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Modeling Factors Influencing the Adoption of Low-Emission Practices in Rice Farming in the Vietnamese Mekong Delta

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ABSTRACT

The Mekong Delta is a vital rice-producing region in Vietnam, but conventional rice farming continues to generate considerable greenhouse gas emissions, placing increasing pressure on the sector to transition toward more sustainable production models. This study investigates the socio-economic and perception-based factors shaping farmers' adoption of low-emission rice farming practices. Using survey data collected from 748 farmers across six provinces, a generalized ordered logit model is employed to identify key determinants and adoption patterns. Results show that farmers with larger landholdings, higher education levels, and stronger perceptions of economic and environmental benefits are more likely to adopt low-emission practices. In contrast, household size, land fragmentation, and limited access to resources constrain participation. Financial uncertainties, market instability, higher input requirements, and concerns over pest and disease risks remain major barriers. While farmers adopting multiple low-emission practices often achieve greater profitability and improved resource efficiency, perceived risks related to yield variability and cost fluctuations continue to discourage widespread uptake. Reputational gains, environmental stewardship motivations, and policy-driven incentives also play an important role in supporting adoption. To accelerate the transition to sustainable rice production, the study recommends enhanced financial

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support mechanisms, targeted training and capacity-building programs, improved market linkages, and robust institutional frameworks to mitigate risks and strengthen farmer confidence.

Keywords: Adoption; Climate-Smart Agriculture; Low-Emission Rice; Ordered Logit; Sustainable Agriculture

JEL Codes: Q54; O13; Q16

1. Introduction

1.1. Rationale

The Mekong Delta (VMD) is Vietnam's primary rice-producing region, contributing over 50% of the nation's total rice output and more than 90% of its rice exports^[1]. This production plays a crucial role in ensuring food security at both national and global levels. However, the region faces significant challenges due to its vulnerability to climate change, including sea-level rise, saltwater intrusion, and extreme weather events, which threaten agricultural sustainability^[2]. Despite the Mekong Delta's strategic importance, rice farming systems remain heavily dependent on conventional continuous flooding methods, making them one of the country's largest sources of agricultural greenhouse gas (GHG) emissions. This situation underscores a critical need to identify context-appropriate pathways for transitioning toward climate-smart and low-emission production systems.

Although numerous climate mitigation measures have been developed globally, there is a lack of empirical understanding of the specific factors that enable or constrain their adoption in Vietnam's rice sector. Traditional rice farming in the Mekong Delta is a major contributor to GHG emissions, particularly CH₄ from anaerobic decomposition in flooded fields^[3]. The agricultural sector accounts for approximately 13% of total global emissions, with rice cultivation playing a significant role^[4]. In addition, excessive use of nitrogen-based fertilizers and pesticides not only contributes to N₂O emissions but also leads to soil degradation, biodiversity loss, and water pollution, exacerbating environmental challenges^[5]. To address this, the Vietnamese government has promoted several low-emission practices, including alternate wetting and drying (AWD), integrated pest management (IPM), and organic fertilization to re-

duce methane and nitrous oxide (N₂O) emissions while maintaining productivity^[6-9]. These practices represent practical and scalable options for Vietnam's context, but their diffusion remains uneven and poorly understood from a behavioral and institutional perspective. For instance, by 2015, only 840 hectares of rice fields applied VietGAP methods, representing just 1.3% of farmer organizations engaged in certified rice production^[10].

A major step in this transition is the ambitious 1-million-hectare low-emission rice project, which aims to transform rice farming in the Mekong Delta by increasing the adoption of climate-smart agricultural techniques. This initiative focuses on optimizing water use, reducing chemical inputs, and improving soil health to cut emissions while ensuring food security and farmers' economic resilience^[11]. However, the gap between policy ambition and on-ground adoption highlights the need for research that clarifies the determinants of farmer behavior and institutional barriers affecting technology uptake.

The adoption of low-emission practices in rice farming in the Mekong Delta faces several challenges, hindering the widespread transition to sustainable agriculture. Financial constraints are a significant barrier, as implementing techniques like AWD or using organic fertilizers often requires upfront investment in new infrastructure and training^[12]. Additionally, a lack of technical knowledge and extension services further impedes adoption, with many farmers unaware of the long-term benefits of these practices or lacking proper guidance on their implementation^[13]. Resistance to changing traditional farming methods persists, as farmers prioritize short-term yields and perceive new techniques as risky or complex. Market incentives for low-emission rice are also weak, with limited access to premium markets and certification programs that could encourage adoption. Moreover, inconsistent policies and fragmented support programs create uncertainty, preventing coordinated ef-

forts to scale up sustainable rice production^[6]. Addressing these challenges requires a combination of financial support, farmer education, strengthened market incentives, and well-structured policies to promote the long-term viability of low-emission rice farming in the region.

This study addresses these theoretical and practical gaps by examining the factors influencing farmers' adoption of three key low-emission practices - AWD, IPM, and organic fertilization - in the Mekong Delta. By identifying socio-economic drivers, and enabling conditions, the findings will provide evidence-based insights for policymakers and stakeholders to design targeted interventions and incentive structures that promote the transition toward a sustainable and competitive rice sector. The next section outlines the conceptual framework and analytical approach, followed by a discussion of data collection, results, and policy implications.

1.2. Literature Review

The adoption of low-emission agricultural practices is influenced by multiple interacting factors, with perceived ease of use and expected economic benefits emerging as two of the most significant determinants. Davis^[14] introduced the Technology Acceptance Model (TAM), which suggests that a technology's adoption is primarily driven by its perceived usefulness and ease of implementation. In the context of emission-reducing agricultural practices, farmers' attitudes toward risk significantly impact their willingness to transition to sustainable methods. This study builds on TAM as a conceptual foundation, integrating it with behavioral and socio-economic perspectives to better explain technology adoption decisions in smallholder rice farming.

Risk perception plays a critical role in shaping adoption behaviors. Barreiro-Hurlé et al.^[15] found that risk-averse farmers are less likely to participate in agri-environmental programs, indicating that uncertainty about production outcomes, policy instability, or financial risks can deter farmers from adopting low-emission techniques. In the context of Vietnam, where rice farming remains a key livelihood, perceived risks may significantly outweigh perceived benefits, leading to low uptake of climate-smart practices despite government support.

Environmental awareness and perceptions of farming practices also play a crucial role in adoption decisions. Studies have shown that farmers who recognize environmental degradation and climate change impacts are more likely to implement sustainable practices. Adesina and Zinnah^[16] found that technology perceptions significantly influenced the adoption of modern rice varieties in Sierra Leone, while Negatu and Parikh^[17] observed that Ethiopian farmers' perceptions of soil erosion severity affected their decisions to adopt soil conservation measures. Similarly, Wang et al.^[18] reported that Chinese farmers with greater environmental awareness were more inclined to adopt low-emission agricultural practices, such as organic fertilization, AWD, and IPM. These findings highlight the importance of farmers' attitudinal and cognitive factors in shaping sustainable farming transitions.

Extrinsic factors, including farm biophysical characteristics, government regulations, and financial constraints, are also critical to the adoption process. Knowler and Bradshaw^[19] conducted a meta-analysis demonstrating that farm size, land tenure, and access to credit consistently influence the adoption of conservation practices. Lee^[20] highlighted the importance of government policies, regulatory frameworks, and institutional support in promoting sustainable agricultural practices. Meijer et al.^[21] emphasized that access to information, extension services, and training programs significantly influence technology uptake among farmers. Additionally, Wang et al.^[18] noted that financial incentives, subsidies, and technical assistance play key roles in encouraging farmers to transition toward low-emission agricultural practices.

Despite these insights, previous studies have tended to focus primarily on general economic and environmental factors while underexploring farmers' perceptions of risks and their interaction with socio-demographic characteristics. Furthermore, research findings have been inconsistent across different geographic regions and types of conservation practices. In the Vietnamese Mekong Delta, studies on low-emission practice adoption have primarily focused on integrated rice-fish farming systems and mono-rice cultivation. Research by Berg et al.^[22], Bosma et al.^[23] has explored

these limited contexts, making it difficult to generalize policy recommendations for broader adoption across the region.

This study addresses these gaps by extending the traditional TAM framework to incorporate both socio-demographic and risk perception variables into the analysis of low-emission practice adoption. Specifically, the research examines household characteristics such as family size, age, gender, and education level (primary, secondary, high school), as well as farm structure variables including plot number and total farm size, which have been shown to influence technology adoption capacity. By integrating these dimensions, the proposed theoretical framework goes beyond traditional economic or attitudinal models to provide a more comprehensive understanding of farmers' adoption behavior. This approach recognizes that adoption decisions are shaped not only by perceived utility but also by individual socio-demographic attributes and subjective risk-benefit assessments, which are particularly salient in smallholder farming contexts.

2. Materials and Methods

2.1. Data Collection

This study utilized structured interviews with 748 rice farmers selected randomly from different provinces in the Mekong Delta. To ensure balanced representation between conventional and eco-friendly farming systems, a stratified random sampling strategy was employed. Farmers were first categorized according to their primary farming practices based on secondary data sources, including local agricultural extension records, commune-level land use databases, and lists of households participating in low-emission pilot projects. The stratification criteria were developed in close coordination with local agricultural extension officers, who provided guidance on identifying and classifying farmers involved in different production models. This approach was particularly relevant because the national low-emission rice project was in its pilot phase, and several household-level demonstration models were be-

ing implemented across the region. As such, categorization of farming practices was grounded in officially documented project data and verified with extension workers.

This research protocol was reviewed and approved by the Institutional Review Board of Can Tho University, ensuring full compliance with national and institutional ethical standards. The procedures regarding informed consent, confidentiality protection, and voluntary participation were clearly explained to each farmer prior to the interview.

The survey gathered information on farming practices, input usage, and socio-economic conditions. Interviews, lasting around 40 minutes, were conducted at farmers' homes or other convenient locations. To enhance data accuracy, interviewers requested permission to verify responses against household bookkeeping records detailing agricultural input purchases.

The geographic distribution of the sample reflected the agro-ecological zoning of the Mekong Delta, with 53 farmers in An Giang and 70 in Dong Thap (upper region), 350 in Hau Giang and 51 in Can Tho (middle/alluvial region), and 110 in Soc Trang and 114 in Kien Giang (coastal region). The survey collected detailed socio-economic data, including education levels, income, and access to agricultural resources, providing a comprehensive insight into the factors influencing farming practices in the Mekong Delta.

The study surveyed 748 farmers, with 384 (51.34%) practicing conventional farming and 364 (48.66%) adopting at least one low-emission practices. These were classified into single (16.98%), dual (7.62%), and multiple (24.06%) practice groups. Among single-practice farmers, the most common methods were AWD (6.02%), Rice-Shrimp (4.41%), VietGAP (2.94%), Organic (2.27%), and SRP (1.34%). Dual-practice adoption was led by SRP-AWD (3.61%). Multiple-practice combinations were most prevalent in SRP-AWD-IPM (14.30%), followed by RS-SRP-ORG (1.74%), SRP-AWD-IPM-ORG (3.61%), RS-SRP-AWD-IPM-ORG (2.14%), and SRP-AWD-IPM-GAP (2.27%). The sample structure for each group of low-emission practice is detailed in **Table 1** below.

Table 1. Sample distribution by farming practices.

| Farming Practice | Frequency | Percentage | Cumulative |
|------------------------------|------------|--------------|---------------|
| 0. Conventional | 384 | 51.34 | 51.34 |
| 1. Single practice | 127 | 16.98 | 68.32 |
| 1.1 Rice shrimp | 33 | 4.41 | 55.75 |
| 1.2 SRP | 10 | 1.34 | 57.09 |
| 1.3 AWD | 45 | 6.02 | 63.10 |
| 1.4 Organic | 17 | 2.27 | 65.37 |
| 1.5 GAP | 22 | 2.94 | 68.32 |
| 2. Dual practices | 57 | 7.62 | 75.94 |
| 2.1 SRP-AWD | 27 | 3.61 | 71.93 |
| 2.2 RS - ORG | 19 | 2.54 | 74.47 |
| 2.3 AWD-IPM | 11 | 1.47 | 75.94 |
| 3. Multiple practices | 180 | 24.06 | 100.00 |
| 3.1 RS-SRP-ORG | 13 | 1.74 | 77.67 |
| 3.2 SRP-AWD-IPM | 107 | 14.30 | 91.98 |
| 3.3 SRP-AWD-IPM-ORG | 27 | 3.61 | 95.59 |
| 3.4 RS-SRP-AWD-IPM-ORG | 16 | 2.14 | 97.73 |
| 3.5 SRP-AWD-IPM-GAP | 17 | 2.27 | 100.00 |

Note: RS: Rice-Shrimp, SRP: Sustainable Rice Platform, AWD: Alternate Wetting and Drying, IPM: Integrated Pest Management, ORG: Organic, GAP: Good Agricultural Practices.

2.2. Data Analysis

An ordered logit model was employed to analyze the factors influencing the adoption of low-emission practices. Farmers were categorized into four groups: (0) conventional rice farming, (1) adoption of a single low-emission practice, (2) adoption of two practices, and (3) adoption of more than two practices. This approach enabled us to assess the probability of farmers transitioning from conventional to more sustainable practices based on their socio-economic and farm characteristics. The model estimates the impact of variables such as education, farm size, and awareness of low-emission rice farming—including its environmental benefits and potential for creating safe products for consumers—on the likelihood of adopting multiple low-emission practices.

Drawing on the utility maximization model, this study considers utility as encompassing both tangible and intangible benefits derived from adopting new practices. In the context of eco-friendly rice production, tangible benefits primarily refer to financial gains, whereas intangible benefits reflect the environmental values that adopters seek to preserve. Accordingly, the utility function (U_{ij}) for the i th farmer in deciding whether to adopt a new practice or alternative can be expressed as follows:

$$U_{ij} = \beta_j X_i + e_{ij} \tag{1}$$

Let X_i denote a set of factors influencing adoption,

with β_j representing the corresponding coefficients to be estimated. The subscript j refers to the chosen alternative, and i identifies individual farmers ($i=1,2,3,\dots,N$). The model includes a random error term e_{ij} . Thus, the utility derived from adopting a new technology instead of the existing one can be expressed as:

$$U_{ij} > U_{i(j-1)} \tag{2}$$

$$\beta_j X_i + e_{ij} > \beta_{j-1} X_i + e_{i(j-1)}$$

$$e_{ij} - e_{i(j-1)} > \beta_{j-1} X_i - \beta_j X_i$$

Let Y_k denote the adoption decision with $k = 0,1,2,3$.

Farmers have access to various low-emission practices, as summarized in **Table 1**. The baseline alternative is conventional rice production, where farmers who do not adopt any low-emission practices are categorized as non-adopters and assigned a value of zero ($Y_0 = 0$). Adopters are classified based on the number of practices they implement: those adopting a single practice are assigned 1 ($Y_1 = 1$), those using two practices are coded as 2 ($Y_2 = 2$), and those employing multiple practices are labeled 3 ($Y_3 = 3$).

Under the assumption of utility maximization, we define Q_h ($h = 1,2,3$ and $Q_1 < Q_2 < Q_3$) as unobserved thresholds of utility. These thresholds determine the transition from conventional rice farming ($Y_0 = 0$) to single practice ($Y_1 = 1$) or from single practice ($Y_1 = 1$) to

dual practices ($Y_2 = 2$) or from dual practices ($Y_2 = 2$) to multiple practices ($Y_3 = 3$).

Following Equation (2), we get Equation (3) as below

$$U_{i0} \leq Q_1 < U_{i1} \leq Q_2 < U_{i2} \leq Q_3 \quad (3)$$

or

$$\begin{aligned} \beta_0 X_i + e_{i0} &\leq Q_1 \\ Q_1 &< \beta_1 X_i + e_{i1} \leq Q_2 \\ Q_2 &< \beta_2 X_i + e_{i2} \leq Q_3 \\ Q_3 &< \beta_2 X_i + e_{i2} \end{aligned}$$

It is evident that Equation (3) can be represented using an ordered logistic regression model. The ordered logistic function for Equation (3) can be reformulated in terms of probability as follows:

$$\begin{aligned} P(Y_0 = 0) &= Pr(\beta_0 X_i + e_{i0} \leq Q_1) \quad (4) \\ P(Y_1 = 1) &= Pr(Q_1 < \beta_1 X_i + e_{i1} \leq Q_2) \\ P(Y_2 = 2) &= Pr(Q_2 < \beta_2 X_i + e_{i2} \leq Q_3) \\ P(Y_2 = 3) &= Pr(Q_3 < \beta_2 X_i + e_{i2}) \end{aligned}$$

In general, the probabilities of a farmer choosing different adoption levels, as derived from the ordered

logit model, are expressed as follows:

$$\begin{aligned} P(Y_{ik} = k) &= Pr(Q_{h-1} < \beta_k X_{ik} + e \leq Q_h) \\ &= \frac{1}{1 + \exp(-Q_h + \beta_k X_{ik})} \\ &= \frac{1}{1 + \exp(-Q_{h-1} + \beta_k X_{ik})} \end{aligned} \quad (5)$$

Here, ($k = 0, 1, 2, 3$) represents the adoption choices, while β_k denotes the parameter vector to be estimated for each alternative k .

3. Results

3.1. Socio-Economic Characteristics of Correspondents

Table 2 presents the socio-economic characteristics of farmers across different levels of adoption of low-emission rice farming practices. These characteristics provide insights into how demographic and farm-specific factors may influence the decision to adopt sustainable agricultural practices. Notably, variations in family size, education, farm size, and land distribution among the groups suggest potential differences in resource availability, experience, and capacity to implement new techniques.

Table 2. Socio-economic characteristics of correspondents.

| Variables | Conventional | Single Practice | Dual Practices | Multiple Practices |
|--------------------|---------------------|--------------------|--------------------|---------------------|
| Family size | 4.43 ^b | 3.98 ^a | 4.10 ^{ab} | 4.10 ^{ab} |
| Age of the head | 52.53 ^{ab} | 50.31 ^a | 54.21 ^b | 52.25 ^{ab} |
| Gender of the head | 0.88 ^a | 0.86 ^a | 0.92 ^a | 0.90 ^a |
| Education | | | | |
| —Primary | 0.30 ^a | 0.27 ^a | 0.28 ^a | 0.20 ^a |
| —Secondary | 0.43 ^a | 0.45 ^a | 0.52 ^a | 0.44 ^a |
| —High school | 0.20 ^c | 0.09 ^b | 0.00 ^a | 0.12 ^{bc} |
| —College | 0.01 ^a | 0.03 ^a | 0.00 ^a | 0.03 ^a |
| Number of plot | 2.07 ^a | 1.87 ^a | 1.82 ^a | 2.03 ^a |
| Farm size | 1.88 ^a | 2.45 ^a | 2.67 ^a | 4.16 ^b |

Note: The same superscript letters ^{a, b, c} within the same row indicate no significant difference at the 5% level based on Duncan's test. Source: Author's estimates based on survey data from 2023, n = 748. Data available upon request.

Results indicate that conventional farmers tend to have slightly larger households (4.43 members) than those adopting single (3.98), dual (4.10), or multiple practices (4.10). However, Duncan's test shows no significant difference between dual and multiple-practice adopters. The age of household heads varies, with

those adopting dual practices being the oldest on average (54.21 years), significantly differing from single-practice adopters (50.31 years). Gender distribution remains consistent across all groups, with over 85% of farm heads being male.

Education levels exhibit some variation. Farmers

with secondary education are the most common across all groups, while high school-educated individuals are significantly more prevalent among conventional farmers (20%) compared to those adopting dual practices (0%). Similarly, high school education levels in the multiple-practice group (12%) differ significantly from those in the dual-practice group (0%).

Farm characteristics show notable differences, particularly in landholding size. Farmers adopting multiple practices have the largest average farm size (4.16 ha), significantly larger than conventional farmers (1.88 ha), while single and dual-practice adopters hold intermediate values (2.45 ha and 2.67 ha, respectively). Although the number of plots per farm shows no significant variation, those using multiple practices tend to manage slightly more fragmented land.

Overall, these findings suggest that larger farm sizes and higher education levels may facilitate the adoption of low-emission practices, whereas household size and gender have a less pronounced impact. These patterns underscore the importance of targeted policies that enhance accessibility to sustainable practices, particularly for smaller-scale and less-educated farmers.

3.2. Perception of Farmers about Low-Emission Rice Farming

This section synthesizes rice farmers' perceptions regarding low-emission cultivation practices across three key dimensions: perceived ease of use, perceived benefits, and perceived risks. These dimensions reflect both cognitive and experiential evaluations of low-emission rice farming, thereby offering a comprehensive understanding of farmers' readiness and motivation to adopt such practices. These detailed results are presented in **Appendix A**, serving as a foundation for the subsequent analysis and discussion.

3.2.1. Perceived Ease of Use of Low-Emission Rice Farming Practices

Assessing farmers' perceptions of low-emission rice farming is essential for evaluating its feasibility and adoption. The following section analyzes key factors, including implementation, resource accessibility, technical support, and costs, to understand the practicality and

transition to these practices.

Figure 1 illustrates that farmers generally have a positive perception of low-emission rice farming techniques, with mean scores ranging from 4.12 to 4.33. They find these methods easy to understand (mean = 4.23), well-aligned with current farming routines (mean = 4.22), and requiring minimal additional training (mean = 4.21). Farmers also consider the transition from conventional to low-emission farming to be straightforward (mean = 4.30) and report relatively high accessibility to necessary resources such as seeds, organic fertilizers, and equipment (mean = 4.31). Moreover, they believe that adopting these techniques does not require significant changes in their farming methods (mean = 4.22) or excessive labor (mean = 4.12). Technical support availability (mean = 4.22) and the cost of adoption (mean = 4.31) are also viewed favorably. Notably, farmers express a strong sense of confidence in independently using low-emission rice farming techniques (mean = 4.33), the highest-rated aspect. Overall, these findings suggest that low-emission rice farming is perceived as practical, accessible, and feasible for adoption. One of the most interesting findings is that conventional rice farmers perceive low-emission practices as less easy to use compared to those who have adopted at least one such practice. Notably, farmers who have adopted multiple low-emission practices report the highest levels of perceived ease of use among all groups. This aligns with real-world observations, as these farmers have typically attended more training sessions and gained a deeper understanding of low-emission practices.

3.2.2. Perceived Benefits of Low-Emission Rice Farming Practices

Beyond the practical aspects of low-emission rice farming, its broader economic and social implications also influence adoption. Farmers' perceptions of cost savings, income opportunities, and external support play a significant role in determining their willingness to adopt and recommend these practices. Understanding these factors provides insights into the incentives and potential barriers that shape decision-making in sustainable agriculture.

The findings from **Figure 2** indicate that farmers moderately agree on the economic and reputational ben-

efits of low-emission rice farming. They recognize its potential to reduce production costs and generate income through carbon credits (both with a mean score of 3.51). However, these financial benefits do not appear to be the strongest motivators for adoption. Interestingly, conventional rice farmers acknowledge that low-emission practices can reduce production costs and enhance their farm’s reputation—the latter being rated highest among all groups. This suggests that while these farmers are aware of the benefits, they have not yet adopted low-emission practices—possibly due to factors such as farm socio-demographic characteristics, perceived risks as-

sociated with adoption, or their tendency to be late adopters of new technologies.

Similarly, the perceived improvement in soil fertility (mean = 3.49) is recognized but not considered a dominant driver of change. Notably, conventional farmers also rate this benefit highest, further reinforcing that awareness does not necessarily translate into action. On the other hand, farmers perceive switching to low-emission farming as beneficial for their farm’s reputation (mean = 3.87) and feel strongly encouraged by government subsidies (mean = 3.82), highlighting the importance of external incentives in promoting adoption.

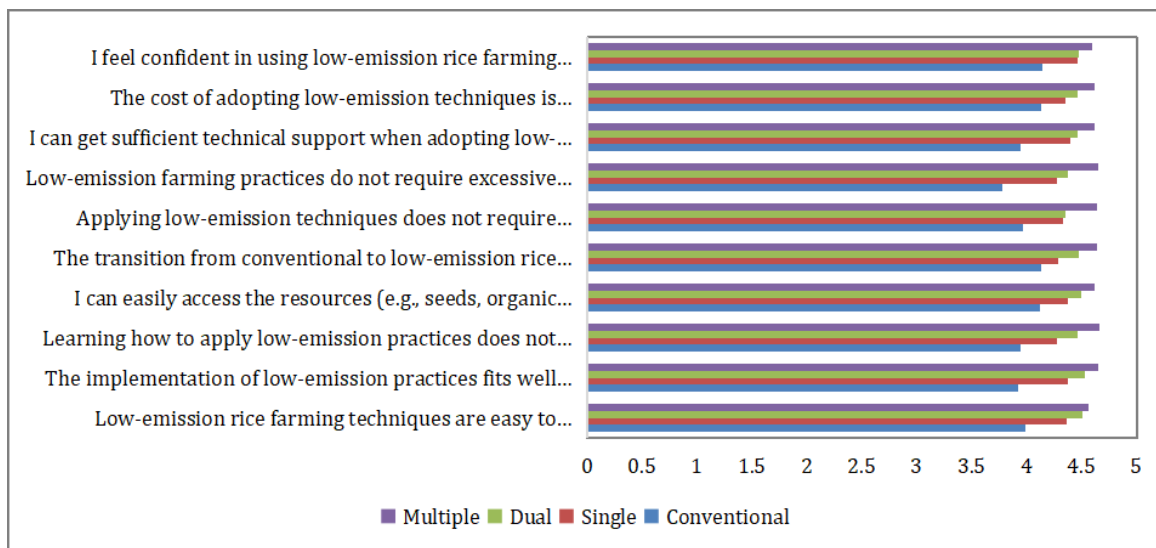


Figure 1. Perceived ease of use of low-emission practices by types.

Source: Author’s estimates based on survey data from 2023, n = 748. Data available upon request.

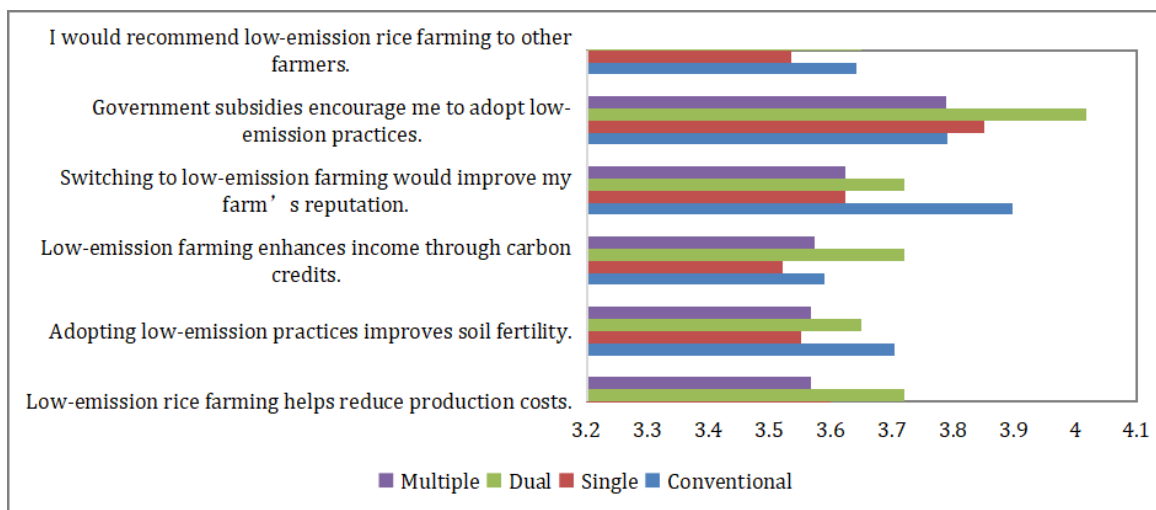


Figure 2. Perceived benefits of low-emission practices by types.

Source: Author’s estimates based on survey data from 2023, n = 748. Data available upon request.

3.2.3. Perceived Risks of Low-Emission Rice Farming Practices

While farmers recognize the benefits of low-emission rice farming, they also express concerns about potential risks and challenges. Economic uncertainties, technical limitations, and environmental factors influence their perceptions of adoption feasibility. The following results highlight key barriers that may hinder widespread implementation, emphasizing the need for targeted interventions to address these concerns.

Figure 3 shows that farmers identify several risks associated with adopting low-emission rice farming, with concerns spanning economic, technical, and policy-related factors. The greatest hesitation stems from fears that adopting these practices may reduce yields (mean = 3.88) and increase uncertainty in market demand (mean = 3.80), both of which directly impact profitability. Financial concerns are also prominent, particularly the higher costs associated with implementation (mean = 3.78). Additionally, farmers perceive potential risks

related to pest and disease outbreaks (mean = 3.68), which could threaten productivity. The transition to low-emission practices is also seen as demanding, with concerns about increased labor requirements (mean = 3.72) and the lack of sufficient technical support (mean = 3.69). Policy-related uncertainties, including fears of inconsistent government policies and incentives (mean = 3.71), add another layer of risk, potentially discouraging adoption. One interesting finding from **Figure 3** is that conventional rice farmers perceive the risks associated with low-emission practices as the highest among all groups. This heightened perception of risk may be a key reason why they continue using conventional practices and are slower to adopt low-emission alternatives.

Overall, these findings suggest that while low-emission farming offers clear environmental benefits, farmers remain cautious due to financial burdens, agronomic challenges, and policy uncertainty. This highlights the need for stronger support systems and risk-mitigation strategies—especially for conventional rice farmers.

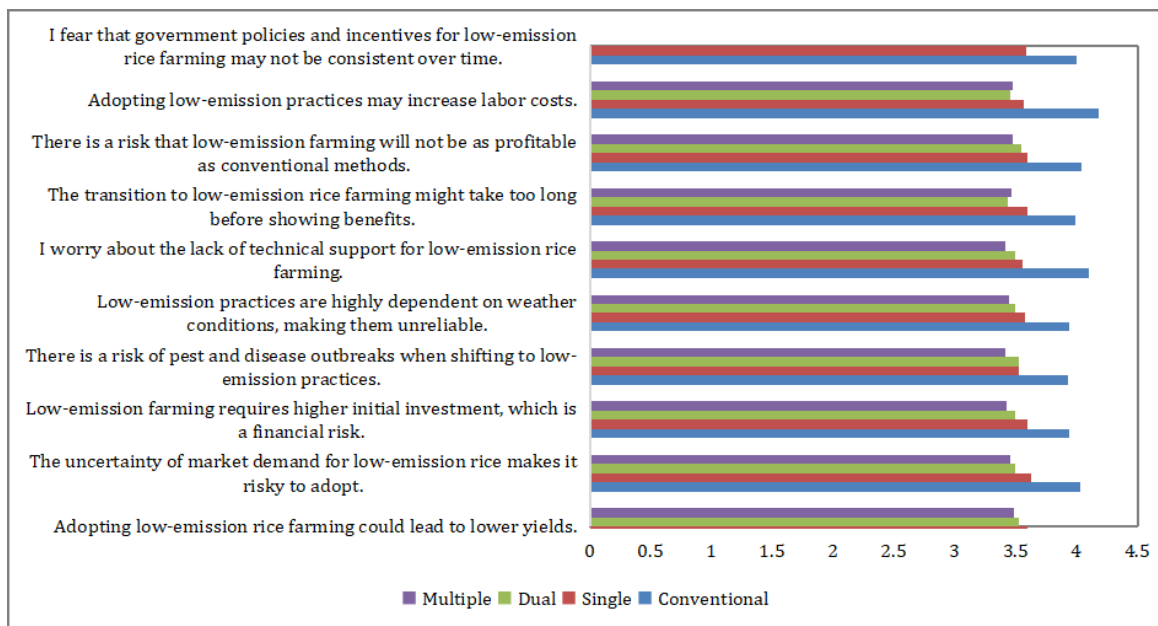


Figure 3. Perceived risks of low-emission practices by types.

Source: Author’s estimates based on survey data from 2023, n = 748. Data available upon request.

3.3. Financial Analysis of Low-Emission Rice Versus Conventional Rice

Understanding the financial performance of adopting low-emission practices is crucial for assessing their

feasibility and long-term sustainability. While these practices offer environmental benefits, farmers’ decisions are often driven by economic considerations, including production costs, yields, and overall profitability. This section compares the financial performance of low-

emission rice farming with conventional methods, highlighting key differences in input costs, revenue, and net income.

The results from **Table 3** indicate notable differ-

ences in key economic indicators, particularly in selling price, productivity, total revenue, profit, and profitability ratios, as determined by Duncan’s test at the 5% significance level.

Table 3. Financial performance of farming practices.

| Indicators | Unit | Conventional | Single Practice | Dual Practices | Multiple Practices |
|---------------|-------------|--------------------|--------------------|---------------------|--------------------|
| Total cost | Mil. VND/ha | 18.06 ^a | 17.58 ^a | 18.04 ^a | 17.19 ^a |
| Selling price | 1000VND/kg | 6.58 ^a | 7.05 ^b | 6.95 ^b | 6.88 ^b |
| Productivity | Tons/ha | 6.91 ^{ab} | 6.60 ^a | 6.67 ^a | 7.03 ^b |
| Total revenue | Mil. VND/ha | 45.59 ^a | 45.54 ^a | 45.94 ^{ab} | 48.13 ^b |
| Profit | Mil. VND/ha | 32.93 ^a | 32.96 ^a | 32.90 ^a | 35.94 ^b |
| Profit/Cost | | 1.92 ^a | 1.98 ^a | 2.01 ^a | 2.24 ^b |

Note: The same superscript letters ^{a, b} within the same row indicate no significant difference at the 5% level based on Duncan’s test. Source: Author’s estimates based on survey data from 2023, n=748. Data available upon request.

Total costs per hectare do not significantly differ among the groups, ranging from 17.19 to 18.06 million VND/ha. However, selling prices vary significantly, with conventional farmers receiving the lowest price (6.58 thousand VND/kg) compared to farmers adopting single (7.05), dual (6.95), and multiple practices (6.88). Duncan’s test confirms that the latter three groups achieve significantly higher selling prices than conventional farmers.

Productivity differences are also observed. Farmers practicing multiple low-emission techniques achieve the highest yield (7.03 tons/ha), significantly higher than single and dual-practice adopters, but not significantly different from conventional farmers (6.91 tons/ha). Total revenue follows a similar trend, with multiple-practice adopters earning the highest revenue (48.13 million VND/ha), significantly higher than conventional farmers (45.59 million VND/ha), while dual-practice adopters (45.94 million VND/ha) do not significantly differ from the other groups.

Profitability outcomes reveal that multiple-practice farmers achieve the highest profits (35.94 million VND/ha), significantly surpassing other groups, whose profits range around 32.90–32.96 million VND/ha. The OLS regression results on factors affecting profitability, presented in **Appendix B**, show that multiple-practice farmers earn higher profits than conventional rice farmers by 2.7 million VND/ha (equivalent to 104.8 USD). Conversely, the results also indicate that rice-shrimp farmers earn lower profits than con-

ventional rice farmers by 4.68 million VND/ha (equivalent to 181.6 USD). The profit-to-cost ratio also follows this pattern, with multiple-practice adopters achieving a significantly higher ratio (2.24) compared to the other groups (1.92–2.01).

These findings highlight the economic advantages of adopting multiple low-emission farming practices. Farmers who implement a combination of sustainable techniques benefit from higher productivity, improved selling prices, and greater profitability. While cost differences are negligible, the higher economic returns indicate that broader adoption of low-emission practices could enhance farm financial sustainability. Policymakers and extension services should prioritize support for these practices, ensuring farmers can access the necessary resources and knowledge to maximize their financial benefits.

3.4. Factors Affecting the Adoption of Low-Emission Practices

To analyze the factors influencing the adoption of low-emission practices, the study conducted an Exploratory Factor Analysis (EFA) alongside socio-economic characteristics to group 26 variables into three categories: perceived benefits, ease of use, and risks associated with adoption^[24]. The results, presented in **Appendix C**, led to the exclusion of three items (X15, X22, and X24) due to two key reasons: (1) low factor loadings, as these variables did not load strongly (typically <0.4) onto any extracted components, mean-

ing they did not significantly contribute to any identified factors; and (2) cross-loading issues, where variables loaded onto multiple factors without a clear distinction^[24, 25]. The factor analysis was performed using Principal Component Analysis (PCA) with Varimax rotation, extracting three main components that explain 59.06% of the total variance. The variables were grouped into three distinct factors: Factor 1—Perceived Ease of Adoption of Low-Emission Rice Farming, which includes variables reflecting how easily farmers can adopt low-emission practices (loading ≥ 0.6); Factor 2—Perceived Risks of Low-Emission Rice Farming, capturing concerns about economic risks, policy instability, and production uncertainty (loading ≥ 0.68); and Factor 3—Perceived Benefits of Low-Emission Rice Farming, emphasizing the financial and environmental advantages of low-emission practices (loading ≥ 0.63).

The ordered logit regression model was conducted using a dataset where the dependent variable (Y) takes four values: 0 = conventional rice, 1 = single practice, 2 = dual practices, and 3 = multiple practices. The independent variables (X) include socio-economic characteristics and the three factors identified from the Exploratory Factor Analysis (EFA).

Before interpreting the results, the parallel-line assumption was tested using Brant's test, which indicated a violation of this assumption ($P_{value} > \chi^2_{critical} = 0.009$). As a result, the generalized ordered logit model was used instead^[26]. However, during the implementation, the generalized ordered logit produced 390 observations with predicted probabilities less than 0, which suggests a potential issue. This problem likely occurred due to small sample sizes in some categories of the dependent variable, particularly the dual practices group, which contained only 57 observations. To address this, categories 2 (dual practices) and 3 (multiple practices) were combined^[26]. Consequently, the generalized ordered logit model was re-estimated with three groups: 0 = conventional rice, 1 = single practice, and 2 = multiple practices.

The parallel lines assumption was tested using the `autofit(0.01)` option, which sequentially imposed constraints where necessary. The results indicate that the assumption was not violated for most variables, as evi-

denced by their high p -values (> 0.01) in the stepwise testing process. However, Factor 1 (Perceived Ease of Adoption) violated the assumption ($p = 0.00256$), suggesting that its effect varies across different adoption levels. The final Wald test for the constrained model yielded $\chi^2(9) = 15.85$, $p = 0.104$, which is not significant, indicating that the final model satisfies the proportional odds assumption after applying the necessary constraints.

The results from **Table 4** shows that the adoption of low-emission practices is shaped by household and farm characteristics, perception factors, and education levels. Larger households (-0.162 , $p < 0.01$) and more fragmented landholdings (-0.444 , $p < 0.01$) are less likely to adopt, whereas larger farms (0.223 , $p < 0.01$) show a greater likelihood of adoption. This finding aligns with previous studies indicating that farm size is a key determinant of technology uptake. Knowler and Bradshaw^[19]; Meijer et al.^[21] found that larger and more consolidated farms are better positioned to invest in new technologies due to economies of scale, easier management, and greater access to credit. In contrast, land fragmentation often creates operational inefficiencies that limit the adoption of resource-intensive or knowledge-demanding practices^[18].

Among perception factors, Perceived Ease of Adoption (Factor 1) significantly influences initial adoption (-0.392 , $p < 0.01$) but does not distinguish between partial and full adopters (-0.135 , $p > 0.1$). This result supports the Technology Acceptance Model of Davis^[14], which posits that perceived ease of use strongly affects initial behavioral intention but may have less explanatory power once adoption becomes established. Similar patterns have been observed in conservation agriculture and integrated pest management studies, where ease of implementation matters more during the early adoption phase^[16, 17].

The positive relationship between perceived risks and adoption (0.332 , $p < 0.01$) may seem counterintuitive. While risks are typically expected to deter adoption, this finding suggests that farmers who perceive risks may also be more aware of both potential losses from inaction and possible long-term benefits of adopting low-emission practices. This is consistent with the

findings of Barreiro-Hurlé et al.^[15], who observed that risk-aware farmers are often more informed and better equipped to manage uncertainties, viewing risks as manageable challenges rather than insurmountable barriers. Furthermore, this result may reflect the influence of tar-

geted government programs, subsidies, and technical assistance in the Mekong Delta, which mitigate perceived risks and make adoption more attractive. Similar dynamics have been reported in studies on climate-smart agriculture in China and India^[6, 18].

Table 4. Generalized ordered logit model results considering adoption of low-emission practices.

| Variables | Unrestricted Model | | | | Restricted Model | | | |
|-----------------------------|--------------------|-----|----------|-----|------------------|-----|----------|-----|
| | 0↔1&2 | | 0&1↔2 | | 0↔1&2 | | 0&1↔2 | |
| | α | | α | | α | | α | |
| <i>FAMILY SIZE</i> | -0.162 | *** | -0.162 | *** | -0.162 | *** | -0.162 | ** |
| <i>AGE</i> | 0.005 | | 0.005 | | | | | |
| <i>GENDER</i> | 0.176 | | 0.176 | *** | | | | |
| <i>PRIMARY</i> | -1.223 | *** | -1.223 | *** | -1.210 | *** | -1.210 | *** |
| <i>SECONDARY</i> | -0.975 | *** | -0.975 | *** | -0.946 | *** | -0.946 | *** |
| <i>HIGH SCHOOL</i> | -1.591 | *** | -1.591 | *** | -1.556 | *** | -1.556 | *** |
| <i>PLOTS</i> | -0.444 | *** | -0.444 | *** | -0.443 | *** | -0.443 | *** |
| <i>FARM SIZE</i> | 0.223 | *** | 0.223 | *** | 0.223 | *** | 0.223 | *** |
| <i>FACTOR 1[†]</i> | -0.392 | *** | -0.135 | | -0.391 | *** | -0.135 | |
| <i>FACTOR 2</i> | 0.332 | *** | 0.332 | *** | 0.333 | *** | 0.333 | *** |
| <i>FACTOR 3</i> | 0.359 | *** | 0.359 | *** | 0.357 | *** | 0.357 | *** |
| Intercept | 1.566 | *** | 0.706 | | 1.941 | *** | 1.083 | *** |
| Log likelihood | | | -658.694 | | | | -659.219 | |
| Pseudo R ² | | | 0.126 | | | | 0.125 | |
| Wald $\chi^2(12)$ | | | 144.210 | | | | 143.930 | |

Note: *p* indicates the significant level; * *p* < 0.1; ** *p* < 0.05; *** *p* < 0.01; † indicates the unconstrained variables. Source: Author’s estimates based on survey data from 2023, n=748. Data available upon request.

Perceived Benefits (Factor 3, 0.359, *p* < 0.01) are also positively associated with adoption, reinforcing the notion that farmers’ decisions are shaped by their evaluation of both risks and expected gains. This aligns with Umetsu^[9], who found that financial and environmental benefits—such as improved soil fertility, reduced water use, and market access—are strong incentives for the adoption of sustainable practices. Taken together, these results indicate that risk and benefit perceptions are not mutually exclusive but can act as complementary motivators in farmers’ decision-making processes.

Education plays a crucial role, as farmers with only primary (-1.223, *p* < 0.01), secondary (-0.975, *p* < 0.01), or high school (-1.591, *p* < 0.01) education are significantly less likely to adopt compared to those with a college education. This highlights the importance of education in fostering adoption, likely through better access to information, greater openness to innovation, and stronger engagement with sustainable agricultural prac-

tices. This is consistent with previous research showing that education improves farmers’ ability to process technical information, assess new technologies, and access institutional support^[20]. More educated farmers are also more likely to engage in training and extension programs, making them early adopters of climate-smart practices^[18].

Overall, these findings contribute to the existing literature in several ways. First, they confirm well-established relationships between farm size, education, and adoption of sustainable practices. Second, they extend current understanding by showing that higher perceived risk can, under certain policy and support conditions, be associated with increased adoption—a result less commonly documented in previous studies. Third, by integrating both risk and benefit perception factors into the analysis, this study provides a more nuanced explanation of farmers’ decision-making processes, particularly in the context of large-scale low-emission rice initiatives in the Mekong Delta. This offers important in-

sights for designing targeted extension strategies and incentive structures to promote wider adoption of climate-smart practices.

- The findings of this study provide several important implications for policymakers, agricultural managers, technology developers, and extension services to enhance the adoption of low-emission rice farming practices in the Vietnamese Mekong Delta and similar agro-ecological contexts.
- Since larger farms are more likely to adopt low-emission practices, policy frameworks should prioritize providing financial incentives, credit access, and infrastructure support to smallholders and farmers with fragmented plots. Mechanisms such as land consolidation programs or cooperative models could help reduce production inefficiencies and improve farmers' capacity to invest in sustainable technologies.
- The positive association between risk perception and adoption suggests that well-designed risk-sharing schemes, including crop insurance, guaranteed minimum price mechanisms, or input subsidies, can transform perceived risks into manageable challenges. These measures can make adoption more attractive, especially for resource-constrained farmers.
- Because perceived ease of adoption strongly influences initial uptake, technologies and farming practices should be tailored to local conditions—simple, cost-effective, and easy to integrate with existing production systems.
- Education level was found to be a significant determinant of adoption. Strengthening extension networks through training workshops, farmer field schools, and demonstration plots can bridge knowledge gaps, especially for farmers with lower education levels.

4. Conclusions

The study highlights key socio-economic factors influencing the adoption of low-emission rice farming practices. Larger farm sizes and higher education lev-

els facilitate adoption, while household size and land fragmentation act as constraints. Farmers generally perceive these practices as feasible and accessible, yet financial risks, market uncertainties, and potential yield reductions remain key barriers. Additionally, concerns about increased production costs, pest and disease outbreaks, and inconsistent government policies contribute to adoption hesitancy. Reputational benefits and policy incentives significantly shape adoption decisions, highlighting the role of external support. Profitability analysis confirms that multiple-practice adopters achieve higher financial returns, but concerns about policy stability and technical support persist. These findings emphasize the need for targeted financial incentives, capacity-building initiatives, and strengthened policy frameworks to enhance adoption and long-term sustainability.

This study has several limitations. The small sample size, especially among dual-practice adopters, affected statistical modeling, leading to category consolidation. Uncontrolled external factors like climate, policy changes, and infrastructure variations may limit generalizability. Additionally, the study focuses on short-term adoption, while long-term impacts require further research. Future studies should use longitudinal and qualitative approaches to explore behavioral drivers, risk mitigation, and economic sustainability. Furthermore, a limitation of our survey design is the absence of detailed information on irrigation access, altitude, proximity to the coast, and soil characteristics, which were not collected due to various logistical constraints.

Author Contributions

Conceptualization, V.H.T. and N.T.T.; methodology, V.H.T.; software, N.T.T.; validation, N.T.T. and V.H.T.; formal analysis, V.H.T.; investigation, N.T.T.; resources, N.T.T.; data curation, N.T.T.; writing—original draft preparation, V.H.T.; writing—review and editing, N.T.T.; visualization, V.H.T.; supervision, V.H.T.; project administration, V.H.T.; funding acquisition, N.T.T. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

All procedures performed in studies involving human participants were in accordance with the ethical standards or comparable ethical standards. The research was reviewed and approved by the Research Ethics Committee for Social Sciences and Humanities at Can Tho University under application number: CTU-RECSH25002.

Informed Consent Statement

Informed consent was obtained from all individual participants involved in the study. Consent to Publish

declaration: not applicable.

Data Availability Statement

Data available upon request.

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A.

Table A1. Frequency of rice farmers' perceptions regarding low-emission practices.

| No. | Items | Farmer's Statement Evaluation | | | | |
|---|--|-------------------------------|---|-----|-----|--------------------|
| | | 1 = Strongly Disagree | 2 | 3 | 4 | 5 = Strongly Agree |
| Ease of use of low-emission rice farming | | | | | | |
| X1 | Low-emission rice farming techniques are easy to understand. | 0 | 0 | 31 | 517 | 200 |
| X2 | The implementation of low-emission practices fits well with my current farming routine. | 0 | 0 | 75 | 433 | 240 |
| X3 | Learning how to apply low-emission practices does not require much additional training. | 0 | 0 | 78 | 433 | 237 |
| X4 | I can easily access the resources (e.g., seeds, organic fertilizers, equipment) needed for low-emission farming. | 0 | 0 | 31 | 454 | 263 |
| X5 | The transition from conventional to low-emission rice farming is straightforward. | 0 | 0 | 34 | 454 | 260 |
| X6 | Applying low-emission techniques does not require significant changes in my current farming methods. | 0 | 0 | 79 | 429 | 240 |
| X7 | Low-emission farming practices do not require excessive labor or effort. | 0 | 0 | 138 | 385 | 225 |
| X8 | I can get sufficient technical support when adopting low-emission farming methods. | 0 | 0 | 77 | 431 | 240 |
| X9 | The cost of adopting low-emission techniques is manageable. | 0 | 0 | 29 | 461 | 258 |

Table A1. Cont.

| No. | Items | Farmer's Statement Evaluation | | | | |
|--|---|-------------------------------|---|-----|-----|--------------------|
| | | 1 = Strongly Disagree | 2 | 3 | 4 | 5 = Strongly Agree |
| Ease of use of low-emission rice farming | | | | | | |
| X10 | I feel confident in using low-emission rice farming techniques on my own. | 0 | 0 | 24 | 456 | 268 |
| Perceived benefits of low-emission rice farming | | | | | | |
| X11 | Low-emission rice farming helps reduce production costs. | 0 | 0 | 277 | 462 | 9 |
| X12 | Adopting low-emission practices improves soil fertility. | 0 | 0 | 278 | 461 | 9 |
| X13 | Low-emission farming enhances income through carbon credits. | 0 | 0 | 322 | 416 | 10 |
| X14 | Switching to low-emission farming would improve my farm's reputation. | 0 | 0 | 234 | 452 | 62 |
| X15 | Government subsidies encourage me to adopt low-emission practices. | 0 | 0 | 244 | 397 | 107 |
| X16 | I would recommend low-emission rice farming to other farmers. | 0 | 0 | 298 | 442 | 8 |
| Perceived risks of low-emission rice farming | | | | | | |
| X17 | Adopting low-emission rice farming could lead to lower yields. | 0 | 0 | 224 | 510 | 14 |
| X18 | The uncertainty of market demand for low-emission rice makes it risky to adopt. | 0 | 0 | 238 | 433 | 77 |
| X19 | Low-emission farming requires higher initial investment, which is a financial risk. | 0 | 0 | 244 | 468 | 36 |
| X20 | There is a risk of pest and disease outbreaks when shifting to low-emission practices. | 0 | 0 | 260 | 450 | 38 |
| X21 | Low-emission practices are highly dependent on weather conditions, making them unreliable. | 0 | 0 | 247 | 463 | 38 |
| X22 | I worry about the lack of technical support for low-emission rice farming. | 0 | 0 | 246 | 410 | 92 |
| X23 | The transition to low-emission rice farming might take too long before showing benefits. | 0 | 0 | 256 | 420 | 72 |
| X24 | There is a risk that low-emission farming will not be as profitable as conventional methods. | 0 | 0 | 243 | 418 | 87 |
| X25 | Adopting low-emission practices may increase labor costs. | 0 | 0 | 246 | 367 | 135 |
| X26 | I fear that government policies and incentives for low-emission rice farming may not be consistent over time. | 0 | 0 | 266 | 395 | 87 |

Appendix B.

Table A2. The OLS regression results on factors affecting profitability.

| Profit | Coefficients | Standard Error | t-Value | $p > t $ |
|--------------------|--------------|----------------|---------|-----------|
| <i>Rice shrimp</i> | -4.679*** | 1.701 | -2.750 | 0.006 |
| <i>SRP</i> | 2.273 | 2.958 | 0.770 | 0.443 |
| <i>AWD</i> | 1.273 | 1.450 | 0.880 | 0.380 |
| <i>ORGANIC</i> | 1.727 | 2.264 | 0.760 | 0.446 |
| <i>GAP</i> | 1.936 | 2.011 | 0.960 | 0.336 |
| <i>Dual</i> | -0.253 | 1.319 | -0.190 | 0.848 |

Table A2. Cont.

| Profit | Coefficients | Standard Error | t-Value | $p > t $ |
|----------------|--------------|----------------|---------|-----------|
| Multiple | 2.702*** | 0.851 | 3.170 | 0.002 |
| Family size | 0.210 | 0.222 | 0.940 | 0.346 |
| Age | -0.005 | 0.031 | -0.170 | 0.862 |
| Gender | 0.980 | 1.082 | 0.910 | 0.365 |
| Primary | -1.745 | 1.174 | -1.490 | 0.138 |
| Secondary | -1.282 | 1.084 | -1.180 | 0.237 |
| High school | -2.508* | 1.325 | -1.890 | 0.059 |
| Plots | 0.729** | 0.298 | 2.450 | 0.015 |
| Constant | 31.513*** | 2.376 | 13.260 | 0.000 |
| F-test | 3.1 | | | |
| F statistics | 0.000 | | | |
| R ² | 0.06 | | | |

Note: p indicates the significant level; * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Appendix C.

Table A3. Results of rotated component matrix in EFA.

| Items | Component | | |
|-----------------|--|---|--|
| | Factor 1 Perceived Ease of Adoption of Low-Emission Rice Farming | Factor 2 Perceived Risks of Low-Emission Rice Farming | Factor 3 Perceived Benefits of Low-Emission Rice Farming |
| X ₂ | 0.776 | | |
| X ₈ | 0.765 | | |
| X ₃ | 0.753 | | |
| X ₆ | 0.735 | | |
| X ₇ | 0.716 | | |
| X ₉ | 0.708 | | |
| X ₄ | 0.682 | | |
| X ₅ | 0.678 | | |
| X ₁₀ | 0.673 | | |
| X ₁ | 0.591 | | |
| X ₂₁ | | 0.831 | |
| X ₂₆ | | 0.805 | |
| X ₂₃ | | 0.796 | |
| X ₁₈ | | 0.782 | |
| X ₁₉ | | 0.775 | |
| X ₂₀ | | 0.757 | |
| X ₂₅ | | 0.750 | |
| X ₁₇ | | 0.683 | |
| X ₁₂ | | | 0.858 |
| X ₁₁ | | | 0.830 |
| X ₁₆ | | | 0.758 |
| X ₁₄ | | | 0.752 |
| X ₁₃ | | | 0.635 |

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