and sustainable development objectives (Abedin & Shaw, 2014; Billah et al., 2025; Ma & Rahut, 2024).

The Government of Bangladesh has implemented a range of policy initiatives and institutional reforms aimed at promoting CSA and improving the delivery of agricultural extension services (Nandi et al., 2024). Agricultural extension services (AESs) serve as a critical link between research institutions and farming communities, facilitating the dissemination of knowledge, technologies, and practices that promote sustainable and adaptive farming (Somanje et al., 2021). When effectively delivered, these services can play a transformative role in strengthening farmers' resilience, enhancing productivity, and ensuring long-term food security (Becerra-Encinales et al., 2024).

However, despite significant investments, several challenges persist within the country's extension system. These include limited outreach in remote and marginalized regions, insufficient farmer training, inadequate integration of indigenous knowledge, and administrative inefficiencies (Mamun-ur-Rashid et al., 2018). Scholars further note that many coastal smallholder and marginal farmers continue to face barriers such as limited access to timely agricultural information, weak technical support, financial constraints, labor shortages, insufficient modern farm knowledge, and poor access to quality inputs and markets (Billah et al., 2025; Lou et al., 2024). These constraints reduce their capacity to adopt CSA practices effectively and raise important questions regarding how effectively existing AESs address the differentiated needs of climate-exposed farming communities.

A critical gap also exists in understanding how farmers themselves perceive the effectiveness of extension services, particularly in climate-stressed coastal regions where local relevance and farmer engagement strongly determine service outcomes. Farmer perception plays a pivotal role in the adoption of extension-led innovations: when services are perceived as credible, accessible, and beneficial, uptake improves substantially (Somanje et al., 2021). From a theoretical perspective, farmers' perceptions can be understood through Expectation–Confirmation Theory (ECT), which posits that individuals evaluate services by comparing prior expectations with perceived performance after service use (He et al., 2023). Applying Expectation–Confirmation Theory to agricultural extension underscores why farmers' perceptions are central to the ultimate success or failure of extension interventions. According to ECT, positive evaluations emerge when perceived performance meets or exceeds expectations, whereas unmet expectations result in negative perceptions (Sackl et al., 2017). In the context of agricultural extension, even well-designed and policy-supported programs may fail to promote climate-smart agricultural practices if farmers perceive a mismatch between expected support and actual service delivery. Conversely, when farmers perceive extension services as effective and responsive, trust in extension agents increases, adoption of recommended CSA practices improves, and sustained engagement with extension systems is more likely (Wang et al., 2023). In this sense, perceived effectiveness functions as a key evaluative mechanism linking extension service provision to farmers' behavioral responses and adaptive outcomes.

Although a substantial body of research in Bangladesh has explored CSA adoption, adaptation strategies, and farmers' perceptions of climate risks (Filho et al., 2022; Mnukwa et al., 2025), far less attention has been devoted to understanding how farmers evaluate the effectiveness of AESs in facilitating CSA, particularly in climate-exposed coastal regions. Existing studies tend to focus on policy frameworks or generalized service delivery performance (Vincent & Balasubramani, 2021), often overlooking farmers' differentiated assessments of specific extension service components such as training, credit facilitation, ICT-based advisory support, infrastructure assistance, and market access. This gap limits the ability of policymakers and extension agencies to develop demand-driven, context-sensitive extension strategies that respond to farmers' lived experiences.

This study fills that gap by focusing on a highly climate-vulnerable coastal region to generate new insights into how smallholder farmers evaluate the effectiveness of AESs in supporting CSA adoption. Specifically, the study aims to explore farmers' perceptions of the effectiveness of AESs in promoting climate-resilient agriculture in a coastal district of Bangladesh. Specifically. It seeks to (i) identify perceived climate change impacts and adopted CSA practices; (ii) assess overall AES effectiveness as perceived by farmers; (iii) examine demographic and socio-economic variations to perceived effectiveness; and (iv) investigate the determinants that contribute to farmers' perceptions of the effectiveness of AESs.

This study makes several significant contributions. It advances a farmer-centered evaluative perspective by positioning farmers as active assessors of extension service effectiveness rather than passive recipients of extension interventions, grounded in Expectation–Confirmation Theory. It also employs a convergent parallel mixed-methods approach that integrates a Perceived Effectiveness Index (PEI), inferential statistical analysis, and qualitative insights from focus group discussions to provide a robust assessment of extension performance. Empirically, by focusing on a highly climate-exposed coastal context, the study generates context-specific evidence on how climate stress intensity, adoption barriers, and farm characteristics shape farmers' evaluations of extension services. The findings offer actionable insights for policymakers and extension organizations by identifying both effective service domains and critical gaps, thereby informing the design of more inclusive, responsive, and climate-adaptive agricultural extension systems for vulnerable coastal regions.

2. Materials and Methods

2.1. Study Area

The study was conducted in Koyra Upazila of Khulna District (Figure 1), which is located in the southwestern part of Bangladesh. Koyra Upazila is situated in close proximity to the Bay of Bengal. This area faces significant agricultural vulnerability due to climate change (Iqbal & Aziz, 2022). Fluctuating temperature, rainfall, and humidity, along with hot and humid rainy seasons (Chowdhury et al., 2020), negatively impact the agricultural settings in this region. Multiple environmental hazards, including cyclones, flooding, storm surges, waterlogging, and soil salinity, also affect crop production in this region (Biswas et al., 2024; Iqbal & Aziz, 2022).

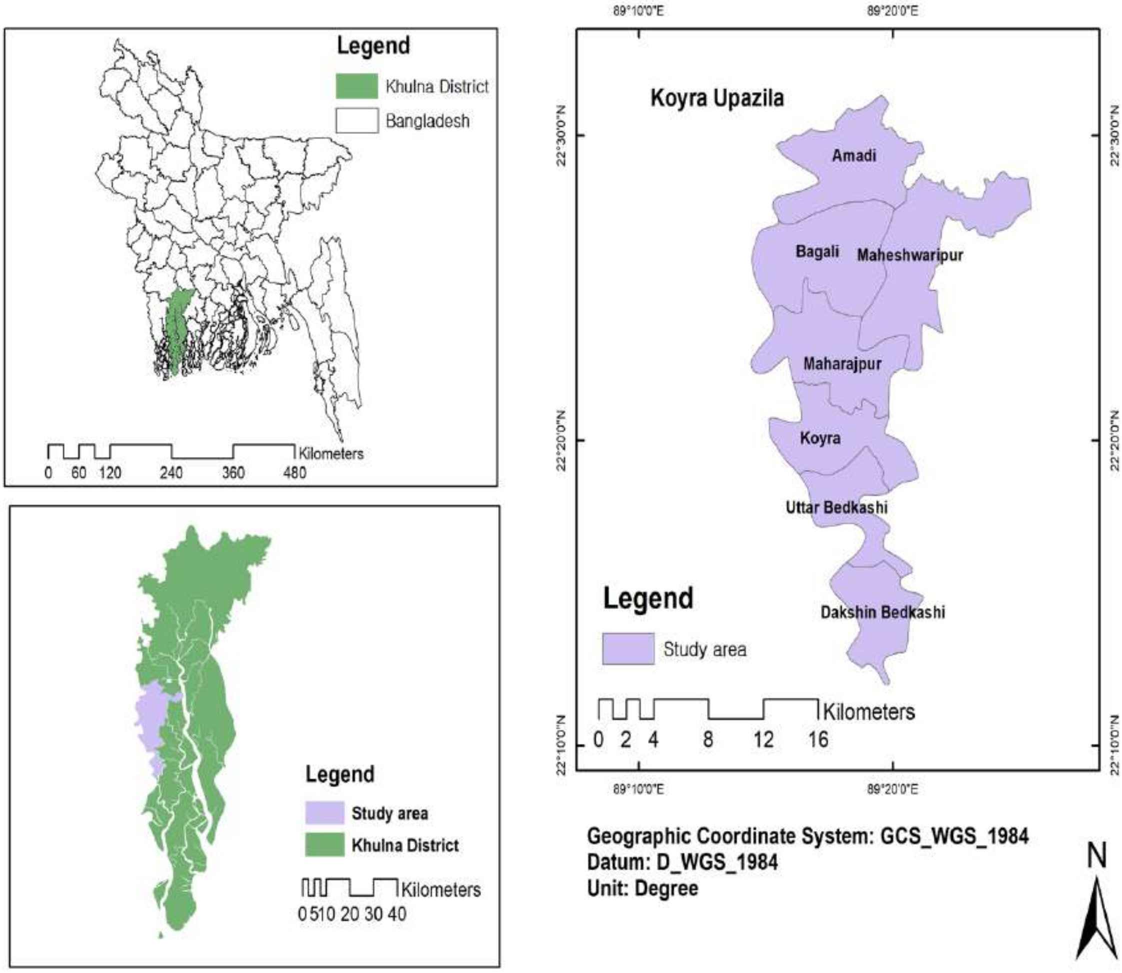

Figure 1. Geographical location of the study area.

Beyond environmental stressors, the socio-economic conditions of coastal communities also heighten their exposure to climate risks. Limited access to resources, weak market infrastructure, and constrained livelihood opportunities increase their overall vulnerability (Kundu et al., 2020). The economy of Koyra Upazila is predominantly agrarian, with a large share of the population dependent on crop farming, aquaculture, and fishing for income and subsistence (Kundu et al., 2020; Mamun et al., 2024). Household incomes tend to be low, and many families frequently face seasonal food insecurity due to climate-driven uncertainties in agricultural production (Mamun et al., 2024). Low levels of education and limited technical knowledge further restrict farmers' ability to adopt modern agricultural practices and to fully benefit from agricultural extension services (M. K. Islam & Farjana, 2024).

Agricultural extension services (AESs) in the upazila are primarily delivered by the Department of Agricultural Extension (DAE), which provides farmers with information, training, and technical guidance at the local level. The Government of Bangladesh has undertaken several projects in the region focusing on climate change adaptation through infrastructure development, early warning systems, and the dissemination of climate-resilient agricultural technologies. Notably, from 2021 to 2025, the DAE has been implementing the project titled "Adaptation to Climate Change through Climate-Smart Technologies in Khulna Agriculture Region", aimed at minimizing climate-related impacts and reducing the agricultural sector's contribution to climate change in the region (Nandi et al., 2024). The study area is therefore highly suitable for examining farmers' perceptions of the effectiveness of AESs in promoting climate-smart agriculture under conditions of high climatic stress and institutional intervention.

2.2. Sampling and Data Collection

The study population consisted of 353 registered farmers listed by the local agricultural extension office in Koyra Upazila, all of whom had continuously received extension services during the previous two years under the project "Adaptation to Climate Change through Climate-Smart

Technologies in the Khulna Agricultural Region." The required sample size of 190 farmers was determined using Yamane's (1967) formula:

$$n = \frac{N}{1 + N(\delta)^2} \quad (1)$$

where n denotes the sample size, N represents the total population, and $\delta = 0.05$ denotes the acceptable level of sampling precision (5% margin of error)

A stratified random sampling technique was employed, where each of the seven unions of Koyra Upazila was treated as a distinct stratum. To ensure proportional representation from all seven unions of the upazila, the number of respondents from each union was calculated according to its share of the total registered farming population. The final distribution was as follows: Amadi (34 of 66), Bagali (24 of 41), Koyra (28 of 50), Maharajpur (23 of 48), Maheshwarpur (27 of 49), Uttar Bedkashi (27 of 48), and Dakshin Bedkashi (27 of 51). This proportional allocation strategy preserved population representativeness (N = 353) and minimized sampling bias by capturing farmers from diverse socio-economic backgrounds and geographically distinct areas.

Although the sample consists of project-registered farmers who were actively engaged with agricultural extension services, the age distribution and farm-size composition of the sampled farmers closely reflect the dominant characteristics of smallholder farmers in Koyra Upazila, where agriculture is predominantly small-scale and largely practiced by middle-aged and older farmers. Therefore, the findings can be reasonably extrapolated to the broader population of smallholder farmers receiving AESs in the coastal area of Bangladesh.

A convergent parallel mixed-method design was employed to examine farmers' perceived effectiveness of AESs in promoting CSA practices in coastal Bangladesh. Quantitative and qualitative data were collected simultaneously from 9 March 2025 to 26 April 2025 through a semi-structured questionnaire and focus group discussions (FGDs), respectively. Four FGDs were conducted, each involving seven farmers, who were included from the survey sample. To capture diverse viewpoints, participants were selected to reflect variations in age and farming experience. Prior to data collection, the research objectives were clearly explained to all participants to ensure informed and voluntary participation.

2.3. Variable Definition, Measurement, and Instrument Validation

The study employed well-defined operational definitions and measures for all variables, utilizing established scales and context-specific indicators to ensure consistency and analytical rigor (Table 1). It included socio-demographic and farm-related variables (e.g., age, education, income, farming experience, and farm size) as well as perceptual and behavioral variables (e.g., adoption of CSA practices, perceived climate change impacts, farming barriers, and perceived effectiveness of AESs). These variables are essential because they capture the key socio-economic and perceptual factors that influence farmers' decision-making, adaptive behavior, and overall evaluation of extension services.

Table 1. Operational definitions and measurement approaches of study variables.

List of variables	Definition	Measurement
Age	Age of respondents	Assign 1 for each year
Farming experience	Total number of years the respondent has been engaged in agricultural activities.	Assign 1 for each year of experience
Income	Annual household income derived from agricultural sources.	Assign 1 for each Bangladeshi taka (1$ = 117.65 BDT)
Education	Formal education level attained by the respondent	Can't read and write=0; Primary = 1 up to class 5 Secondary = 2 (class 6–10); Higher Secondary = 3 (class 11–12); Graduate = 4
Use of information sources	Frequency of using agricultural information sources	3–4 time/week = 4; 2–3 time/15 days = 3; Once/ month = 2; Don't use = 1
Climate change impact on agriculture	Perception of how climate change affects their agriculture productivity	Strongly Agree = 5; Agree = 4; Undecided = 3; Disagree = 2; Strongly Disagree = 1
Training	Number of days the respondent participated in CSA-related training	Assign 1 for each day of training experience
Farm size	Respondent's total cultivated land area	Assign 1 for each hectare (1 hectare = 247.128 decimal)
Farming practice barriers	Perceived level of barriers that limit adoption of CSA practices	High = 4; Moderate = 3; Low = 2; Not at all = 1.
Adoption of CSA practices	Degree to which respondents adopt CSA practices	Always = 5; Frequently = 4; Occasionally = 3; Rarely = 2; Do not Use = 1
Perceived effectiveness of AESs	Perception of AES effectiveness in promoting CSA practices	Highly Effective = 4; Moderately Effective = 3; Low Effective = 2; Not Effective = 1

Note: AES refers to the agricultural extension services.

The survey instrument was designed by integrating insights from existing empirical research with contextual knowledge obtained through field consultations involving experienced farmers and local extension officers. This mixed approach ensured that the instrument was both theoretically grounded and contextually relevant to the realities of coastal agriculture in Bangladesh. We began by identifying 10 key climate change impacts on agriculture, focusing on how coastal farming systems are affected by changing weather patterns, salinity, flooding, and other climate-related challenges.

Following this, we outlined 14 CSA practices that coastal farmers currently apply to cope with these climate challenges. The internal consistency of the adopted CSA practices was satisfactory, with Cronbach's alpha values of 0.74, indicating acceptable reliability of these practices. These practices included a range of adaptive and mitigation techniques tailored to local conditions, offering insight into how farmers are responding on the ground. To explore the barriers in adapting to climate change, five categories of barriers were included: social, economic, technological, organizational, and personal. The barrier items were adopted from previous studies, which reported a Cronbach's alpha of 0.79, further supporting the reliability of this construct (Biswas et al., 2024).

In addition, we incorporated 15 AESs based on the National Agricultural Extension Policy 2020 and National Agricultural Policy 2018 (Ministry of Agriculture, 2018; 2020). These services included, among others, training on climate change adaptation, dissemination of stress-tolerant crop varieties, farm management advisory support, facilitation of access to quality inputs and credit, ICT-based information services, support for infrastructure development, and assistance with market access and value addition. Each item was measured using a 4-point Likert-type scale, where responses were coded as: Highly Effective (4), Moderately Effective (3), Low Effective (2), and Not Effective (1). The PEI score was calculated by summing the weighted frequencies of responses across these four categories, with higher scores indicating higher perceived effectiveness (Anzum et al., 2023). To ensure the questionnaire was contextually appropriate, clear, and relevant, it was reviewed and validated by a panel of regional extension officers. Their feedback helped refine the wording and focus of the questions, enhancing the instrument's accuracy and local relevance. Finally, we tested the internal consistency of the AES effectiveness scale, which showed good reliability, as indicated by a Cronbach's alpha coefficient of 0.81.

2.4. Data Analysis

We have used descriptive statistics (mean, standard deviation, frequency, and percentage) to describe respondents' characteristics and key variables (Table 2).

Table 2. Descriptive statistical analysis of study variables.

List of variables	Categories	Frequency	Percent (%)	Mean	SD
Age	Young (18–37)	54	28.4	46.51	13.64
	Middle aged (38–57)	91	47.9		
	Old aged (above 57)	45	23.7		
Farming experience	2–16 years	63	33.2	24.25	14.51
	17–31 years	75	39.4		
	32–46 years	38	20.0		
	Above 47 years	14	7.4		
Income	20000–213000 BDT	181	95.3	94136.84	73001.43
	214000–406000 BDT	7	3.1		
	Above 406000 BDT	2	1.6		
Education	Illiterate	31	16.3	6.85	4.4
	Primary	49	25.8		
	Secondary	81	42.6		
	Higher secondary	15	7.9		
	Graduate/Diploma	14	7.4		
Use of information sources	Low (10–15)	132	69.5		
	Medium (16–20)	52	27.3		
	High (above 20)	6	3.2		
Climate change impact on agriculture	Low impact (35–38)	9	4.7	43.78	3.08
	Medium impact (39–44)	82	43.2		
	High impact (above 44)	99	52.1		
Training	No training	96	50.5	3.72	11.07
	1–30 days	91	47.9		
	31–60 days	1	0.5		
	Above 60 days	2	1.1		
Farm size	0.12–0.84 Hectare	171	90	0.48	0.37
	0.85–1.56 hectare	13	6.8		
	Above 1.56 hectare	6	3.2		
Farming practice barriers	Low barrier (31–44)	7	3.7	55.45	6.66
	Medium barrier (45–58)	129	67.9		
	High barrier (above 58)	54	28.4		
Adoption of CSA practices	Low adoption (17–28)	28	14.7	35.61	7.09
	Medium adoption (29–40)	109	57.4		
	High adoption (above 40)	53	27.9		
Perceived effectiveness of AESs	Low effectiveness (18–28)	44	23.2		
	Moderate effectiveness (29–39)	78	41.0		
	High effectiveness (above 39)	68	35.8		

To assess farmers' perceptions of the effectiveness of AESs, we analyzed the Perceived Effectiveness Index (PEI) by using the following equation that was cited from the previous research articles (Anzum et al., 2023; Debnath & Biswas, 2022).

$$\textbf{Perceived Effectiveness Index (PEI)}: PEI_h \times 4 + PEI_m \times 3 + PEI_l \times 2 + PEI_n \times 1 \quad (2)$$

Where, PEIh, PEIm, PEIl, and PEIn represent the frequencies of respondents who reported the high, moderate, low, and not effectiveness of AES for CSA practices, respectively. The weights (4, 3, 2, and 1) reflect the relative intensity of perceived effectiveness, with higher values indicating stronger perceived effectiveness of agricultural extension services.

One-way ANOVA was performed to test whether the mean perceived effectiveness of AESs differed significantly across groups categorized by age and years of farming experience. According to Levene's Test for Homogeneity, the assumption of equal variances was met for the age groups; therefore, the Tukey HSD post hoc test was employed. In contrast, the assumption was violated for the farming experience groups, indicating unequal variances and group sizes; hence, the Games-Howell post hoc test was applied for those comparisons. Furthermore, a multiple regression analysis was performed to determine the extent to which selected predictor variables explain the perceived effectiveness of AESs in promoting CSA practices in coastal Bangladesh. The regression model used is as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_k X_k + \varepsilon \quad (3)$$

Where: Y denotes the perceived effectiveness of agricultural extension services, β_0 is the intercept, $\beta_1, \beta_2, \ldots, \beta_k$ are the regression coefficients for the predictor variables $X_1, X_2, \ldots, X_k$ and ε is the error term.

All statistical analyses were performed using IBM SPSS Statistics, Version 24.0. After analyzing the quantitative data, we integrated the qualitative insights from focus group discussions (FGDs) to contextualize and enrich the interpretation of related findings, thereby illustrating the actual conditions in the research area.

3. Result and Discussion

3.1. Descriptive Characteristics of Respondents

The descriptive statistical analysis (Table 2) indicated that the majority (48%) of the respondents were middle-aged (38–57 years), with an average age of 46.51 years. The majority possessed 17–31 years of farming experience, averaging 24.25 years, making them well-suited to assess agricultural extension policies. The findings revealed that 95.3% of the respondents had a low annual income (20000–213,000 BDT or 170–1810$), suggesting potential challenges in adopting new agricultural technologies without external financial assistance. A substantial portion of the farmers (42.6%) had attained secondary-level education (6–10 years of schooling), while 16.3% were illiterate, which could affect their ability to access and use technical agricultural information. Furthermore, 69.5% of respondents had limited access to agricultural sources, with minimal engagement with government extension agents.

In terms of the perceived impact of climate change on agriculture, more than half of the farmers (52.1%) reported a high level of impact. This highlights widespread vulnerability to climate variability and extreme weather events. Access to training was also limited; 50.5% of respondents reported receiving no training, with an average of just 3.72 days. This reveals a considerable need for enhanced capacity-building support. The majority (90%) of farmers operated on small farms between 0.12 and 0.84 hectares, with an average landholding of 0.48 hectares, suggesting significant land constraints.

Regarding farming barriers, a total of 96.3% of farmers encountered medium to high-level barriers, with a mean barrier score of 55.45. These include challenges related to technology access, financial resources, institutional support, and personal limitations. Despite these challenges, 57.4% of farmers reported medium-level adoption of CSA practices and 27.9% showed high adoption, reflecting moderate implementation of climate-smart techniques. As for perceptions of AESs, 41% of farmers found it somewhat effective, 35.8% thought it was highly effective, and 23.2% did not see it as very effective. These findings suggest that while the extension system is generally recognized as relevant, there is substantial scope for improving its reach, responsiveness, and impact.

3.2. Perceived Impact of Climate Change on Agriculture

Our study found that increased soil salinity (mean 4.85), altered weather patterns (mean 4.78), reduced fresh water resources (mean 4.74), poor harvest (mean 4.71), poor vegetative growth in plants (mean 4.65), and declined soil moisture retention capacity (mean 4.55) were the most perceived climate change impacts by the farmers (Figure 2). These factors directly impinge on agricultural productivity, exacerbating livelihood vulnerabilities and underscoring the urgent need for CSA practices.

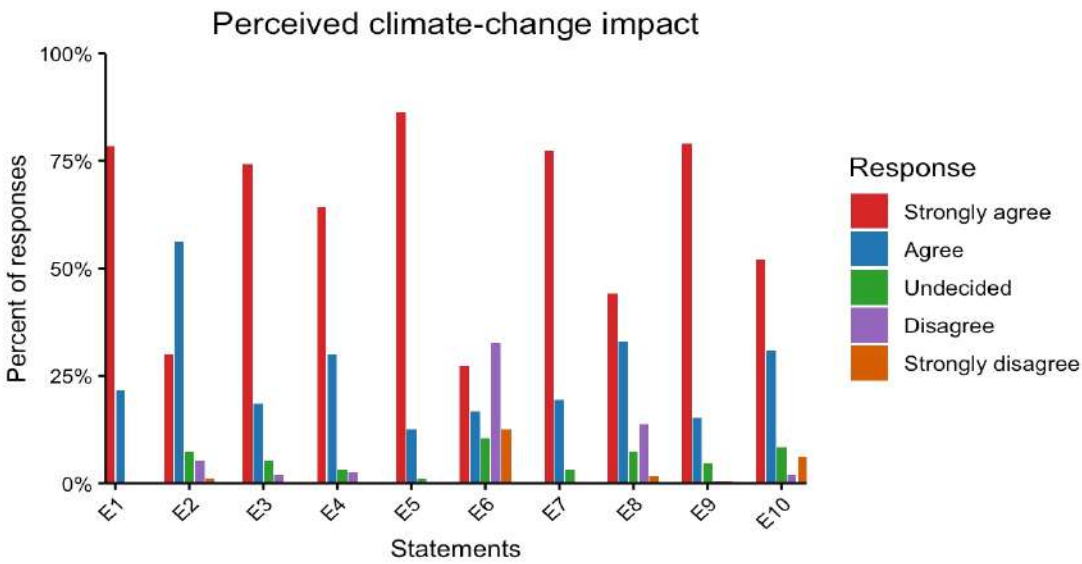

Figure 2. Farmers' perceptions regarding the impact of climate change on agriculture.
Note: E1: Change in weather pattern; E2: Change in farming schedule; E3: Poor vegetative growth in plants; E4: Declining soil moisture retention capacity E5: Increasing soil salinity in dry season; E6: Extinction of local crop varieties; E7: Reducing fresh water resources; E8: Tidal flood intrusion and waterlogging; E9: Poor harvest: E10: Unpredictable pest and disease outbreaks.

Soil salinity, in particular, severely compromises soil fertility by causing nutrient imbalances and ion toxicities, primarily due to elevated levels of sodium (Na^+) and chloride (Cl^-), which disrupt plant metabolic functions, induce oxidative stress, and result in seedling mortality and reduced crop quality (Rahman et al., 2023). Additionally, changes in temperature and rainfall patterns impose significant stress on coastal farming systems by affecting germination rates and vegetative growth, pest and disease dynamics, and increasing the risk of tidal water intrusion and prolonged waterlogging (Biswas et al., 2024; Iqbal & Aziz, 2022).

These climatic challenges have also forced farmers to alter the cropping schedule and, in some cases, abandon traditional local varieties altogether. Despite these hardships, a previous study has reported that adopting CSA practices can offer economic and environmental benefits. Helping farmers sustain livelihoods in the face of climate change (Arfanuzzaman et al., 2016). This underscores the critical importance of promoting and scaling up CSA solutions tailored to the specific challenges of coastal agricultural communities.

3.3. Adoption of Climate Smart Agriculture Practices

The study revealed that coastal farmers have adopted a range of CSA practices, though adoption levels varied across the 14 practices assessed (Figure 3). The most widely used practices included stress-tolerant rice varieties, homestead farming, intercropping, organic farming, the sorjon method, stress-tolerant vegetables and fruits, soil and water conservation, and low external input use. Empirical evidence shows that CSA practices can increase crop productivity by 10.5% and farm profitability by 29.4%, while improving resource efficiency and environmental sustainability (Farah et al., 2025). Conversely, practices such as agricultural waste recycling, mixed cropping, dyke cropping, AWD irrigation, rainwater harvesting, and adjusted cropping schedules showed lower adoption, primarily due to limited resources, inadequate extension support, low awareness, and perceived high costs (Arfanuzzaman et al., 2016).

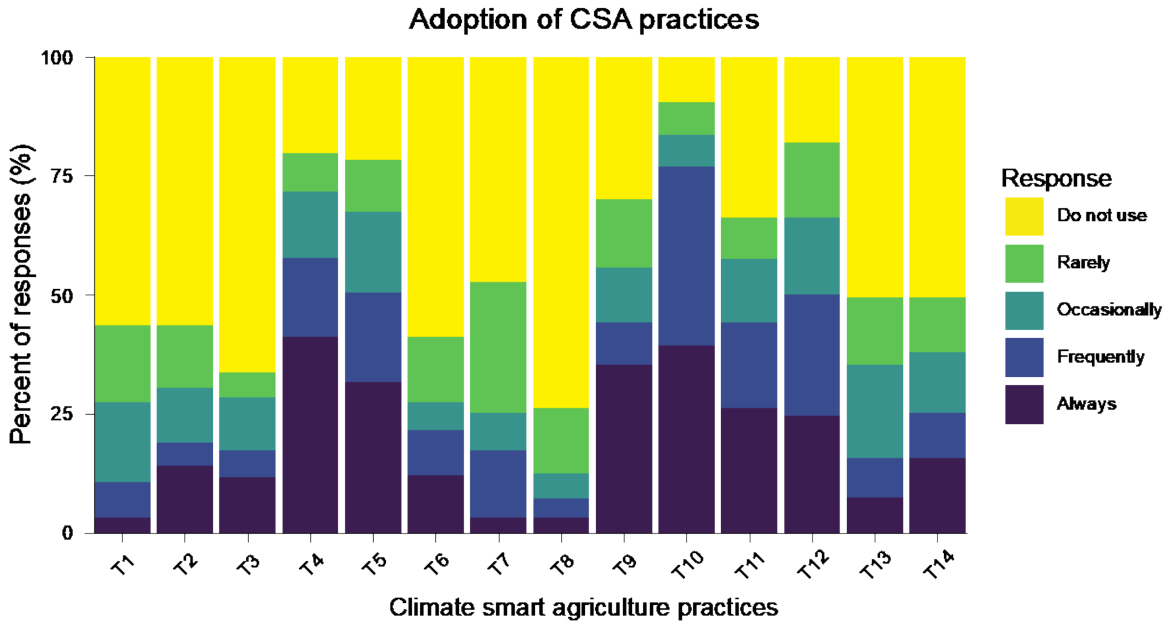

Figure 3. Farmers' perceptions regarding the adoption of CSA practices.
Note: T1: mixed cropping; T2: change in cropping schedule; T3: dyke cropping; T4: homestead farming; T5: intercropping; T6: rainwater harvesting; T7: alternate wetting and drying (AWD) irrigation; T8: recycling of agricultural waste; T9: sorjon method; T10: stress-tolerant rice varieties; T11: stress-tolerant vegetables and fruits; T12: organic farming; T13: use of low external inputs; and T14 = soil and water conservation.

Adoption of stress-tolerant rice varieties (saline, drought, short-duration, and submergence-tolerant types) has become essential for maintaining yields under harsh climatic conditions (Roy et al., 2019). Such adaptation is crucial for smallholder farmers, as resilience-building directly supports livelihood sustainability (Billah et al., 2025). Current adopters of stress-tolerant varieties experience a 41-percentage point reduction in multidimensional poverty compared to non-adopters (M. K. Islam & Farjana, 2024). Yield gains average 1.1 tons/ha (28%), increasing from 3.87 to 4.97 tons/ha, while net farm income rises from US$229/ha to US$307/ha, reflecting an income gain of about US$78/ha (23%; Pal et al., 2024). FGDs also confirmed that "stress tolerant crop varieties enable coastal farmers to minimize crop damage during flash floods in the rainy season and reduce irrigation demand for boro rice in the winter season."

Homestead vegetable farming, particularly using elevated "tower system" during flood and tidal water intrusion in the rainy season, has proven effective in enhancing food security (Biswas et al., 2024). Organic farming and sorjon methods were also widely adopted, helping reduce soil salinity and mitigate climate impacts (Ruba et al., 2024). Farmers noted that "homestead vegetable cultivation and organic practices reduced input costs while increasing dietary diversity, contributing to household food security." Vermicomposting is increasingly used as a low-cost organic fertilizer, reducing dependence on synthetic inputs.

The sorjon method integrates horticulture on raised beds with fish culture in ditches, optimizing resource use and strengthening farm profitability. Farmers also cultivate stress-tolerant fruits (e.g., watermelon) and apply mulching for high-value vegetables such as capsicum, brinjal, and tomato. Intercropping—such as maize or sugarcane with lentil, chickpea, or vegetables—was widely practiced for resource efficiency and risk reduction. As one farmer noted, "We plant lentils and vegetables between maize or sugarcane rows so that if one crop fails due to salinity or heavy rain, the other still gives us some income." Another added, "Intercropping helps us use the land better—we get more yield from the same field and can harvest at different times, which gives us cash flow throughout the year." Prior studies confirm its benefits in enhancing productivity and income diversification in saline regions (Ali et al., 2021).

Although less common, a few farmers have adopted harvesting rainwater by digging small ponds and utilizing this conserved water for irrigation during dry spells, which enhances water availability for crop production and reduces reliance on erratic rainfall (Sarker et al., 2024). Farmers participating in FGDs mentioned that "A few farmers dug small ponds near their fields to store rainwater. During the dry season, we use this water for irrigation-it saves our crops when rainfall is delayed. However, constructing a new pond is very expensive for small-scale farmers; we need more support or collective efforts on a cooperative basis." Many of the farmers who established such ponds also used the surrounding embankments for dyke farming—cultivating creeping vegetables and fruits—which further contributed to food production in these flood-prone zones.

3.4. Perceived Effectiveness of Agricultural Extension Services

The Perceived Effectiveness Index (PEI) was used to evaluate farmers' insights on 15 key extension service areas related to agricultural extension policy (Table 3). The findings reveal that farmers viewed several extension services as highly effective, especially the introduction of stress-tolerant crop varieties, stakeholder participation in agricultural decision-making, and training on climate change adaptation (Table 3). CSA promotion campaigns, provision of quality seeds, fertilizers, and pesticides, support for cooperative farming systems, and health and food safety programs were also regarded as valuable areas of extension support. FGDs confirmed that extension organizations played a key role in introducing salt-tolerant and short-duration rice varieties (e.g., BRRI dhan 61, 67, 97, 75, 87), as well as alternative crops such as sunflower, maize, watermelon, and various vegetables, helping farmers diversify and reduce salinity-related risks (Kundu et al., 2020). As one farmer noted, "When the extension officer showed us how to use the new rice variety in the field, I felt more confident to try it myself." This highlights the importance of institutional support and credibility, which are central to motivating technology adoption. Support from extension organizations not only facilitates the effective dissemination of CSA practices but also builds farmers' confidence in adopting innovative practices.

Table 3. Farmers' perceived effectiveness index (PEI) of AESs (N = 190).

Agricultural extension services	HE	ME	LE	NE	PEI	Mean	Rank
Introduction of stress-tolerant crops and varieties	55 (71.6%)	66 (11.6%)	58 (15.3%)	3 (1.6%)	678	3.53	1st
Stakeholder involvement in local agricultural decision-making	468 (61.6%)	99 (17.4%)	62 (16.3%)	9 (4.7%)	638	3.36	2nd
Training to cope with climate change impacts.	448 (58.9%)	108 (18.9%)	32 (8.4%)	26 (13.7%)	614	3.23	3rd
Promotion for climate-smart agricultural practices	216 (28.4%)	276 (48.4%)	30 (7.9%)	29 (15.3%)	551	2.9	4th
Access to quality seeds, fertilizers, and pesticides.	120 (15.8%)	225 (39.5%)	126 (33.2%)	22 (11.6%)	493	2.59	5th
Subsidies to support farmers.	240 (31.6%)	108 (18.9%)	40 (10.5%)	74 (38.9)	462	2.43	6th
Promotion of cooperative farming systems	152 (20%)	126 (22.1%)	118 (31.1%)	51 (26.8%)	447	2.35	7th
Health and food safety initiatives	132 (17.4%)	117 (20.5%)	128 (33.7%)	54 (28.4%)	431	2.26	8th
Advisory support to farmers	124 (16.3%)	147 (25.8%)	66 (17.4%)	77 (40.5%)	414	2.18	9th
Assistance for the adoption of modern agricultural machinery	16 (2.1%)	84 (14.7%)	160 (42.1%)	78 (41.1%)	338	1.78	10th
Initiatives for Fair Market Access	48 (6.3%)	105 (18.4%)	82 (21.6%)	102 (53.7%)	337	1.77	11th
Facilitation in infrastructure development	12 (1.6%)	72 (12.6%)	118 (31.1%)	104 (54.7%)	306	1.61	12th
Use of ICTs in agricultural extension	104 (13.7%)	15 (2.6%)	28 (7.4%)	145 (76.3%)	292	1.54	13th
Value addition of agricultural products	0 (0%)	66 (11.6%)	94 (24.7%)	121 (63.7%)	281	1.48	14th
Credit facility or financial assistance	24 (3.2%)	51 (8.9%)	76 (20.0%)	129 (67.9%)	280	1.47	15th

Note: HE = Highly Effective = 4; ME = Moderately Effective = 3; LE = Low Effective = 2; NE =Not Effective = 1; and PEI= Perceived effectiveness index.

Farmers emphasized that participation in decision-making and cooperative learning strengthened their ability to adopt climate-resilient practices (Abid et al., 2016). "Communal learning and shared experiences significantly enhance our capacity to implement new methods," they stated. This collaborative approach, supported by extension services, fosters social capital and enhances community resilience against the impacts of climate change. Training initiatives were also considered highly beneficial, though farmers stressed the need for field-level follow-up: "Training helped us understand new practices, but we need more follow-up in our own land." This finding indicates that the effectiveness of training interventions is maximized when theoretical instruction is complemented by continuous, practice-oriented support through on-farm guidance.

The localization training should move beyond generic capacity-building toward context-specific and problem-oriented approaches. In coastal areas such as Koyra Upazila, training programs should explicitly address site-specific challenges, including salinity intrusion, soil and water conservation, reduction of agriculture's contribution to climate change, and climate-risk-based cropping decisions.

Delivering such training through on-farm demonstrations, farmer field schools, and systematic post-training field-level follow-up can enhance the practical relevance of extension messages and support the effective adoption of climate-smart agricultural practices.

However, some extension service areas, such as credit access, value addition, ICT use, infrastructure facilitation, and market access, were perceived as less effective. Smallholder farmers often face difficulty accessing credit due to a lack of collateral, complex application procedures, and high interest rates, which limit their ability to invest in new technologies (Herliana et al., 2018). As several farmers explained during the FGDs: "We want to take loans, but the process is too complex, and without collateral we are not eligible." Given the very low perceived effectiveness of credit services, stronger coordination between AESs and microfinance institutions is needed. The development of green credit schemes tailored to CSA, along with simplified subsidy application and disbursement through local extension offices, could reduce administrative barriers and enhance smallholders' financial access, thereby supporting wider adoption of CSA in coastal regions.

Similarly, the low perceived effectiveness of ICT-based extension services suggests the need for more context-appropriate digital strategies. Rather than relying solely on complex mobile applications, AESs could prioritize the development of local-language, data-based agricultural advisory platforms, combined with strengthening extension personnel's capacity to use social media groups (e.g., WhatsApp, Facebook Messenger) to disseminate timely weather alerts, pest warnings, and crop-specific recommendations. Such hybrid digital approaches may improve information accessibility among farmers with limited digital literacy.

Although climate projects installed mini ponds, poly net houses, and machinery (Nandi et al., 2024), their long-term effectiveness depends on continued technical support, as infrastructure alone is insufficient without follow-up. Moreover, although value addition of agricultural products, such as processing, packaging, branding, and improved market access, can significantly increase profitability (Mbukanma et al., 2025), their practice remains underdeveloped due to limited technical skills, inadequate extension guidance, lack of facilities, and poor linkage to profitable markets. Overall, strengthening weak AES areas, particularly in financial services, value chain development, ICT integration, market access, and infrastructure maintenance, is essential for improving CSA adoption and enhancing resilience in coastal farming systems.

3.5. Perceived Effectiveness of AESs by Age Group

The one-way ANOVA analysis revealed a statistically significant difference among the groups (F = 7.017, $p = 0.001$), indicating that age significantly influences farmers' perceptions of extension policy support effectiveness (Table 4). Descriptive statistics showed that younger farmers reported the lowest mean perception score (M = 31.56, SD = 7.54), while the older age group showed the highest mean score (M = 36.96, SD = 6.87). This trend suggests that perceptions of AESs' effectiveness tend to increase with age.

Table 4. One-way ANOVA results showing differences in perceived effectiveness of AESs by age group

Dependent Variable	Age Group	Descriptive statistics			ANOVA results		
		N	Mean	SD	df	F value	*p* value
Perceived Effectiveness of AESs	Young (18 – 37)	54	31.56	7.54	2, 187	7.017	0.001***
	Middle aged (38 – 57)	91	35.03	7.53			
	Old aged (above 57)	45	36.96	6.87			

*** represents less than 1% significance level.

Additionally, the Tukey HSD post hoc test (Table 5) identified significant differences between the young and middle-aged groups (mean difference = −3.48, $p = 0.018$) and the young and old-aged groups (mean difference = −5.40, $p = 0.001$), both statistically significant at the 5% and 1% levels, respectively. However, no significant difference was observed between the middle-aged and old-aged groups (mean difference = −1.92, $p = 0.328$). These findings suggest that older farmers are generally more likely to perceive agricultural extension policies as effective compared to younger farmers, possibly due to greater experience, more prolonged engagement with extension services, or higher levels of trust in institutional support mechanisms.

Table 5. Tukey HSD post hoc test comparing respondent groups based on age.

Group Comparison	Mean Difference (I–J)	Std. Error	*p*-value	95% Confidence Interval
Young aged vs Middle aged	−3.48**	1.27	0.018	−6.47, −0.48
Young aged vs Old aged	−5.40***	1.49	0.001	−8.92, −1.88
Middle aged vs Old aged	−1.92	1.35	0.328	−5.10, 1.26

Note: Group sizes' variances were assumed equal based on Levene's test ($p = 0.789$). The dependent variable in this model was the perceived effectiveness of AESs.
*** represents less than 1% significance level; ** represents less than 5% significance level.

3.6. Perceived Effectiveness of AESs by Farming Experience

The analysis of ANOVA presented in Table 6 demonstrates a significant difference in farmers' perceptions of AESs effectiveness based on their years of farming experience (F = 7.152, $p < 0.001$). Descriptive statistics show that farmers with 32–46 years of experience reported the highest perception of extension policy effectiveness (M = 38.86, SD = 5.74), whereas those with 2–16 years (M = 32.16) and above 46 years (M = 32.07) reported lower scores. Furthermore, the Games-Howell post hoc test (Table 7) also revealed statistically significant differences between the groups 2–16 years vs. 32–46 years ($p < 0.001$), 17–31 years vs. 32–46 years ($p = 0.012$), and 32–46 years vs. above 46 years ($p = 0.040$). These results suggest that farmers with 32–46 years of experience are more likely to recognize extension policy interventions as effective. This pattern may reflect the optimal combination of accumulated practical knowledge, openness to innovation, and active engagement with extension services among farmers in this experience group.

Table 6. One-way ANOVA results showing differences in perceived effectiveness of AESs by farming experience.

Dependent Variable	Farming Experience	Descriptive statistics			ANOVA results		
		N	Mean	SD	df	F value	*p* value
Perceived Effectiveness of Agricultural Extension Services	2 – 16 years	63	32.16	6.69	3, 185	7.152	$p < 0.001$***
	17 – 31 years	75	34.68	8.23			
	32 – 46 years	38	38.86	5.74			
	Above 46 years	14	32.07	7.93			

*** represents less than 1% significance level.

Table 7. Games-Howell post hoc test comparing respondent groups based on Farming experience.

Group Comparison	Mean Difference (I-J)	Std. Error	*p* value	95% Confidence Iterval
2–16 Years vs 17–31 Years	−2.52	1.27	0.199	−5.82, 0.78
2–16 Years vs 32–46 Years	−6.71***	1.27	0.000	−10.02, −3.39
2–16 Years vs above 46 Years	0.09	2.28	1.000	−6.38, 6.56
17–31 Years vs 32–46 Years	−4.18***	1.34	0.012	−7.69, −0.68
17–31 Years vs above 46 Years	2.61	2.32	0.680	−3.93, 9.15
32–46 Years vs above 46 Years	6.79**	2.32	0.040	0.25, 13.33

Note: Levene's test indicated a violation of the homogeneity of variance assumption ($p = 0.016$); therefore, equal variances were not assumed, and the Games–Howell post hoc test was applied. The dependent variable in this model was the perceived effectiveness of AESs.
*** represents significance at the 1% level; ** represents significance at the 5% level.

3.7. Determinants of Farmers' Perceived Effectiveness of Agricultural Services (AESs)

The results of a multiple linear regression analysis (Table 8) identified significant predictors contributing to farmers' perceptions of the effectiveness of AESs. The overall model was statistically significant (F = 8.071, $p < 0.001$) and accounted for approximately 31.1% of the variance in the perceived AES effectiveness ($R^2 = 0.311$), with a standard error of 6.497, indicating a good model fit.

Table 8. Determinants of farmers' perceived effectiveness of AESs.

Prediction	β(Unstandard-ized)	β (Standard-ized)	Std. Error	t-value	*p* value	VIF
(Intercept)	47.969***		9.173	5.229	<0.001	
Age	0.148	0.264**	0.065	2.286	0.023	3.469
Farming Experience	0.001	0.002	0.059	0.015	0.988	3.280
Income	0.022	0.212*	0.011	1.948	0.053	3.068
Education	0.079	0.045	0.117	0.669	0.504	1.197
Information Source	0.297	0.113	0.19	1.565	0.119	1.353
Climate Change Impact	−0.500	−0.202***	0.162	−3.092	0.002	1.110
Training	0.123	0.179***	0.044	2.779	0.006	1.072
Farm Size	−4.647	−0.223**	2.089	−2.224	0.027	2.606
Barrier	−0.201	−0.176***	0.073	−2.766	0.006	1.050
Adoption to CSA	0.214	0.199***	0.069	3.09	0.002	1.082
R^2 = 0.311, Adj. R^2 = 0.272, F (10, 179) = 8.071, $p < 0.001$, SE = 6.497						

*** represents less than 1% significance level; ** represents less than 5% significance level; * represents less than 10% significance level.

Among the explanatory variables, age (β = 0.264), training (β = 0.179), and adoption of CSA practices (β = 0.199) were positively associated with farmers' perceptions of AES effectiveness. Older farmers reported higher AES effectiveness, suggesting that accumulated knowledge and long-term farming experience strengthen adaptive capacity and improve understanding of extension recommendations (M. S. Kabir et al., 2024). This also reflects their longstanding engagement with extension agents, greater familiarity with advisory services, and increased trust built through repeated interactions (Somanje et al., 2021). Training significantly reduced uncertainty and enhanced farmers' self-efficacy, thereby improving their perceived ease of applying extension advice (Masha et al., 2024). Adoption of CSA practices further reinforced perceptions of AES's usefulness, as farmers who actively implemented CSA practices were better able to observe the tangible benefits of extension guidance in enhancing productivity, resilience, and decision-making (M. K. Islam & Farjana, 2024). When farmers perceive extension services as offering practical, context-appropriate, and easily integrated CSA solutions, adoption increases, leading to stronger positive evaluations of AES effectiveness (M. K. Islam & Farjana, 2024; Omotoso & Omotayo, 2024). Well-designed training programs and targeted promotion of CSA practices can therefore strengthen farmers' perceptions of extension services, which is essential for sustained engagement and broader adoption of climate-resilient agricultural practices (Akpan & Agulu, 2019).

In contrast, perceived climate change impacts (β = −0.202), farm size (β = −0.223), and barriers to adoption (β = −0.176) were inversely related to perceived effectiveness of AESs. Farmers experiencing greater climate stress, such as salinity intrusion, water scarcity, or extreme weather events, may view existing extension support as insufficient for addressing their specific challenges (M. J. Kabir et al., 2017). This finding suggests that external environmental pressures can overwhelm institutional capacity (Barron et al., 2021). Larger farm sizes might reduce reliance on extension services due to economies of scale, as these farmers often have better access to resources, technology, and private advisory services, lessening their dependence on public extension support (Jamil et al., 2021). Additionally, barriers to adoption, such as a lack of initial investment, poor embankment infrastructure, and low crop prices, could diminish the perceived effectiveness of extension efforts by creating obstacles to implement CSA practices (Billah et al., 2025).

Although the model explains a meaningful share of variation in perceived AES effectiveness, approximately 69% of the variance remains unexplained. This unexplained component likely reflects institutional and social factors not captured in the present analysis, such as the technical competence and communication skills of extension personnel, the quality of farmer–extension agent relationships, levels of social capital and peer influence, and the role of local power structures in shaping access to extension services (Billah et al., 2025).

It is also important to emphasize that this study assesses perceived effectiveness rather than the actual effectiveness of agricultural extension services. Perceived effectiveness reflects farmers' subjective evaluations based on their experiences, expectations, and interactions with extension services (Somanje et al., 2021), whereas actual effectiveness would require objective indicators such as yield gains, income changes, or measurable improvements in adaptive capacity (Knook et al., 2018). Although perceived and actual effectiveness may not always align, perceived effectiveness remains a critical determinant of farmers' trust, adoption behavior, and sustained engagement with extension programs (Turyahikayo & Kamagara, 2016).

Overall, these findings highlight the complex interplay of individual, institutional, and environmental factors shaping farmers' evaluations of AESs and underscore the need for more adaptive, context-sensitive extension approaches to promote CSA in vulnerable coastal regions.

4. Limitations of the Study

Despite its valuable insights, this study is subject to several methodological limitations. The use of self-reported data may introduce potential subjective bias, as responses depend on individual perceptions and recall accuracy. Furthermore, while the relatively small sample size (190) was adequate for this exploratory study, it may limit the generalizability of the findings to the broader coastal regions of Bangladesh, necessitating caution when extrapolating these results (Aryal et al., 2020). Therefore, the findings should be interpreted as indicative rather than universally conclusive. Although the study employed descriptive statistics, ANOVA, and regression analysis to identify the determinants of perceived AES effectiveness, the use of more advanced analytical techniques such as Structural Equation Modeling (SEM) or Multilevel Modeling (MLM) was not applied due to methodological considerations related to sample size and research objectives. Future studies could expand the sampling frame to include non-registered farmers and larger samples across multiple coastal districts to increase statistical power and enhance the generalizability of findings. The geographical scope of the study, confined to a single Upazila, also restricts a comprehensive understanding of regional variations in agricultural extension service delivery and farmer engagement across Bangladesh's diverse coastal zones.

5. Conclusion

This study provides an in-depth assessment of farmers' perceptions of the effectiveness of agricultural extension services (AESs) in promoting Climate-Smart Agriculture (CSA) practices among smallholder farmers in coastal Bangladesh. Although 76.8% of respondents reported moderate to high levels of perceived effectiveness, the findings reveal a combination of notable strengths and persistent gaps within the extension system. Effective interventions such as the dissemination of stress-tolerant crop varieties, participatory decision-making processes, and targeted capacity-building programs were strongly associated with increased CSA adoption and more positive views of AESs.

However, farmers also identified significant shortcomings, particularly related to insufficient access to credit, limited value-chain support, inadequate ICT-based services, and weak agricultural infrastructure—issues that were especially pronounced among marginalized and resource-poor households. Perceptions of effectiveness varied significantly by age and farming experience, with older and more experienced farmers expressing more favorable assessments, while greater climate vulnerability, smaller farm size, and higher levels of adoption barriers contributed to more negative perceptions. These findings underscore that a uniform extension approach is unlikely to meet the diverse needs of coastal farmers; instead, a more inclusive, demand-driven, and context-responsive AES model is needed.

Strengthening extension services requires targeted, evidence-based, and institutionally coordinated interventions. Priority actions include developing CSA-oriented green credit products through collaboration between extension agencies and microfinance institutions, simplifying subsidy access via decentralized extension offices, and expanding low-cost, local-language digital advisory services supported by trained extension personnel. In addition, enhancing field-level follow-up, market linkages, and infrastructure support is essential for sustaining CSA adoption. Future research should employ longitudinal designs to examine changes in farmers' perceptions over time and conduct comparative studies across different agro-ecological zones to improve the generalizability of findings.

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Abbreviations

The following abbreviations are used in this manuscript:

AES	Agricultural Extension Service
AWD	Alternate Wetting and Drying
CSA	Climate Smart Agriculture
DAE	Department of Agricultural Extension
ECT	Expectation Confirmation Theory
FGD	Focus Group Discussion
ICT	Information and Communication Technology
PEI	Perceived Effectiveness Index

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Agricultural & Rural Studies

Article

Tourist Imaginary and Rural Values: What Are the Agricultural Perceptions? A Reflection on Crossed Imaginaries

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Abstract: This article deciphers tourist imaginary in a transitional context, in its permanence and evolutions, specifically associated with French countryside. Firstly, we question to what extent the rural represents a dreamt, imagined, and chosen place. Secondly, we analyze how the farmers who are visited fit into this surge of tourist imaginary: what rural perceptions emanate from the agricultural populations themselves? To answer our questions, we focus on the on-farm market, an agritourism concept that has been developing for some years in France. We highlight the interpenetration of two perceptive worlds in the same co-construction process. "Purifying," "socializing," or "nostalgic," the countryside produces idealized representations both for the visitor and for the visited, simultaneously causing dissonances and contrasts in the interaction at play.

Keywords: agritourism; rural imaginary; rural France; on-farm market

1. Introduction

While exploration and conquest of other places had always existed, up until the first third of the 20th century, it was something reserved only for a minority of people who wished to reach beyond their familiar environment. A social luxury, this eclectic tourism changed very quickly and underwent various social mutations. This taste for exoticism, different places, the other, a change of scenery, until then reserved for the rich, became a social fact in the second half of the 20th century, asserted, exalted, and democratized. Subsequently, temporary escape became an integral part of everybody's social imaginary. In France, two, then four, and then even five weeks of holiday a year gave way to the rise of a mass phenomenon, ever-changing migratory movements shaped by dreams and fantasy. Over the years, the coast, the mountains, and rural areas became tourist destinations, showcasing multiple liberating, ludic, and purifying images that balanced out the time constraints of everyday life.

Studying this tourism phenomenon today leads us to reflect on the behaviours and motivations of tourist travel: into which field of representations does the tourist fall? What imaginary and sociability that lead to travel: a search for meaning, a search for social connection, a search for images, or a unifying "sacredness"? While the health crisis damaged and disrupted established tourism practices and representations, it is now proving to be a lever for questioning and for an inevitable transition that is forcing us to reevaluate tourism in a changing and evolving universe. Also, we will endeavor to decipher the tourist imaginary in a transitional context, in its foundations, its permanence, and its evolutions, in this case, specifically associated with rural areas.

The first part of this article will focus on considering the tourist act as a break from everyday life. We will try to see how, more specifically, the rural area today represents a dreamt, imagined, and chosen place. How did a countryside long rejected, denigrated, and devalued become this desired, preferred, and glorified place? The first stage of the study will be based on a review of scientific literature, before moving on to define the research questions and field methodology. In a third stage, based on the results and a conclusive discussion, the article will analyze how the farmers who do the welcoming or are visited fit into this surge of tourist imaginary: what rural perceptions and imaginaries emanate from the agricultural populations themselves? How do they intersect and fit into this contemporary tourist imaginary?

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2. Review of Literature

2.1. The Tourist Experience, a Break from Everyday Life

The following approach will briefly question the advent of leisure in French society: in what historical, social, and economic context did leisure become a common social practice for the individual, a commodity, a social reality? What function does it play and how does it integrate the phenomena of mobility, both in terms of time (annual, weekly trips ...) and geography? The emergence of social time free of work, with time for oneself, is the result of a long-term evolution of the economic and social system (Dumazedier, 1988). This is how leisure activities, fundamental elements of our society and now marked by a real "cultural revolution of free time," emerged and spread. This leisure-time, reserved until the 19th century for privileged social categories excused from "productive labor" and subsequently called ostentatious by Veblen (1970), has now, with the growth of free time and institutional recognition, become democratized, popularized, and has spread across the entire population and generations. Once marginal because of its links with a despised idleness, mother of all vices, leisure-time is now deemed essential. In Dumazedier's (1988) analysis, it already appeared in the 1970s, described as a chosen activity, one outside of professional, family, or educational obligations. It became a complementary and compensatory phenomenon of human labor. Thus, speaking to recovery functions that provide a release from fatigue, boredom, and the routines imposed by daily life, choosing and implementing this free time is seen as a time for oneself, detached from an institutional environment, during which the individual can experience self-liberation. Leisure time, in general, is seen today as a temporary valorization of a more liberated individuality, often dominated by fantasy, dreams, and myths. Not only a compensation for everyday life, but it also provides images of the ideal life.

Holiday activities are the most important among leisure activities, both in terms of their duration and their appeal. Holidays, called "great inventions of the 20th century," are today a common commodity, a fact of society experienced by about 60% of French people (Berhuet et al., 2024). While travel increasingly represents the big adventure of the year, it's not just a ritual practice; it's a liberating myth even when the results are disappointing. Indeed, this encounter with the never-before-seen, the never-felt, the never-perceived, that need to escape something we know too well, a daily or over-standardized routine, means that the tourist act today is fabricated all year long, feeding off dreams, images, and representations. In this way, holidaymakers use travel images to penetrate unknown universes. These images allow tourists to grasp at a spectacle, a production, and not just an ordinary encounter. They establish a distance between the daily place and the holiday place. As explained by Gravari-Barbas and Graburn (2012), it is this distance, this imaginary of places or myth created by the image of places, that is ultimately the driving force behind the movement: "Tourist imaginaries facilitate the transition between here and elsewhere, near and exotic, known and unknown. They play a decisive role in travel plans." Salazar (2023) explains to us:

> It is hard to imagine tourism without the creative use of enticing as well as limiting imaginaries of both places and peoples. Tourism imaginaries are socially transmitted representational assemblages that interact with people's imaginings and are used as meaning-making and world-shaping devices. (p. 1)

Imaginaries have also been defined by Astudillo and Salazar (2024) as "ways to understand and (re)create history and projections of the self and others that ground ever-changing identities. They are embedded in the cultural meaning-making systems of each society." From this perspective, they are understood as relevant analytical tools for rethinking the meaning and practice of heritage in the tourist experience.

Whether it's a question of escaping an ordinary routine, freeing oneself from professional or family constraints, overcoming or distancing oneself from stress, insecurity, or a polluted environment, the tourist act, carried by imagination, stems from a socially constrained daily schedule. Resulting from a desire for change, it embraces the development of new aspirations to do with the body, sensitivity, affectivity, curiosity, belonging, and recognition. Constituting places of freedom, self-expression, fulfilment, and personal growth, but also prestige and reputation, tourism and its values create an imaginary world for the individual, one with a different logic to that of ordinary life. Between the known and the unknown, there is an imagined, dreamed, thought-out space, one that has most probably been idealized. It is this fantasy world of the tourist that we will try to penetrate: that of mental images revealing a perceived external reality.

In this sense, Amirou (1995) provides some elements for analysis. He describes the tourist imaginary as a "transitional object": the tourist constructs a symbolic intermediate space between the familiarity of everyday life and the unfamiliarity of distant places, a zone that accommodates imagined forms of elsewhere, from exotic fantasies to ritualized holiday practices.

Furthermore, beyond socio-economic variables such as age, income, place of residence, time, and type of job, he evokes the notion of the search. The search for oneself, the search for a place, the search for the other, all form part of a set of motivations inherent to tourist travel, thereby proclaiming the search for new constructive values of identity. This search for meaning, developed here, specifically refers to the identification of ostentatious behaviours and imitation effects. Indeed, holidays, due to the places, the practices, and the representations, are in fact external indications of the individuals' and households' tastes. Social distinction, a symbol of class, speaks of the individual's social status, built around a "search for societal belonging."

Tourism, in the search for the other and commonplaces, also plays a socialization role. In the face of poverty and the breakdown of family ties, in the face of the complexity of daily life, tourism remains a search, albeit ephemeral, for social bonds that tend to break the isolation, loneliness, and atomization experienced by individuals. The need for sociability, having more human relationships, participating in more fraternal societies nourished by spontaneous exchanges, becomes a driving force behind tourist travel. As we will see, the rural space and its identity markers play a symbolic role of conviviality and solidarity in the collective conscience. Therefore, observes Amirou (1995), a collective phenomenon, tourism is similar to the search for a "communitas," "a kind of nostalgia where social status, individualities, and societal environment are erased to found a simulacrum of ideal society." Is it, subsequently, this atomization of social ties, subordination to an anonymous and unbound environment, and, more recently, pandemic lockdowns and also frequenting places emptied of all identity, that lead the individual to go off in search of more reconciling and humanized values? The widely used expression by Edgar Morin summarizes this value vacuum: "the vacancy of values is what makes holidays valuable." Also, the majority of tourism research agrees that this "transhumance society," so named by Viard (2006), is a consequence of the conditions created by the development of our industrial era.

Ultimately, travel, seen as a plural search for significance and meaning, is considered beneficial to the individual because it brings with it a new identity. Upon returning from a trip, the identity of the tourist is renewed, renovated, and enriched by values acquired from contact with the other, new places, and oneself. In "the tourist experience," Laplante (1996) sees "a global model" that builds identity before, during, and after the trip. Tourist travel, exploring other places, is accompanied by an identity fantasy where the individual feels that they have come back different, reconciled with societal values. So, time spent on holiday, seen as a form of "mental hygiene," has become a determining element in the construction of individual and collective identities.

The Sacralization of Tourism

Often compared to a pilgrimage, tourism can be equated to a sacred encounter. After all, tourism practices create a ritual, sacralizing or spiritual dimension around certain tourist sites or destinations. Being out of the ordinary, these locations or "High Places" are revered, consecrated, making them strong, privileged, or paradisiacal emblematic spaces. They are exhibited and spectacularized for the tourists. The High place is specified by its sacred character, as analysed by Debarbieux (1995): "This sacred place ensures the communication of the Worlds and the linking of Heaven and Earth, the visible and the invisible, the local and the all-encompassing. [...] It is the point of the territory that it symbolically structures." Therefore, for tourists, these High places provide images, points of collective attachment. They are staging sites that symbolize belonging to the same unit, the same whole. They give the place a character of universality or exemplarity. Furthermore, each individual carries some sacred places within them, qualitatively different from the others because they are unique or indicative of a story, a personal experience, or a family memory. Mythical spaces, constructed spaces, can be a place of individual or specific collective experience (one's natal land, a transient city, a meeting place, etc.).

The dialectic between the profane and the sacred, described by Jafari (1988) as a dialectic between "the ordinary and the non-ordinary," refers to the opposition between daily life and tourist life; the latter being assimilated to a universe of the sacred, the ritualized. This tourism religiosity is also expressed by Amirou (1995), who pits a "periphery" against a "center," an "outside" against an "inside." In contrast to the everyday "periphery," the touristic "center" is a home, a unitary emblem, a place of sociability, solidarity, and conviviality in which the community blissfully flourishes. The tourist is searching for this center, this idyllic interior, a reassuring "inside," rich in meaning, emotional, more symbiotic and natural. "The holiday space is just one scene among others where the original fantasy of Unity can be replayed" (Amirou, 1995).

We have observed that farmers or rural people travel little, or certainly less than city-dwellers. This phenomenon can be explained, in addition to the economic variables and constraints implied by the production cycle, by a more developed community presence, a stronger sociability and proximity, as well as a more significant sense of belonging to the land, to the earth. Every day, in contact with their land, farmers have space, fresh air, and relative autonomy in their work. Do they need holidays? Is their daily setting not precisely what many city dwellers are looking for? A somewhat sedentary lifestyle, coupled with greater solidarity, makes the need to leave and get away from the everyday world seem less important for rural people than it is for urban people.

The tourist imaginary also translates into the search for a reassuring, secure, understanding, "mothering" environment of protection and forgotten sensations. Places of "affectivity" and feelings, tourist places are chosen partly due to the emotional shock they provide, their memory roots, and their sensory and perceptive dimension. "We not only move from one space to another but above all from one emotion to another. [...] Some places are idolatrous, others provoke aversion. These places exist only because of their emotional charge of euphoria, pleasure," adds Amirou (1995). Also, the tourist organizes and defines their journey towards an emotional self-realization.

The ritual aspect of tourist travel is also verified by the repetitive, renewed, and routine dimension. By making a certain trip, a certain recommended and consecrated itinerary, the tourist is adhering to a set of collective codes recognized by the community. Urbain (1991) observes in the tourist: "an uninterrupted series of ceremonies accenting a ritualized route that imposes a series of obligatory visits on millions of travelers. [...] Bending to a chain of implications as if to a law, the tourist performs a rite." A rite defined as "a conventional act performed mechanically through which the individual expresses their respect and deference to an object of fundamental value." We should add, however, that while the notion of rite implies the idea of common attitude and collective cohesion, the journey is accompanied by an exclusivity, a rarity, an individualized emotion that each person seeks to empower. The tourist is then the hero of multiple unique experiences to which no other person can relate. The collective myth suddenly becomes indexed under individual myth.

Additionally, the participation or non-participation in a rite has a function of social integration or exclusion of the tourist in the host group. Therefore, the tourist phenomenon would translate as the consumption of a series of local rites, allowing a social and cultural integration of the individual in the local group by absorbing and reproducing cultural codes. These ritual situations prove to be a privileged form of staging the memory that one finds in dancing, at the dining table, in social life, and in various commemorations; let us then pose the problem of the non-acceptance, or non-integration of the tourism phenomenon in certain territories (conjuring images of colonization or cultural appropriation). Can we not look for the causes of this phenomenon in the forms of adaptation to local rites? The refusal to adapt to the daily life discovered, on the part of the tourist, or vice versa, the refusal to distribute or share this same daily life on the part of the locals? Often equated with "a rite of passage," the tourist journey is characterized by the transition from one state to another, from a troublesome everyday life to an idealized universe. True identity fantasies, tourist trips suggest a break, the desire to go beyond, to overcome the boundaries of everyday life in order perhaps to come back better or different ... like a pilgrim seeking to convert their soul.

Finally, contemporary city life presents identity crisis indicators that justify the aforementioned notions of "break away" and search. Overcrowded cities, the complexification of social life and professional relationships, the transformations of social roles, promiscuity, but also insecurity, unemployment ... these are all elements that make the city a place that's often criticized, seen as artificial and rejected, especially during the holiday periods. Instead of bringing people together and unifying, the city seems to isolate people more, increasing anonymity and solitude. In this vein, Mathieu (2017) has noted the emergence of an anti-city ideology where the city is consistently portrayed as a technical hub dominated by material infrastructures whose modern features have taken on negative connotations. The city is depicted as congested, artificial, and prone to pollution, offering poor living conditions marked by long commutes, economic difficulties, and visible

As we will see, the rural area, in opposition to the city, now has a positive image, reinforced since the health crisis. This urban crisis, just like any other crisis, generates myths, and especially tourist myths. Desires and expectations revolve around leisure and holidays; tourist trips, as factors of hope, compensate for a certain disenchantment with the world. Tourism and its imaginary correspond to a need for compensation and rebalancing in the face of industrialization and contemporary rationalism.

Let us ponder the rural space more, then, a space highly valued in the collective consciousness due to its eternal and natural representations. How do these new rural tourist sites meet new aspirations, and are they sources of images, myths, and symbols for the tourist?

2.2. The Rural Area, a Place of Compensation and Identity Building

In a context of changing rural areas and the diversification of agricultural activities, part of the tourism demand over the last fifteen years seems to have shown an elevated interest in rural areas. Here, it's a matter of examining the advent of these practices, the nature of the field of representations, and the current patrimonialization movement; the "myth of the natural," the search for an "original community," and the enthusiasm for recovering the past seem, today, to structure the rural imaginary of city dwellers.

The Social Reshaping of Rural Areas and the Resurgence of Consecrated Images

For a long time, the French rural world was loaded with negative values. It was confined to purely agricultural functions, and its landscapes were of little appeal. A fragile territory, place of grunt work, on the brink of poverty, the countryside was of no interest to the explorers of the time, until the 19th century, that is. It conjured up images of misery, poverty, isolation, and boredom (Weber, 1971). The first forms of leisure in rural areas date back to the 19th century, when a few circles of intellectuals discovered the countryside and its landmarks. The 20th century was already more prosperous: the 1920s, after the war, saw the countryside as a refuge against the horror, a recourse against the dominant order; then, the paid holidays of 1936 brought about an undeniable increase in tourist attendance, dominated by a working class whose peasant origins were still all too recent. The countryside then took on new ideological values, some of which have survived to this day.

But it was only from the 1980s onwards that the rural sphere emerged as a true leisure area and became aware of the economic role played by tourism. After the growth and allure of post-war cities, after the great exodus, people once again dreamt of conviviality and simplicity. They rejected the misdeeds of the industrial civilization and saw the most deserted places in a new rose-tinted light.

This new appreciation may have led to an idealized, even fantasized, vision of the rural sphere that hid the complexity of contemporary rural spaces by erasing diversity, power relations, or possible tensions between its inhabitants. After all, today, the social reshaping of rural areas is obvious: "Peri-urbanization," "urban deconcentration," "urban exodus," "urbanization" ... an endless list of terms that highlight the fact that the current countryside has less and less to do with the old "farming societies." The social group of farmers continues to shrink, and new categories of the population (employees, pensioners, middle classes...) are gradually emerging. We're therefore talking about the disappearance of the farming population or "deagrarianization" of the rural environment (an expression that refers to new uses of space); The recurrent crisis in the agricultural sector and its policies has led to a steady decline in the number of farmers and the use of land for agriculture. Furthermore, the incessant growth of communication and information means associated with a significant change in productivity and production systems has greatly contributed to rural districts opening themselves to the outside. The social and economic spaces of rural areas, as well as their networks, have expanded and now stretch far beyond the village. These new territories have new functions: residential and recreational. After all, the large proportion of pensioners, second homes, and summer tourist movements attest to the recreational role played by rural areas. Spaces with high ecological, symbolic, and cultural values are quickly becoming tourist spaces. At the same time, with the development of ecology, rural areas have been assigned an environmental function. The maintenance of rural areas is therefore a real issue for the whole of society. The historian Duby and Wallon (1975) note that since the 1970s, "the fusion between town and countryside is hastening"; indeed, if we look at the consumption system, we note that rural areas have seen, in just a few years, a massive influx of household equipment that is commonplace today. Some people talk of standardization. In 1980, Mendras (1980) evoked "a strong and growing standardization of French society due to the total elimination of rural civilizations and the progressive urbanization of rural regions." Kayser (1990), too, observed a "normalization" and noticed the countryside entering the consumer society as early as the 1990s. Furthermore, at the heart of environmental and broader societal transitions, rural areas are the subject of new collective representations analysed in particular by Stokowski et al. (2021), focusing on residents of rural communities and the construction of an imaginary of tourism transition. In addition, a study published in 2024 on images and representations of agriculture in French society shows the diversity and structuring role of these perceptions in public debates, which are useful for analyzing current controversies (agribashing, pesticides, animal welfare): whether seen as nourishing, in crisis, polluting or virtuous, the image of French agriculture is becoming a strategic issue, reflecting various contemporary social tensions (Gassie et al., 2024).

Finally, now reinforced by a health crisis that has made, for a time, the "world unavailable" (Cousin et al., 2021) and reconfigured our relationship with local discovery (as evidenced by the strong interest for domestic and inland tourism during the summer of 2020), this "rural" reference point of identity is involved in the construction of the urban imaginary. After holding a negative image for centuries, the rural space is now peaceful, solid, and secure, to the point of being idealized. Purifying, socializing, conservative, the countryside is beheld, exalted, adulated (Bessiere, 2000). These perceptual figures of the rural imaginary that we will discuss later also inevitably question the perceptions of the host populations, both rural and agricultural, subsequent receivers and participants in their own images.

3. Questioning and Methodology

From a historical point of view, several authors have shown that rural and agricultural populations have more often been "objects" of the rural imaginary than "subjects" (Banos & Candau, 2014; Caquot-Baggett & Annes, 2016; Frémont, 1997; Reed-Danahay, 2002). In other words, they have often been excluded from the construction, reproduction, and perpetuation process of these representations, which nevertheless concern them. It's also clear that, although they represent an increasingly small proportion of the population, the social group of farmers is a fundamental cultural reference point in France and Europe, and one with its own identity, which exceeds 1.5% of the working population (Givois & Apers, 2025). Albeit caught up in a movement of modernity, it retains elements of specificities and particularities that, today, still constitute a strong rural identity. Therefore, agri-tourism, defined as the set of tourist activities practiced on an agricultural holding (Lerbourg, 2013) and presented as a means of diversification with multiple benefits, is at the heart of our study. In this sense, it is closely related to other forms of tourism, such as ecotourism, culinary tourism, or rural tourism (Durrande-Moreau, 2018). Agritourism can also be approached more narrowly, referring specifically to tourism or leisure activities conducted directly on working farms (Durrande-Moreau et al., 2017). While agri-tourism, through the valorization of agricultural products, is analysed as a means to renew dialogue and weave links between the agricultural population and civil society (Banos & Candau, 2014), for the agricultural population it can also be seen as a means to promote a rural identity, to repossess its own image, control it, and create a dialogue with a non-agricultural population. The subsequent social interaction between the agricultural and non-agricultural population would therefore give farmers an opportunity to showcase their work and their daily life, surpassing the process of idealization and marginalization of rural representations.

In our reflection, we ask ourselves how much the agricultural population itself participates in building a rural and tourist imaginary.

To answer our questions on agricultural perceptions, we will focus on the farm market, a concept that has been developing for some years in France (Banos & Candau, 2014). These markets come in several different types: they can be regular (all year round) or seasonal (usually during the summer period), individual (one producer offering several products) or collective (a farmer organizes the market on their farm but several other producers are present and sell their products), ones that allow customers to eat on-site (customers/tourists are encouraged to buy farm products and enjoy them on-site) or not, or even ones that organize activities (music, horse/pony rides, farm tours, etc.).

This study is grounded in data derived from qualitative semi-structured interviews. Regarding on-farm markets, our goal was to investigate not only how farmers stage their farm, their own appearance, and farm activities so as to embody the "rural idyll," but also how they construct meaning around their work and involvement in agritourism. Central to this aim was gaining a deeper understanding of their rationality in incorporating tourism into their activity and setting up an on-farm market. As stated, we believe on-farm markets are particularly suitable to explore our research questions, in providing a space to re-imagine agriculture. These on-farm markets bring different people, farmers and non-farmers, rural and urban dwellers, to one particular place, at a given time. Therefore, farmers can stage and choreograph agriculture, as well as their own image.

We began by selecting potential respondents through their involvement in agricultural networks such as *Bienvenue à la Ferme*, *Accueil Paysan*—popular French agritourism networks—or their presence in agricultural outlets showcasing farmers involved in direct selling or organic agriculture. We then used a snowball sampling method to identify other respondents. We met with 25 farmers, all located in South West France (Occitanie region[1]). Interviews were conducted during two research fields: one during the summer of 2015 (15 interviews conducted), and one during the summer of 2019 (10 interviews conducted)[2]. Interviews took place on the farm and were usually followed by a tour of the farm. Our interview guide covered several themes: the farm history, farmers' life trajectory, values, motivations, and networks, and the on-farm market. Special attention was paid to how the market grew up and was organized and run, and to relations with other farmers and visitors. Our sample brings together a variety of experiences and life trajectories (farmers with a farm background or a non-farm background, practicing agriculture alone or with a partner, involved in conventional or unconventional agriculture). All participants share the same general involvement in activities of agricultural diversification, and farm tourism in particular, through the organization of an on-farm market. All markets organized were seasonal and collective, and gave an opportunity for tourists to picnic on the farm. Additional agriculture-related activities (farm tour,

[1] Located in the south of France, the Occitanie region is characterized by its great geographical diversity, stretching from the Mediterranean coastline to the Pyrenees and the Massif Central mountains. This natural heterogeneity is accompanied by a strong presence of rural areas, where agriculture, livestock farming and tourism are major economic pillars. Marked by an ancient agropastoral history and a rich cultural heritage, Occitanie occupies a central place in the construction of rural and agricultural imaginaries, often associated with 'authenticity', 'terroir', nature and food quality, but also affected by contemporary tensions linked to environmental and social transitions.

[2] This research is part of different research programs, one exploratory research (2015–2018), TOURALIM 1 (2018–2021) and TOURALIM 2 (2022–2026). All these research programs question relationships between tourism, agriculture and food in French rural spaces.

milking demonstration, animal feeding, etc.) and non-agricultural activities (concert, etc.) were provided for visitors.

It is also noteworthy that all farms in our sample are working farms whose tourism activity is not their main source of income. Farmers became involved in agritourism for different reasons, from generating additional income to reconnecting with non-farm people. This desire to communicate about their job and their enthusiasm for it is regularly referred to in brochures or websites advertising these events. Educating people (about the production of agricultural goods, the specificities of one region and its products, particular customs and traditions, etc.) as well as linking up urban and rural dwellers, are also mentioned as a motivation for farmers to organize these on-farm markets.

Finally, a general inductive approach to data analysis was used. Both authors systematically read and coded each transcript, which brought out the significant textual themes. Certain limitations to these data should however be noted; given the small sample size, it is not possible to say how widely these findings are representative of all agricultural entrepreneurs. We offer them to encourage further scrutiny of how farmers represent agriculture through agritourism. In particular, we believe this work reveals the existence of two somewhat contradictory approaches, resulting from opposing rationalities, with different implications regarding the images of the rural and agricultural world offered to tourists.

Finally, our in-depth analysis of the statements gathered will highlight the perceptions emanating from these farmers in terms of the production of images. In what way do they converge, enhance, or thwart the tourist imaginary that so corresponds to them?

4. Results and Discussion: Towards a Cross-Analysis of Rural Tourism Imaginaries

In addition to the imaginary of places and practices, the tourist imaginary is crossed by an imaginary of actors (Gravari-Barbas & Graburn, 2012). The tourist imaginary is also the imaginary of the tourists themselves: both producers of imaginaries and the very element imagined by the welcoming and host populations. Stereotyped images of the tourist, their practices and codes, have long produced a strong and powerful imaginary that infuses the approaches and behaviours of the hosts. Based on the analyses of Gravari-Barbas and Graburn (2012), we can therefore consider tourist imaginaries to be constituted of shared representations, fed by “material and immaterial images, worked by imagination and socially shared by tourists and/or tourism stakeholders.” As for the tourist imaginary associated with the rural sphere, we will see that the perceptive figures widely distributed around the image of the countryside (Bessiere, 2000) influence, penetrate, and construct the discourses and representations of agricultural actors, even seeing them adjust their practices. How do the farmers surveyed play with and thwart the tourist imaginaries? How do they create interest? How do they decode the imaginary from a local “authenticity”? Therefore, following a cross-analysis of the components that make up the tourist imaginary, produced on the one hand by tourists and on the other hand by agricultural populations, we will develop the following reflection.

4.1. Towards a Typology of Tourist Imaginaries Associated with Rural Areas

4.1.1. A Purifying and Therapeutic Countryside

Today, the idea of nature is clouded by multiple images of preservation and conservation brought to light by tourism (Bessiere, 2000). The last few decades have been marked by a powerful drive behind the conservation of nature, preserving its air, its water, and its wildlife. A new relationship with nature has emerged, one that is particularly evident during holidays. Reserves, parks, and tourist routes place particular value on the preservation of the natural environment, its purity, unspoilt beauty, and overall greatness. Thereby, a powerful collective aspiration to live more in symbiosis with nature has emerged among urban citizens, feeling threatened by the excesses of urban life. The countryside has therefore come to be seen as a natural reserve, a purifying and hygienic place. Testimony of a type of nature that’s unspoilt, preserved, still pure, and accessing it would translate as a spiritual journey to a place with therapeutic virtues. Moreover, seeing and having contact with nature (for example, panoramic places), for the tourist, becomes a moral regeneration. Here, we come again to the aforementioned sacralising dimension where the countryside and its preserved places become spaces of veneration and healing. Amirou (1995) emphasizes this therapy, both physical and spiritual. The return to nature acquires a transformative, almost redemptive quality, as rural spaces, once viewed as desolate, are reinterpreted as curative place for urban populations in search of redemption.

The city now incorporates the old values once intended for rural areas: the city combines negative features and symbolizes turmoil, peril, and poverty. The attractiveness of rural areas may be a sign of rejection of the consumer society. Doing outdoor activities, this return to nature, often stems from a refusal to partake in a type of leisure that feels artificial and “gadgetized.” In some cases, tourists travel to rural areas to show their opposition to the pressure of the consumer society. This profound desire to rebalance and return (the rediscovered nature) also demonstrates a certain nostalgia for a past where man was in symbiosis with his environment. The image of the countryside as an antidote to the city and its evils is also evident in the success of the many green classes available, along with summer camps, different types of hikes, and second home purchases. The concepts of ecotourism and space tourism, aimed at a harmonious development of tourist structures, also fit with this imaginary. The importance attributed to landscape today reinforces the image of a "lost paradise." The landscape, seen as a cult, becomes a place of identity, heritage, and memory. The whole countryside is akin to a landscape, a spectacle to contemplate and consume. This heritage-nature is overrun with plenty of clichés about the relationship between man and space. In this way, says Lowenthal (2008), the enduring idealization of the farmer as an inherent ecologist proves difficult to dispel, as the small number of individuals who continue to cultivate the land are frequently portrayed as stewards of nature.

As far as the farmers who welcome tourists are concerned, our study shows the same enthusiasm for a purifying countryside, a savior of all evils, where nature and rural culture are closely linked. Like an echo, as both producer and receiver of images, the agricultural perceptions gathered centrally demonstrate how nature plays a key role in justifying and legitimizing their diversification activity: rejection of polluted cities, a change of life in order to return "to a regenerative and therapeutic nature." The motivations for farming and its subsequent touristic, environmental, and biological diversification are underlined in the responses, which successively emphasize the beauty and appeal of the natural setting, the attractions of the area, and the biotopes of both the plant and animal world. This imaginary is repeatedly used in opposition to the city, a place of flight and abandonment for some of them. "If I were to do it all over again, I'd do exactly the same, and worse. I'm very happy. Because being a researcher was a really theoretical job, a little ungrounded. Here, in nature, I'm much closer to everything. It's exciting. I feel reconnected with the environment after years of being 'ungrounded' in city offices," explains Alice, a fruit producer. In the representations of the farmers interviewed, the countryside is associated with the organic and ecological. An unrivalled space in terms of biodiversity and naturalistic values, the countryside is a place that's free of pollution, where it's good to take refuge and work in order to escape a city that is described as "oppressive" (Denise, producer of duck fat). An opportunity to live and work, this countryside is also the place for producing healthy food, without any gimmicks. From developing farming methods that are as close to nature as possible, to producing pure food "taken from the land," agriculture and rural life are represented here as idyllic places for environmental reconciliation. "We live in this environment. Some people pay to come here; we're so lucky!" exclaims Denise again. Patrick, a dairy and meat producer, says: "As I often say, when I'm sitting in front of my bay window looking out at the mountains, on Friday evening at 7 p.m., I think of the bypass in Toulouse, the ring road in Paris, the motorways and all that, and I tell myself that I made the right decision. Here, I cut my own wood to keep me warm, we eat vegetables from the garden, we breathe relatively clean air compared to many people, we certainly don't have the pollution problems they have in Paris. What I offer to visitors here is nothing but natural."

In terms of food and its purifying and therapeutic values, the answers are recurrent among the farmers surveyed who work and advocate for a more rational and "cleaner" production and consumption model. "We have a role to play. To produce good food and show our visitors that we respect nature. That's our main role, and then to produce good food in systems that are reproducible. ... In what I do, there's a small element of resistance to the industrial steamroller," says Alice, a fruit producer. The food products distributed at farm markets carry messages and perceptions about the health and naturalness of foods; from foods linked to the soil, the landscape, natural attributes, or harvesting. The agri-touristic service therefore makes the eater aware of a diet that's "truer," "more natural," free from pollution. This food reconciliation for the eating tourist (Bessiere, 2012) is constructed through the denunciation of contemporary food trends. The images produced therefore juggle an idealization of a rediscovered land with the prosecution of a more industrialized food system. "Restoring a dietary truth" then becomes the mantra of some of the farmers interviewed, determined to promote an image of sincerity and "authenticity" (MacCannell, 1976). The following quotes reflect this stance:

"When tourists come here, they want to eat good food and real products. What they're looking for here are good, natural products. It's for their health too" (Cédric, cereal producer). "The things we're fed every day are intended to kill us slowly, and nobody notices. When you see what children are being fed ... Well, I mean, by feeding them, we're killing them. We want to show that you can have foods that are a little less attractive but still high-quality and natural" (Christelle, meat producer).

Sustainable and local food is based on values of proximity, respect for the environment and the planet. Subsequently, around the rural and agricultural area, we find tourist images with purifying and therapeutic values, produced by the farmers visited and corresponding to the tourist imaginary. Other images focused on the functions of inter-knowledge and sociability also emerged from the analysis.

4.1.2. A Socializing and Unifying Countryside

For the general public, the rural environment, chosen as a holiday destination, plays a role of socialization and community membership in the face of the impoverishment of the daily social bond. We dream of conviviality, a village-like solidarity; the search for a first-hand "original communitas" is symbolized by the village square, markets, local festivals, local rustic meals, etc. Moreover, the rural social group successfully evokes the image of the family unit and the warm community, where the relationship with oneself and others is valued. This is reflected in the brochures of many agri-tourism structures which, under the brand "Welcome to the farm," combine a warm welcome, family atmosphere, and rustic and natural products. Further proof is found in the success of homestays, where the tourist eats at the owner's table and shares the same house. The countryside is indeed the place of intimacy, interiority, the private life; it's the re-discovered "home," the unifying universe. "An idyllic social setting," the village and hamlet are the symbol of a collective life where everyone knows each other, meets up with each other and welcomes each other. Urbain (2002) observes that the contemporary tourist wants to be "the hero of a return to the land", imagining their trip as a search for ancient ways of life and a renewed connection with a simpler, more intimate form of social interaction just outside the reach of modern networks.

Practicing rural tourism is seen as a relational learning process where one learns to live alongside others, to develop forms of sociability that are still unknown. Countryside tourism then takes on an almost initiation-like aspect.

For the farmers, the opinions and imaginaries gathered crystallize the same desires and perceptions: the creation of a friendly, festive atmosphere, one of sharing and exchange on the welcoming farm. "When they come here, they're happy because they feel welcome. We welcome them in as if they were coming into our own home," comments Denise, duck fat producer. Christophe, a poultry farmer, explains: "In the morning, everyone visited the market on their own. Then we had lunch together. Everyone sat around between 1 and 3 p.m. We chatted and we laughed. It was wonderful."

The social function of agri-tourism requires no further proof (Wright & Annes, 2014). It focuses on the discovery of the other, the creation of new sociabilities, and an openness to dialogue. Our study highlights how discourse predominates in the encounter, as well as social openness and the creation of social bonds. This function of inter-knowledge, a source of personal enrichment, in many cases seems to exceed the sole economic and market functions of agricultural diversification. The reinforcement and construction of new sociabilities around products sold and promoted on the farm are recurrent in the statements: it's all about generating exchange and a social link that revolves around the service on offer. The search for sociability in an agricultural universe which is sometimes isolated, socially and geographically closed, seems to be a major objective of the agricultural diversification strategy. When tourists visit the farm, it implies a change of scenery and a new discovery for the farmers themselves. Replacing the farmer's "impossible" holidays, the interaction between visitors and those visited provides hospitality, entertainment, development, and socialization, things commonly sought after in the tourism quest (Amirou, 1995). Christelle, a meat producer, explains: "They come here, we chat, I think it's important. That was the main reason I did it. I've always been in contact with people, I worked in companies and then, from one day to the next, nothing. Because you're isolated there, you quickly become isolated." "It's fulfilling in terms of relationships, in terms of contact, as well. Selling isn't the only thing. It's not just about money; you make contacts, there are exchanges, and new acquaintances. All of those things that ... Yes, it's not just about the money. Money's not everything," says Nadine, a fruit producer.

Furthermore, the "socializing" dimension of agri-tourism is reflected in the production of new forms of sociability. The study highlights a co-production or co-construction of new models of exchange between visitors and those visited, based on forms of mutual or reciprocal cohesion. This new way of making links refers to a collaborative approach, bringing producers and consumers together in the same place in search of proximity and collective participation. This cross-accountability process refers to the "work of the consumer." It's reflected in the tourists' involvement on the farm: picking their own vegetables or fruit, collecting eggs, sponsoring a hen, a goat, bringing the herd in to graze. These actions involve and associate the visitor with production activities on the farm, creating loyalty and awareness of shared work. In the same spirit, we find the wwoofing phenomenon, defined as an organisation system that consists of people working on an organic enterprise or farm in exchange for board and lodging. These new modes of shared sociability are marked by tourists participating in visits: active and attentive listening on the part of the visitors who are engaged and educated about the consumption of farm products, for example. This tourist participation can go as far as involvement in the administration or smooth running of the farm: advice, changes in practices, suggestions for experimenting and innovating from the tourists are sometimes welcome. Through exchanges and meetings, the consumer expresses their wishes or desires, influencing how the farmers choose the activities they offer. The tourist considers this search for learning and knowledge satisfied by the Other (the farmer, the welcomer, the host) a source of enrichment. The engaged and invested visitor searches for extensive information on different aspects of the operation, creating multiple sociabilities in the same place, having many experiences and discoveries in a relatively short period of time. These new forms of sociability identified, which are more invested and more committed, are accompanied by a conservative dimension, attached to the reproduction of a rural heritage.

4.1.3. A Conservative and Nostalgic Countryside

In the collective consciousness, the rural world is still the symbol of a "different life," conservative values, and reserves of meaning. Therefore, this return to the healthy values of the countryman leads us to re-examine the rural ideology as a curator of moralistic values, synonymous with a certain immutability and security of identity. The image of the countryman, after centuries of a negative or even pejorative image, has come to embody the idea that rural life is the source of our traditions and of the tastes and habits that define the nation. As the countryside lost population to the cities, this figure became nostalgic, turning rural life into a symbolic place of origins and authenticity (Burguière & Revel, 1993).

In point of fact, while the countryman was once a sign of misery and poverty, today it is a symbol of authenticity and truth. The image of the farmer as male, as a modern entrepreneur, the countryman close to nature, understated and respectful, has resurfaced. This image is shaped by a set of values: he lives a healthy life, outdoors, is hardworking, economical, a good family father, even devout; he is attached to his land... In short, he is and has exactly what the city dweller believes to not be or have. Moreover, living in the heart of his land, he is close to history, that of his father and his grandfather before him. The past is very present, integrated with the current day; it continuously borrows knowledge and know-how from the past. Lowenthal (2008) states that a profound shift in attitudes has occurred: whereas rural life was once dismissed as disorderly and intellectually stunted, it is now esteemed as embodying natural wisdom and communal virtues absent from major urban centers.

The native countryman has become, to the tourist, the model of the paradisiacal being protected from decadence and evils of all kinds ... so much so that we seek to meet him so that he can explain to us, so that he can tell us that he performs the same actions as his ancestors, so that he can show us his "rustic" productions, made using a common family know-how. The tourist, a dreamer, chooses farm-inns, the most authentic ones possible, tastes the food, the most natural types possible. That way, he can go back, reassured to have seen and heard what he thought was lost. Country areas also have a nourishing image. The rural space has always been a nutritional one, essential for the survival of the community. Like a mother who comforts and reassures, the countryside provides a healing support and identity for tourists. Many farm products come with multiple images of protection, guarantee, childhood, and maternal references, sacralising the "homemade" or the "grandmother's secret." The rural area, which is home to old stones, ancestral knowledge and know-how, traditions and memory, gives the townspeople the belief that there is still something stable, rooted, true, authentic, which can help them regain their lost identity. This way, faced with an uncertain future, the loss of reference points, childhood memories start to resurface, with an abundance of advertising images; a nostalgia for the good old days marked by memory is then established, the reproduction of signs of the past or an eagerness to know, see and understand "what was done before" or "what is still being done"; all this in an attempt to not lose traces of one's own identity. This search for a past, for a memory, responds to a desire to be part of a historical line. Subsequently, everything must tell a story: the village's bell tower, the landscape, the local gastronomy, etc. Everything must prove its roots, a guarantee of authenticity and belief. Our study highlights the conservative role of agri-tourism, through statements and images focused on safeguarding an agricultural and rural heritage. The past is invoked in many statements, like a mirror or an indestructible foundation that justifies the agri-touristic activity. The cultural vocation of the farmer is subsequently confirmed and reinforced in the multiple scenes observed on farms, conveying images of past and nostalgic reflections of life "as it was before." Revealing, for the most part, of "folklorisation" or simplification processes, these statements are based on a marketing rhetoric around the organisation of markets on the farm. Farmers use the term "terroir" to describe their products as unique or specific. "Local products from the terroir," "here, we have a special terroir," "the unique characteristics of our terroir" are commonly mentioned by interviewees anxious to transmit an image that will meet the tourist's expectations. These farmers want tourists to experience their farm visit as a unique, positive, out of the ordinary event, one which corresponds to their idealized vision of the rural and agricultural space. "During their visit, I only show them the positive things, and I wrap it up in fancy paper! It's normal, when you're on holiday, you don't want to see ... you don't want to step in shit, basically. For them, it's idyllic, and that's what they must find," says Philippe, a honey and poultry producer.

Also, agricultural perceptions highlight the educational and citizenry dimension of hosting people on the farm: welcoming people to share, explain, educate, and pass on a legacy. These are the objectives mentioned by many of the people surveyed. This committed dimension of the discourse is reflected, for example, on the farm, by visits from the younger generations, leisure centers and schools, but also elderly people (from retirement homes or clubs for retired people). The farm, as a meeting place, plays an intergenerational role in transmitting messages. The one visited, in their role as teacher for the visitor-learner, plays a role of providing advice, training and relaying information to open the visitor's eyes to a rural and agricultural culture. "When we tour the orchard, I want to explain how we grow the fruit, how we make apple juice using the know-how passed down by my grandparents," says Alice, a fruit producer. "We don't just sell the apple, we sell the way it's produced, how it's picked, how it was passed on to us, how we work, us as farmers, we sell Ourselves," she adds.

The welcome on the farm is therefore set up with the recurring idea of protecting the past, safeguarding knowledge and know-how, and transmitting them. This vision of agriculture as a heritage, shared and valued for and by tourism, is defended by farmers who are convinced of their role in this "resurrection of memory." Their function in saving and preserving traditions is highlighted in their statements, which nourish the urban tourist imaginary. "We're also there to show people how the old generations used to work, how they respected nature and grew quality products. I make my cheese the way my grandmother always taught me," says Paul, a cheese and poultry producer.

These crossed imaginaries, tourist and agricultural, feed off each other, strengthening and nourishing themselves at a common meeting place, infusing valuation and staging practices. "Purifying," "socializing," or "nostalgic," the countryside produces idealized and fantasized representations, both for the visitor and for the visited. However, it also seems to be a place of agitated representations, where tensions and imaginative contradictions emanate.

4.2. Discussion: Tensions and Controversies Around a Crossed Tourist Imaginary

4.2.1. Images and Imaginaries: Correspondences and Dissonances

At a time when the image is omnipresent in our contemporary societies, material images (brochures, photos, posts, videos, films, but also handmade crafts or food souvenirs sold on the farm) and immaterial ones (legends, tales, stories, recipes, anecdotes, memoirs, etc.), play an increasingly crucial role in the tourist experience in rural areas. What's more, we can sense some interference between the images created by the actors and the tourist imaginary (Graburn, 1976). While the agricultural populations try to manufacture and market elements of their own culture, generating tourist imaginaries, they are at the same time obliged to know about and meet the needs and expectations of tourists visiting their farms. This is how images and imaginaries hold dynamic relations, constantly co-constructed and reworked. There are interferences that fluctuate between agreements and disagreements, dissonances and correspondences. Many of the farmers surveyed are wavering between producing images created from scratch "for the occasion" to meet an external tourism demand (legends and stories about cultural know-how or animal breeding) and, on the other hand, the dissemination of true images that reflect a daily reality (animals in pens or the industrialization of food production). These inadequacies or dissonances identified reflect a conflict between the "real" and its representation, generating a feeling of rejection or discomfort on the part of both tourists and agricultural actors. Conversely, the correspondence between the images produced and tourist imaginaries reinforces the proximity between real and imaginary, nourishing the satisfaction and attractiveness of places. Thus, the concept of crossed imaginaries refers neither to a simple coexistence of representations nor to a homogeneous or consensual fusion of imaginaries, but rather to a relational, dynamic and asymmetrical process; It is based on a process of situated co-construction, produced by repeated interaction between tourism and agricultural actors, during which representations of rural life are mobilized, adjusted, negotiated and sometimes contradicted.

Our observations on the farm markets reveal deviations, reinterpretations, or falsifications of the slices of heritage on offer, such as agricultural products for sale or recipes. These can be represented as original and inherited, while they are actually sometimes artificial, recent constructions with no historical trace at all (for example, an aperitif described as "homemade," invented and produced for "the occasion," or a Roquefort pâté, also concocted during the summer). These products, appointed as "folklorism" or stereotypes, may seem like a form of escape therapy, a dimension manufactured for the occasion in order to meet a social imaginary, here, a tourist one. Features of a past life are selected, reintroduced into our present life, adopting a whole range of symbolic apparatus for a tourist hungry for stereotyped images. "They're invention mechanisms of 'popular cultural heritages' that act in the construction of national identities," described by Cuisenier (1995). Traces or slices of heritage are staged, put on a show, dramatized; some aspects are enhanced, magnified, others hidden, concealed, thus forming a new cultural simulacrum that distorts the original unity.

4.2.2. An Organized and Advertised Staging

Our survey shows the importance of organisation and preparation in setting up the system for receiving visitors on the farm. During the farm markets, the specific layout of the places the tourists will visit is thought out and implemented "for the occasion," involving work and collective action. "We fix up the place nicely. It's 'Versailles' between the hen house and the stream," explains Denise, duck fat producer. As well as setting up food stands or stalls, the staging also includes organizing additional festive, cultural, and entertainment elements: hot air balloons, animals on display, games, trails, bands, musical instruments, conferences, debates, etc. It's accompanied by an organized and structured communication effort (wearing an apron or a hat with "Welcome to the farm" on it). Putting yourself in the spotlight so as to be identified and reported in the press becomes a strategy for some farmers, mindful about their image. This staging usually also involves tidying up and ordering. Showing everything to be clean and beautiful in accordance with biodynamics, for example, no plastic or material that goes against the ethics of the place and practices, making and being clean, seducing, decorating, and cleaning are a priority for many farmers. The desire to hide certain aspects of agriculture and livestock farming in favor of the more manicured, smoother sides of the farm emerges in a few comments: "Washing," "changing clothes," and hiding certain aspects of agriculture to welcome tourists can be similar to forms of artificialisation or denaturation of the image portrayed on the farm. Two spheres can therefore be highlighted: agriculture on the one hand and tourism on the other, drawing two poles or two roles "to play" that do not intermingle. The care taken in the "presentation" of the farm and its environment therefore seems disconnected from the production process, according to some of the farmers interviewed. "I try to be presentable, not too grubby so I don't scare people away, but if I happen to find a nice shirt, jacket, or hat, I make sure to put it on" (Patrick, milk and meat producer).

4.2.3. Stay True to What You Are

However, the interviews mostly show a desire not to make the relationship with visitors seem artificial or unnatural: a willingness to remain "true," to not corrupt an image or identity. The shunning of trickery and desire for sincerity in the way of being and showing themselves are discussed: no or little change in behavior towards visitors seems to be the battle cry of a number of farmers, attached to their image of "agricultural modernity": "Showing oneself the way one is," "being honest about the way you are and the way you work," "not lying" about the evolution of the profession and production techniques, are just some of the discourses evoked on the myth of a past, obsolete or illusory tradition. These comments, as opposed to a process of folklorisation or tourist simplification, reveal the desire to convey the image of an agriculture in motion, detached from any backward-looking and museumified connotations. Here, any staging for visitors is reduced and unexaggerated. It is unmanufactured, spontaneous, and unpretentious, leaning heavily on daily life, as indicated by Arnaud, duck breeder: "We welcome people as we are. Sometimes we're clean, sometimes we're dirty. They have to take us the way we are." Nadine, a fruit producer, also talks about this attitude: "Well, they're well aware that they're not going to find us in a suit and tie with our nails painted and everything. If I'm in makeup, so be it; if I'm not, that's just the way it is. If I'm braiding garlic, or there's dust on my shoes, that's the way it is; they have to take me as they find me. And I think that's what they need, the authentic."

4.2.4. Tourist Imaginaries Between Production and Consumption

As we've seen, farmers who offer a tourist activity adhere closely to the tourist imaginary, which justifies, shapes, and orients said action. The agricultural populations obey an exterior urban imaginary, while simultaneously manufacturing another, generated by their own perceptions of the rural and agricultural world. The development of the rural tourist imaginary seems to be the product of a dialectical process, a to-ing and fro-ing and co-construction between two interacting worlds. While being largely mobilized in the agri-touristic offer, rural imaginaries are also produced, recomposed, and appropriated by the tourists themselves, who criticize, validate, or divert them. In this way, sometimes producers and consumers of imaginaries, farmers and tourists, co-produce a rural tourist imaginary. Farmers do not deny the modernity of their profession; rather, they engage in strategic storytelling that reconciles current agricultural practices with tourist expectations. This process illustrates a form of hybridization: the agriculture presented is neither strictly traditional nor entirely technicized, but rather reconfigured through interaction with tourists. The 'crossed imaginary' thus manifests itself as a space for symbolic negotiation, where the reality of agriculture is partially reinterpreted in order to maintain the tourist relationship without completely betraying the professional identity of the farmers. Furthermore, this mutual (re)constitution process is involved in shaping the identity of agricultural populations. The rural tourist imaginaries brought about by this inter-combination of images produced and consumed can therefore contribute to the creation of agricultural communities that will identify with this imaginary until they eventually claim it as an intrinsic component of their own identity (Naef, 2012). Leaving an often indelible mark on the places of reception, the tourist imaginary contributes to the construction of new rural and agricultural identities. This is the case, for example, with agricultural operations that have become, through tourism, the "historic" cradles of ancestral culinary know-how, propelling farmers into a strategic model of well-identified production practices. "The tourist imaginary therefore plays the role of a self-fulfilling prophecy, contributing to bringing about the imagined territoriality" (Staszak, 2000).

5. Conclusion

An analysis of tourist perceptions of rural areas highlights the central role of rurality as a space for identity compensation, both for tourists and for the farming communities that welcome them. Through a study of farm markets in Occitanie, this article shows that rural imagery is not solely the result of idealized urban projections, but is co-produced, negotiated, and sometimes reappropriated by farmers themselves through their hospitality practices, discourse, and staging. Empirical results identify three major structuring figures of the rural tourist imagination: a purifying and therapeutic countryside, a socializing and unifying countryside, and a conservative and nostalgic countryside. These figures, widely documented in the literature, are reactivated and reformulated here by agricultural actors, who use them to give meaning to their diversification activities. The values of naturalness, health, food quality, and environmental regeneration appear to be major drivers of agritourism engagement, reinforcing the image of a restorative rural space, in explicit opposition to the city, which is perceived as polluted, stressful, and dehumanized. The study also highlights the fundamental role of agritourism as a means of mutual socialization. Farm markets are meeting places where social bonds based on conviviality, exchange, and participation are developed. For farmers, welcoming tourists often goes beyond the purely economic function: it fulfils a need for recognition, dialogue, and a break from professional isolation. For visitors, it allows them to temporarily immerse themselves in an idealized form of sociability, perceived as more authentic, more human, and more collective. These interactions produce hybrid forms of sociability, situated at the crossroads of consumption, learning, and engagement.

Furthermore, the results highlight the major role played by agritourism in constructing and transmitting a nostalgic image of heritage. Many farmers claim to have an educational and memorial function, consisting of transmitting knowledge, skills, and stories inherited from the past. However, this heritage preservation is accompanied by recurring tensions: between claimed authenticity and strategic staging, between fidelity to contemporary agricultural reality and idealized tourist expectations. The practices observed thus oscillate between deliberate folklorisation, symbolic simplification, and an assertive desire to 'stay true', revealing the contradictions inherent in any rural tourism venture. Beyond these results, this research contributes significantly to the renewal of rural tourism analysis by shifting the focus to farmers as active producers of tourist imagery, rather than simply as supports or objects of representations constructed from outside. By linking research on tourist imaginaries with that on agritourism and agricultural diversification, the article shows that rural tourism cannot be understood solely as an economic resource or a lever for territorial development. It also constitutes a space for the production of meaning, in which issues of social recognition, cultural transmission, and the recomposition of professional agricultural identities are at stake. The analysis thus highlights the dialectical and performative nature of rural tourist imaginaries. As producers, mediators, and consumers of imaginaries, farmers and tourists co-produce representations that have a lasting influence on agricultural practices, forms of hospitality, and the trajectories of farms. This process contributes to the construction of new rural and agricultural identities, sometimes to the point of producing self-fulfilling prophecy effects, where the tourist imaginary helps to shape the reality it claims to represent.

This research does, however, have certain limitations. The qualitative nature of the survey and the small sample size mean that the results cannot be generalized to the agricultural world as a whole. Furthermore, the analysis focused on farms involved in agritourism, leaving out farmers who refuse or reject these practices, whose perceptions would also be worth exploring.

In this regard, several avenues of research can be considered. Comparative studies, conducted in other regions or national contexts, would make it possible to analyze the diversity of rural imaginaries. Longitudinal approaches would offer valuable insight into the evolution of agricultural representations in the face of environmental, food, and tourism crises. Finally, a deeper understanding of tourist perceptions themselves, mirroring agricultural discourse, would contribute to a better understanding of the logic of co-construction, tension, and negotiation at work in the contemporary construction of rural tourism imaginaries.

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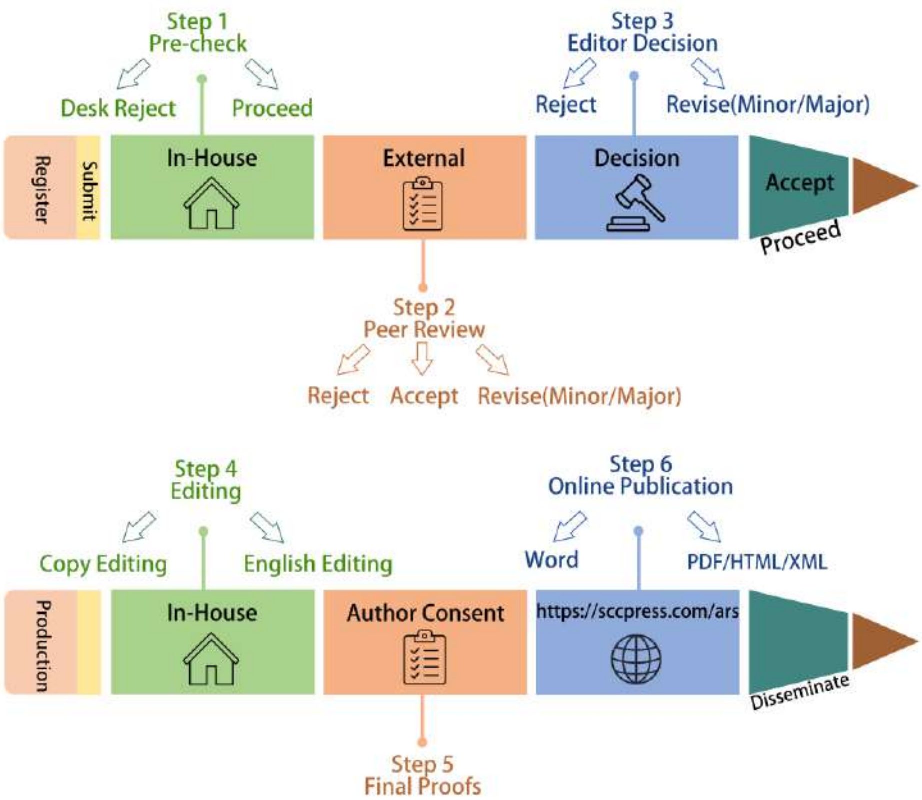

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