APM Center Working Paper Series No. 2026-04

Assessing the Transition of Low-Carbon Rice Cultivation in Selected ASEAN Countries: Implications for Cambodia

Monineath HORN and Vibol SENG

August 2026

APM មជ្ឈមណ្ឌលអគ្គបណ្ឌិតសភាចារ្យ អ៊ុន ពន្ធមុនីរ័ត្ន
Akkak Pundit Sapheachar Aun Pornmoniroth Center

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List of Abbreviations

1M5R	One Must Do, Five Reductions
3R3G	Three Reductions, Three Gains
AWD	Alternate Wetting and Drying
CH_4	Methane
DALRM	Department of Agricultural Land Resources Management (Cambodia)
GHG	Greenhouse Gas
LCRC	Low-Carbon Rice Cultivation
LLL	Laser Land Leveling
MLP	Multi-Level Perspective
MRV	Monitoring, Reporting, and Verification
N_2O	Nitrous Oxide
NAMA	Nationally Appropriate Mitigation Action
NCSD	National Council for Sustainable Development
NDC	Nationally Determined Contribution
SRP	Sustainable Rice Platform
SSNM	Site-Specific Nutrient Management
TAS	Thai Agricultural Standard for Sustainable Rice
VnSAT	Vietnam Sustainable Agriculture Transformation Project

Acknowledgement

We wish to express our sincere appreciation to the many individuals whose support and insights were foundational to the completion of this research.

We express our deepest respect and appreciation to **His Excellency Dr. Kao Thach**, Delegate of the Royal Government in charge as Chief Executive Officer of the Agricultural and Rural Development Bank (ARDB). His visionary leadership and commitment to fostering an academic research ecosystem have provided an invaluable platform for young researchers to initiate meaningful projects.

We are profoundly grateful to **Dr. Oum Sothea**, member of the Board of Directors at the Akka Pundit Sapheachar Aun Pornmoniroth Centre for Policy Studies and Training (APM) Center and advisor for this research project. His mentorship and expert guidance on our methodological framework, together with his invaluable feedback and encouragement throughout the process, have been a tremendous support to enrich the depth and rigor of our work.

We also extend sincere gratitude to the Members of the Board of the APM Center, Advisors of ARDB, and ARDB Management for their constructive guidance on the research proposal and working paper design, as well as for the valuable comments and insights shared during the consultation workshop, which substantially strengthened the overall quality of this paper.

Our heartfelt appreciation to **Mr. Sok Ousa**, Head of Research and Development Department and Chair of the APM Center, for his guidance, coordination and support, which ensured the smooth execution of our research activities.

Finally, we extend our appreciation to all the individuals and institutions, within and beyond ARDB and the APM Center, who generously offered their time, expertise, and encouragement in this research.

Keywords: Agri-food Processing SMEs, Low-Carbon Rice Cultivation, Multi-Level Perspective, Rural Livelihood, Agricultural Financing, Climate-Smart Agriculture, Rice Sector Transition, Agricultural Decarbonization, Sustainable Rice, Thai Rice NAMA, VnSAT, Cambodia, Vietnam, Thailand

Abstract

Low-Carbon Rice Cultivation (LCRC) has emerged as a critical strategy for Southeast Asia to reduce agricultural greenhouse gas (GHG) emissions while maintaining food security and farmer incomes. This paper examines what enables or constrains scaling of LCRC from pilot projects to widespread adoption by analyzing two regional cases: Vietnam Sustainable Agriculture Transformation (VnSAT) Project and Thai Rice Nationally Appropriate Mitigation Action (NAMA) program, using the Multi-Level Perspective (MLP) framework. It then draws implications for Cambodia, which has committed to promote the adoption of low-carbon agriculture.

The analysis identifies four critical success factors: (1) institutional coordination structures that link central policy oversight with decentralized implementation; (2) financial mechanisms designed to reduce risk for farmers, banks, and private actors simultaneously, moving beyond project-dependent models; (3) integrated infrastructure and technical support that ensures physical capacity matches technical practices; and (4) market linkages and value chains that create economic incentives beyond subsidies.

Cambodia is approaching a critical inflection point in its transition to low-carbon rice cultivation. Pilot initiatives have demonstrated technical feasibility, economic viability, and institutional engagement, showing that farmers can adopt improved practices and that monitoring and incentive systems can function effectively. However, progress remains largely confined to pilot projects rather than systemic transformation. Key constraints include fragmented institutional coordination, continued reliance on donor financing, infrastructure deficits that limit effective implementation, and weak integration of sustainability standards into rice value chains.

To move from piloting to scale, Cambodia should prioritize system-building. This requires formalizing national coordination mechanisms, developing blended finance instruments to mobilize private investment, upgrading irrigation infrastructure alongside technical promotion, strengthening market incentives through sustainability certification and buyer engagement, scaling Monitoring, Reporting, and Verification (MRV) systems to access climate finance, and institutionalizing farmer-led extension approaches within the national agricultural system.

1. Introduction

Rice cultivation plays a critical role in the global food production system, sustaining billions of people and serving as a fundamental staple for food security across continents. However, conventional rice production is also a significant source of methane (CH_4) emissions that exacerbate global climate change. The continuous flooding of rice paddies creates anaerobic soil conditions that foster the production of CH_4 by microorganisms (Hannan, nd.). Additionally, the widespread use of synthetic fertilizers in rice farming leads to the emission of nitrous oxide (N_2O), another potent greenhouse gas (GHG) with a significant global warming potential (World Bank, 2022). The combined effect of CH_4 and N_2O from conventional rice farming represents a substantial contribution to climate change within the agricultural sector.

As countries commit to the Paris Agreement and other sustainable development goals, reducing GHG emissions from agriculture has become a priority. Southeast Asia is at the center of this transformation. The region not only accounts for a substantial share of global rice output but also contributes a significant proportion of CH_4 emissions from paddy cultivation. Regionally, rice cultivation accounts for approximately 10% of global CH_4 emissions and contributes 25-33% of the total CH_4 released in the region (Umali-Deininger, 2022). Addressing these challenges is crucial to ensuring food security, protecting rural livelihoods, and fulfilling national climate goals.

Within the broader regional landscape, Cambodia stands at a pivotal juncture where tradition meets environmental necessity. Agriculture remains a cornerstone of the national economy, accounting for approximately 22% of the country's GDP (Sam & Ilyun, 2024). Rice is the predominant crop, utilizing around 66% of the nation's arable land and serving as the primary anchor for rural employment and national food security (National Institute of Statistics et al., 2025). However, this vital sector is acutely vulnerable to the intensifying impacts of climate change. Increasing floods, droughts, and erratic weather patterns threaten both crop yields and the livelihoods of millions. According to INFORM Risk, Cambodia was ranked the 58th most at-risk nation out of 191 countries in 2024 (European Commission: Joint Research Centre, 2024). Consequently, the continued reliance on conventional rice farming methods presents significant environmental and productivity challenges that can no longer be ignored.

As climate change intensifies, Cambodia faces the dual challenge of adapting to its impacts while mitigating its own GHG emissions. Transitioning to low-carbon rice cultivation (LCRC) is seen as a primary pathway to address this challenge, potentially enhancing productivity and resource efficiency while reducing environmental impacts (World Bank, 2022). In response, the Royal Government of Cambodia has established long-term strategies to adapt and mitigate climate impacts within the rice sector. These goals include a commitment to reduce CH_4 emissions from agriculture by 20% by 2030 through accelerating the transition toward sustainable practices, such as the use of less methane-intensive rice cultivars and the adoption of Alternate Wetting and Drying (AWD) techniques (DCC/GSSD-NCSD, 2021; NCSD, 2025).

While LCRC has emerged through various pilot programs across Southeast Asia, the transition from isolated innovations to widespread, national adoption remains a significant hurdle. Regional neighbors, specifically Thailand and Vietnam, have demonstrated considerable progress through large-scale initiatives like the Thai Rice Nationally Appropriate Mitigation Action (NAMA) Program and Vietnam Sustainable Agriculture Transformation (VnSAT) Project (World Bank, 2022; Vnsat.mard.gov.vn, 2023). Given their similar agro-ecological conditions and shared farming cultures, their experiences offer essential blueprints for Cambodia.

However, there remains a critical research gap regarding how these practices can be effectively scaled from niche experiments to regime standards. Understanding how different nations have navigated this process, including the role of supporting systems, the barriers encountered, and the enablers that facilitated growth, can provide vital insights for Cambodia as it enters the earlier stages of this transition.

To address these gaps, this study is guided by two primary research questions:

1. What factors enable or constrain the transition and scaling of LCRC in selected ASEAN cases?
2. What are the implications and priorities for Cambodia's transition to LCRC?

To analyze these selected case studies (VnSAT & Thai Rice NAMA), this paper employs the Multi-Level Perspective (MLP) framework to examine regional scaling experiences, drawing from secondary data, official reports, and academic journals. By adapting the MLP to a project-level analysis, this research captures the dynamic interplay between landscape pressures, regime structures, and niche innovations.

This approach allows for a clear identification of the enablers and hindrances that define the transition pathway.

The remainder of this paper is organized as follows: Section 2 reviews the key concepts and technical foundations of LCRC. Section 3 provides an overview of the MLP framework. In Section 4, the MLP framework is applied to analyze specific case studies of LCRC programs in Thailand and Vietnam. Section 5 examines the implications for Cambodia's transition and synthesizes relevant policy insights. Finally, Section 6 concludes the study and identifies potential avenues for future research.

2. Literature Review

2.1. Overview of Low-Carbon Rice Cultivation

Low-Carbon Rice Cultivation (LCRC) can be understood as a concept rather than a definitive definition. It has been described as a multidimensional approach that revolves around three objectives: (1) reducing GHG emissions, (2) enhancing carbon sequestration, and (3) sustaining or improving crop yields. Huang et al. (2024) define LCRC as the adoption of field-level practices that allow rice paddies to function both as productive systems and as carbon sinks, reducing emissions while maintaining harvests. Similarly, Yan et al. (2025) describe LCRC as a suite of integrated technologies that emphasize efficiency in resource use, recycling of agricultural inputs, and the promotion of both high-yield and environmentally sustainable production systems (Huang et al., 2024; Yan et al., 2025). These approaches stand in sharp contrast to conventional rice cultivation, which typically relies on chemical fertilizers and continuous flooding of paddies, practices that generate high carbon emissions and contribute to environmental degradation (Huang et al., 2024).

LCRC is thus better understood as a holistic approach rather than a technical checklist, embedded within the broader framework of climate-smart agriculture, emphasizing coherence between mitigation and productivity objectives. Among documented practices, AWD has become one of the most applied techniques, capable of cutting CH_4 emissions by roughly 30-50% compared to continuously flooded fields (Alisher, 2024). Still, the full potential of LCRC lies beyond any single method. Environmental and productivity gains are amplified when AWD is combined with complementary practices such as precision nutrient management,

residue recycling, and soil conservation. This integrated orientation reflects what Huang et al. (2024) describe as the technical core of LCRC including site-specific fertilizer application, incorporation of organic matter, crop rotation, straw return, conservation tillage, and circular resource management (Huang et al., 2024). Table 1 outlines several key techniques that form the technical foundation of LCRC.

Table 1: Key Low-Carbon Rice Cultivation and Techniques

Technique	Description	Key Benefits
Alternate Wetting and Drying (AWD)	Water management techniques where rice fields are periodically dried instead of being constantly flooded	48% reduction in CH_4 emissions; 34% reduction in irrigation water use; lower irrigation costs; maintains yield without negative impact (Gao et al., 2024)
Site-Specific Nutrient Management (SSNM)	Approach using modern technologies (remote sensing, GPS, GIS) for precise fertilizer applications based on soil and crop needs	10-50% reduction in excessive fertilizer application; enhanced crop yield and nutrient efficiency; reduced environmental impact; improved soil health (Baishya et al., 2022; Bana, 2024; Verma et al., 2020)
Rice Straw Management	Sustainable handling of rice straw through incorporation into soil, composting with manure, biochar production via pyrolysis, and off-farm uses instead of open-field burning	Eliminates air pollution from burning; increases soil organic carbon; improves soil health and nutrient cycling; reduces greenhouse gas emissions from burning (Allen, 2019)

Source: Author's compilation from the preceding analysis based on existing literature.

2.2. Multi-Level Perspective (MLP) Framework

The Multi-Level Perspective (MLP) framework is an analytical framework for analyzing how large-scale transitions happen in society, especially those involving new technologies, behaviors, or sustainability practices (Geels, 2002). It is commonly used to study transitions like shifting from fossil fuels to renewable energy or why changing food systems can be so challenging and complex through three levels (Geels, 2002):

1. *Landscape*: This level is the big-picture context that creates external pressure but cannot be directly controlled. For example, global economic trends, market trends, climate change, or political changes.
2. *Regime*: This level is the existing and stable system that dominates a sector. For example, rules, technologies, infrastructure, and habits that exist in the mainstream agriculture practices or transportation systems.
3. *Niche*: This level refers to protected spaces where radical innovations, or alternatives practices can develop and mature before entering the existing mainstream.

The concept explains that transitions occur when pressure from landscape make the existing regime unstable, which gives niche innovations a chance to challenge and eventually replace old system. Normally, transitions are rarely smooth or fast, because regimes tend to resist change, while niches have trouble scaling. But when landscape pressures increase strongly and niches are mature, a window of transition opens (Geels, 2002). For example, when climate change becomes a priority in national agenda, putting pressure on existing conventional rice practice and forcing actors to seek alternatives, the established system starts struggling to cope with these pressures. Then the innovations that have matured in the niche, for example low-carbon rice practices, start to get noticed. Consequently, these practices are adopted more widely, sometimes supported by new policies or investment, leading to a reconfiguration or transformation of the regime.

The use of MLP framework in agri-food research is supported by recent systematic review. For instance, a review of studies published between 2018 and 2022 and found that the framework has been applied in multiple cases to understand transitions toward sustainability in agriculture (Elsner et al., 2023). Most of these

studies focused on on-the-ground changes, such as shifts to agroecological farming, adoption of organic practices, or the implementation of climate-smart techniques. Notably, the study highlighted a growing academic interest in the process occurring between the core MLP levels (inter-level dynamics), particularly how niche innovations like new farming practices spread or overlap with existing systems (regime) (Ibid).

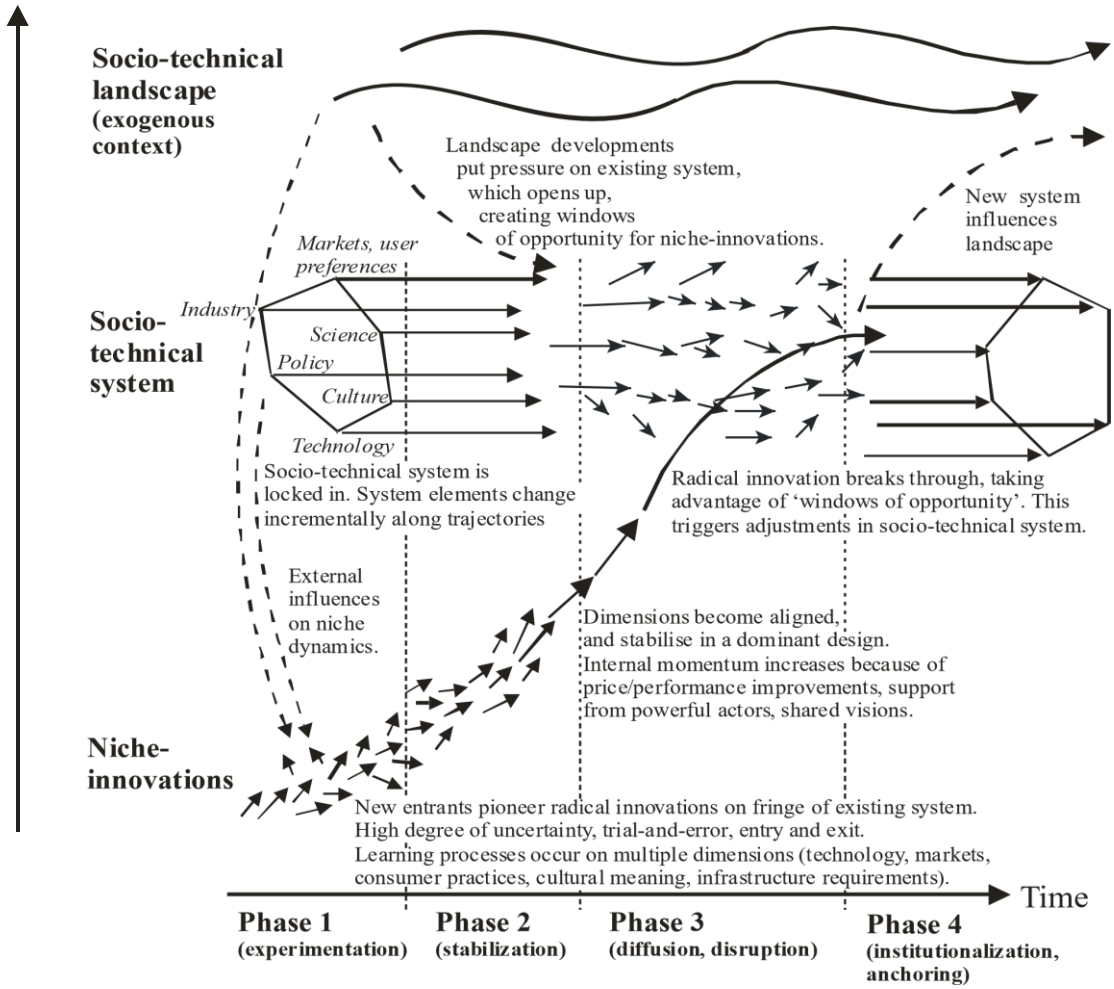
Yet it is also important to recognize the limitations of MLP framework. Wigboldus et al. (2016) observe that while this framework is widely used for mapping sustainable transitions in agriculture, it is most often applied retrospectively to explain or compare the completed transitions, rather than as a tool for real-time intervention or guiding ongoing change. Moreover, the same study points out that although the structure of MLP is strong for understanding broad system dynamics, it may not always capture the finer details of dynamic interaction among specific actors, particularly at the operational level of projects or programs. In response, the study proposes their framework the Theory of Modal Aspects (TOMA) to address these gaps.

Nevertheless, the focus of our study is about tracing how innovations in LCRC move from niche experimentation toward regime integration, under current landscape pressures. Though other frameworks such as the Theory of Modal Aspects (TOMA) might be effective for actor-centered questions, our scope of study prioritizes mapping and understanding transition dynamics at the system scale. Hence, MLP framework remains an analytically robust and validated lens for our analysis because its strength in mapping systematic transition pathways makes it a suitable choice for examining the dynamics and lessons of program-level agricultural change.

Building on this analytical framework, the following section applies MLP framework to examine two prominent low-carbon rice initiative in Thailand and Vietnam: (1) VnSAT project, and (2) Thai Rice NAMA program. These cases were deliberately selected because both Vietnam and Thailand share several geographical and socio-economic characteristics with Cambodia, including a high national dependence on rice cultivation, vulnerability to climate-related risks, and ongoing efforts to align agricultural development with climate change mitigation and

adaptation goals. Additionally, VnSAT and Thai Rice NAMA represent some of the most advanced and well-documented efforts at scaling low-carbon rice practices in Southeast Asia. By analyzing the transition dynamics with these cases, this study aims to draw practical lessons and policy insights that are relevant for Cambodia's emerging low-carbon rice transition, even though Cambodia itself is not a direct case study.

Figure 1. Multi-Level Perspective (MLP) Framework on Socio-Technical Transitions



Source: Geels, 2024

3. Case Study of Low-Carbon Rice Cultivation: A Multi-level Perspective (MLP) Analysis

This section applies the MLP framework to two prominent low-carbon rice initiatives in the ASEAN region: Vietnam's VnSAT project and Thailand's Rice NAMA program. As introduced in Section 2, the landscape level captures broad exogenous pressures that actors cannot directly control; the regime denotes the dominant socio-technical system and its entrenched rules, practices, and infrastructure; and the niche refers to the protected spaces in which innovative alternatives develop and build momentum. Each case is analyzed through these three levels, followed by a within-case reflection on how these three levels interact to shape transition dynamics. A cross-case comparison is then presented to identify the common factors that enable or constrain scaling beyond the pilot stage. Table 2 provides a comparative overview of the MLP components identified across both cases, which are elaborated in the analyses that follow.

3.1. Vietnam Sustainable Agriculture Transformation (VnSAT)

Project Overview

Vietnam Sustainable Agricultural Transformation (VnSAT) Project was initiated to support the implementation of the government's Agricultural Restructuring Plan, a reform that integrates sustainable development elements into agriculture. The project focused on institutional strengthening to support agricultural transformation, sustainable production, technology dissemination, and value chain development, with an emphasis on two main crops, namely rice and coffee. The project covers eight provinces in the Mekong Delta region (rice components) and five provinces in Central Highland region (coffee components), ultimately reaching 184,643 hectares of rice and 70,446 hectares of coffee production systems. The project was financed by the World Bank through International Development Association amounting to USD 242 million (World Bank, 2023).

Landscape Level

At landscape level, Vietnam's rice sector faces intensifying pressures from climate policy commitments, climate change, and global market dynamics. First, the country has pledged to reduce CH_4 emissions by 30% by 2030 and reaching net zero by 2050, identifying LCRC as a key mitigation measure (International Rice Research Institute, 2022; Socialist Republic of Vietnam, 2022). Second, the stability of the rice production system is being undermined by climate change, with rising

temperature, unpredictable rainfall, and extreme weather events like droughts, floods, and typhoons are reducing production stability and increasing reliance on fertilizers. Adding to these challenges, sea-level rise further threatens the Mekong Delta, the country's significant rice producing region, potentially flooding up to 90% of its farmland (World Bank, 2022; Muadz & Muhyidin, 2024). Third, Vietnam's rice production is increasingly exposed to international market pressures. Consumer demand for low-carbon rice and rising regulatory standards in key export markets are growing, directly challenging conventional, carbon-intensive production. For instance, the European Union, Vietnam's third-largest agricultural export destination, is advancing its Green Deal to limit carbon leakage, conditioning market access on compliance with higher sustainability standards (World Bank, 2022). Together, these landscape pressures create a context in which the continuation of conventional cultivation practices becomes both environmentally and commercially untenable.

Regime Level

Vietnam's dominant rice regime has been shaped by decades of prioritizing food security and export competitiveness, supported by major public investment in irrigation infrastructure, particularly in the Mekong Delta, that enabled double and triple cropping systems (World Bank, 2022). Over time, however, this model of intensification has entrenched a set of farming practices characterized by heavy reliance on chemical fertilizers and pesticides, continuous paddy flooding, and inadequate residue management, all of which generate significant GHG emissions while posing health risks to farmers (Cassou et al., 2017). Several structural features reinforce this conventional system. Government subsidies and low-cost energy make domestically produced fertilizers inexpensive, incentivizing overuse of agrochemicals and sustaining input-intensive cultivation. Furthermore, the predominance of small, fragmented landholdings combined with insecure land tenure limits mechanization, constrains long-term investment, and reduces the feasibility of adopting new technologies (Lacambra et al., 2020). These regime characteristics collectively represent a system resistant to change, even as landscape pressures intensify.

Niche Level and Project Implementation

Within this MLP analysis, VnSAT project is selected to analyze as the primary niche-level intervention which promotes LCRC, as it represents the main protected space in which low-carbon rice innovations were developed, tested, and diffused. The

VnSAT project challenged the long-held belief that "more input is better." This was pursued through the scaling of two technology packages, namely the Three Reductions, Three Gains (3R3G) and the more advanced One Must Do, Five Reductions (1M5R) (see Appendix A). By project completion, 151,000 farming households had adopted sustainable practices across 184,643 hectares, including 121,508 hectares under 1M5R, representing 66% of total adoption, while reducing GHG emissions by 1.58 million tons of carbon dioxide equivalent per year (World Bank, 2023).

The niche's uptake was primarily driven by its capacity to demonstrate immediate and tangible economic returns, which significantly reduced adoption barriers. Farmers who adopted these practices cut pesticide, fertilizer, and water costs, reduced post-harvest losses by 20–30%, increased rice productivity by 3–4%, achieved sale price improvements of 5–10%, and realized net profit gains of 28–32%, largely attributable to lower production costs (World Bank, 2022; World Bank, 2023). These measurable benefits created a self-reinforcing incentive structure that stabilized the niche and encouraged wider uptake.

The niche's sustainability was reinforced by strong institutional architecture and coordination. Centralized oversight by the country's Ministry of Agriculture and Rural Development ensured policy coherence, high ownership, budget allocation, and alignment with national priorities, while decentralized implementation at the provincial and departmental levels empowered local actors and maintained accountability. Moreover, capacity-building initiatives strengthened both central and provincial departments, resulting in measurable improvements in service delivery and the sustainability of project interventions (World Bank, 2023). Simultaneously, alignment with the national Agricultural Restructuring Plan secured political commitment and further reinforced policy coherence and budget support (World Bank, 2023). Overall, the institutional framework was clear, hierarchical, and effective in balancing central guidance with local execution.

Farmer organizations and cooperatives served as critical intermediaries, acting as network brokers that connected fragmented smallholders with government support systems and lead firms. This organizational layer was essential for overcoming the structural challenge of small average farm sizes, which individually lacked economies of scale required for modern mechanization (World Bank, 2022; World Bank, 2023). The VnSAT project provided targeted grants to support these

organizations in multiplying certified seeds, reducing post-harvest losses, and improving market access. Small-scale infrastructure improvements, including inter-field roads and channels, better access to electricity, co-investment in pumps, and enhanced irrigation, were implemented based on each group's specific needs. Additionally, the project facilitated linkages between farmer groups and private companies through contract farming arrangements, enhancing production efficiency and providing economic incentives for sustained adoption of sustainable practices (Flor et al., 2021).

At the financing level, the wholesale banking model effectively leveraged public funding to mobilize substantial private investment in the rice value chain, particularly for upgrading processing and milling facilities. Through a combination of the credit from International Development Association (USD 33.27 million), mobilized private capital from commercial banks and agribusinesses (USD 61.93 million), and a Revolving Fund (USD 2.11 million), the project supported ten rice milling and processing enterprises. The total investment of USD 97.31 million exceeded the original target of USD 40 million by 243%, demonstrating how blended public-private financing drove project implementation (World Bank, 2023).

Despite these enabling mechanisms, the niche faced internal contradictions that limited its full potential. Rigid 50/50 allocation of grants between infrastructure and equipment led to underutilized funds for equipment, while high counterpart funding requirements of up to 70% excluded many smallholder farmer organizations, slowing implementation (World Bank, 2023).

Level Interaction

The case of the VnSAT project illustrates how landscape pressures, encompassing climate risks, growing international demand for sustainable goods, and Vietnam's climate policy commitments, created the conditions under which actors were motivated to experiment with and adopt low-carbon rice practices. However, the rate and scope of adoption were not determined by landscape pressure alone; they were actively shaped by the structural features of the existing regime. Entrenched input subsidies, fragmented landholdings, and the absence of price premiums for sustainable rice acted simultaneously as constraints on diffusion and as factors directing the form that adoption took. This dynamic reveal that the transition did not occur as a straightforward displacement of conventional practices; rather, it unfolded

through the interaction of all three MLP levels. Niche innovations gained traction where they aligned with existing incentive structures and were supported by institutional and infrastructural conditions, while regime features continued to moderate the pace and geographic reach of change.

Crucially, the niche-level technical protocols and institutional capacities developed under the VnSAT project have not dissolved; rather, they have been formalized into Vietnam's current macro-level policy regime. In late 2023, the Ministry of Agriculture and Rural Development (MARD) launched the successor initiative: the 'Sustainable Development of One Million Hectares of High-Quality, Low-Emission Rice Project' in the Mekong Delta. Rather than treating carbon markets as a standalone goal, this national program treats emissions reductions as a mechanism for restructuring the entire agricultural value chain (Quynh Chi et al., 2024). Likewise, this program mandates systemic adoption of 'One Must Five Reductions' (1M5R) and AWD, shifting from project-dependent pilots into a standardized socio-technical regime backed by centralized MRV data infrastructure designed for international carbon credit optimization (Mirzabaev et al., 2024).

3.2. Thai Rice NAMA

Project Overview

The Thai Rice NAMA project is a funded initiative aiming to transition the Thai rice sector toward a low-emission path, with rice production responsible for nearly 55% of national agricultural sector emissions. To achieve this goal, the project works through three main intervention strategies including training 100,000 farmers on technologies for LCRC, supporting mitigation service providers, and helping formulate climate policies, targeting six central provinces (Mekong Institution, 2023).

Landscape Level

Thailand's rice sector faces significant landscape pressures arising from its international climate commitments, the competitive dynamics of global markets, and the increasing frequency of extreme climatic events. With respect to climate policy, Thailand's updated Nationally Determined Contributions (NDCs) under the Paris Agreement target a 30–40% reduction in GHG emissions by 2030 and carbon neutrality by 2050. Within this framework, low-methane rice cultivation has been identified as a key mitigation strategy, generating direct pressure on conventional farming practices (UNFCCC, 2022). From a market perspective, intensifying

competition, particularly from Vietnam's growing low-carbon rice sector, has motivated Thai policymakers to encourage the adoption of advanced agricultural technologies to maintain export competitiveness (VietnamPlus, 2026, Vietnam Law Megazine, 2025). Finally, climate-related disruptions, including droughts, floods, heatwaves, and extreme weather events, have already produced tangible production losses; a 10% output decline during the 2022–2023 drought period is one documented example (Ojo et al., 2025). Together, these pressures establish a landscape context in which the continuation of high-emission rice production becomes increasingly difficult to sustain.

Regime Level

Thailand's rice regime is characterized by a combination of environmentally unsustainable farming practices, financial dependencies, and demographic constraints, which collectively reinforce resistance to change. Thailand's conventional rice farming is heavily relied on water-intensive flooding, heavy chemical use, and stubble burning, generating significant GHG emissions and contributing to environmental degradation. Approximately 75% of the country's rice is rainfed, making it highly vulnerable to climate variability, including droughts and floods. The remaining 25%, mostly irrigated in the Central Plains, relies on continuous flooding and water-intensive practices, contributing to high CH_4 emissions and soil degradation (Dharma, 2021). Fertilizer and pesticide overuse further degrades soil and water quality, while stubble burning releases CH_4 and N_2O, causing air pollution and respiratory health risks.

These practices are reinforced by financial structures that reduce incentives for modernization. Thailand's Bank for Agriculture and Agricultural Cooperatives (BAAC) provide low-interest loans, while government subsidies, paddy pledging schemes, and soft loans entrench financial dependency and limit incentives for modernization (Welcher, 2017). This dynamic is compounded by demographic pressure. An aging farmer population coupled with high risk aversion, long-term investment limits and slows adoption of climate-smart practices (Pongsrihadulchai, 2018; Linne et al., 2021; Yasarapu et al., 2024). These interlocking features of the Thai rice regime, namely technological, financial, and demographic, constitute a system in which change is structurally constrained even under intensifying landscape pressure.

Niche Level and Project Implementation

Similar to the VnSAT, the Thai Rice NAMA project is analyzed as the niche-level intervention, constituting the principal protected space through which LCRC were promoted and scaled within Thailand's dominant rice regime. The project promotes low-carbon rice practices such as AWD, laser land levelling (LLL), site-specific nutrient management (SSNM), and straw management.

The Thai Rice NAMA introduced the Half-Half co-payment scheme to provide farmers and agripreneurs with financial support for LLL services that are essential to implementing climate-smart rice farming. Under Package 1, farmers receive a 50% pre-financing contribution and a 50% subsidy, with total support capped at 2,000 THB per rai. The scheme is designed to stimulate the demand side of the market by encouraging farmers to adopt rice production technologies and services, particularly LLL. Meanwhile, The Pro 2 scheme provides a 50% subsidy for service providers investing in LLL equipment, with a maximum subsidy of 200,000 THB per equipment set per person. This measure aims to strengthen the supply side of the market by increasing the availability of LLL services in response to the growing demand generated through Package 1 (ASEAN-Agrifood, 2022).

By the project's end, 2,544 farmer groups covering 319,526 hectares had adopted LCRC practices, achieving a 1.87 million ton of carbon dioxide equivalent reduction, or 93% of the project's target. Over 99,000 farmers and 4,599 "Smart Farmers" were trained, with the latter acting as local multipliers to disseminate knowledge within communities. Farmers reported 20% income increase through lower water, pumping, and nutrient costs, which reinforced wider uptake (Yasarapu et al., 2024).

Adoption was supported across multiple dimensions. At the institutional level, the project established multi-stakeholder coordination, including high-level advisory and steering committees, technical working groups integrating public and private actors, and sub-national actors. These structures ensure alignment with national policies, leveraged sector expertise, and facilitated local implementation. Financial mechanisms, including pre-financing and 50% subsidies for farmers and service providers, reduced perceived risk and increased technology uptake. This evolution revealed that the niche required not merely technical demonstration but financial de-risking to overcome behavioral barriers rooted in farmers' precarious economic situations. Complementary activities including demonstration plots, field training,

and community knowledge-sharing further reinforced adoption (Linne et al., 2022; Yasarapu et al., 2024).

Despite these enabling factors, several constraints limited the project's implementation and long-term sustainability. Coordination challenges arose from the absence of a central authority, leading to inconsistent actions and duplicated efforts. The financial instruments initially faced low uptake. The zero-interest Revolving Fund was avoided by indebted farmers, and the green loan program for service providers suffered from strict eligibility, mismatched targets, and delayed approvals. As a result, only EUR 8.19 million of the EUR 10.4 million public target and EUR 5 million of the EUR 10 million private target were mobilized. Market and infrastructure limitations further constrained impact. Only 92 out of the targeted 210 LLL service providers became operational, and the voluntary Thai Agricultural Standard (TAS) for sustainable rice offered no price premium, reducing incentives for continued adoption (Yasarapu et al., 2024).

Level Interaction

Thailand's rice transition illustrates how strong landscape pressures including international climate commitments, rising competition, and intensifying climate risks, pushed the regime toward sustainability. Yet, entrenched regime structures, including water-intensive flooding, subsidy-driven finance, and an aging, risk-averse farmer base, constrained change. Within this context, the Thai Rice NAMA project functioned as a protected niche, promoting LCRC technologies and financial innovations that achieved measurable emission and cost reductions. However, regime barriers such as the lack of price premiums, weak certification systems, and limited-service infrastructure restricted wider diffusion. These interactions reveal a moderated transition, where landscape pressures catalyze experimentation, but regime inertia slows systemic transformation.

Following the completion of the core Thai Rice NAMA project cycle, Thailand's focus has evolved toward institutionalizing these socio-technical frameworks within formal state climate policies (Mirzabaev et al., 2024). Current initiatives emphasize integrating localized rice cultivation metrics directly into national accounting systems, actively transitioning Thailand's agricultural registries from standard IPCC Tier 1 default coefficients to localized Tier 2 and Tier 3 data infrastructures to reliably verify sectoral methane reductions on a macro scale (Mirzabaev et al., 2024).

Table 2. MLP Components in Vietnam and Thailand's Low-Carbon Rice Transitions

MLP Level	Components	Thailand Case	Vietnam Case
Landscape	– International climate commitments – Global market trends – Climate change impacts	– NDC commitments – Rising global rice market competition – Droughts, floods, heatwaves, and extreme events	– NDC commitments – Rising demand and regulations for low-carbon exports (e.g. European Union) – Rising temperature, unpredictable rainfall, and extreme weather events
Regime	– Policy and institutional framework – Technological system – Farming practices – Land and social structure	– Government subsidies, paddy pledging schemes, soft loans – Irrigated systems in the Central Plains – Flooding, chemical use, stubble burning – Aging farmers, risk-averse, limiting investment and adoption of climate-smart practices	– Government priorities on food security, export competitiveness, and subsidies for fertilizers – Irrigation infrastructure enabling double and triple cropping – Chemical use, flooding, poor residue management – Small, fragmented holdings and insecure tenure limiting modernization
Niche	– Low-Carbon practices – Economic Incentives – Institutional Support – Value Chain / Network – Financial Mechanism – Challenges	– AWD, LLL, SSNM, straw management – Reduced input cost and increased income (20%) – Multi-actor coordination – Service providers, "Smart Farmers", demonstration plots – Pre-financing and 50% subsidies, low uptake of initial financial mechanism – Coordination gaps; limited-service providers; no price premium or contract farming	– 3R3G and 1M5R practice package and infrastructure investment – Reduced inputs (20-30%), increased profits (28-32%) – Centralized coordination and decentralized implementation, alignment with national plan – Farmer organizations, value chain actor – Wholesale banking leveraged additional funding – Rigid 50/50 grant allocation, high counterpart funding

Source: Author's compilation from the preceding analysis

3.3. Cross-cases Comparison

An examination of the MLP analyses of both VnSAT and Thai Rice NAMA reveals a consistent pattern in the factors that drive successful low-carbon transitions in the rice sector. At the niche level, the two cases point to four practical dimensions, including institutional coordination, financial mechanism, infrastructure and technical support, and market linkages, which determined whether niche innovations could build sufficient momentum to challenge regime practices. These dimensions represent the concrete mechanisms through which niche actors navigated regime resistance and responded to landscape pressures. Although each case unfolded under distinct institutional, economic, and policy contexts, these four key factors emerged as critical determinants not only for initial implementation but also sustaining and scaling low-carbon rice initiatives beyond the pilot stage. Table 3 consolidates the key enablers and barriers identified across both cases, organized along the four dimensions discussed above.

3.3.1. Institutional Coordination

The Vietnam case demonstrates how the centralized oversight of Vietnam's Ministry of Agriculture and Rural Development created a coherent policy environment in which strategic decisions were made efficiently, budgets allocated predictably, and provincial actors empowered to adapt practices to local contexts. This balance between central strategic leadership and decentralized implementation appears to have been key to VnSAT reaching over 184,000 hectares. Thailand's experience offers an instructive contrast. Despite strong multi-stakeholder committees, the absence of a central coordinating authority could easily lead to fragmentation, duplicated efforts in some areas, gaps in others, and coordination challenges that ultimately contributed to financing shortfalls. The lesson here is not simply that coordination matters, but that the structure of that coordination, particularly the presence of clear agency leadership, fundamentally shapes implementation speed and effectiveness.

3.3.2. Financial Mechanism

Financial mechanisms represent a second critical factor, though not in the straightforward sense of more money equals more success. What made a difference was how financial instruments were designed and delivered. For instance, VnSAT's wholesale banking model demonstrated that blended public-private financing could

mobilize investment far beyond initial targets, in this case, 243% of the USD 40 million goal. This approach worked because it reduced risk for both farmers and private investors simultaneously. Meanwhile, Thailand's financial mechanisms evolved over the project period precisely because initial instruments (the zero-interest revolving fund and the green loan program) faced low uptake due to eligibility restrictions, delayed approvals, and mismatch with farmers' actual financial situations. Once pre-financing and direct subsidies were introduced, adoption increased substantially. This suggests that financial mechanisms must be not only accessible but also aligned with the specific risk profiles and economic constraints of smallholder farmers.

3.3.3. Integrated Infrastructure and Technical Support

The third factor highlights the connection between technical practices and the infrastructure required to implement them effectively. VnSAT's rapid scaling of practices like AWD was not achieved through farmer training in isolation; it was accompanied by targeted infrastructure improvements such as better irrigation channels, field roads, access to mechanization, and reliable electricity for pumps. These investments ensured that when farmers attempted to implement new water management techniques, the physical systems could support those practices. Meanwhile, Thai Rice NAMA encountered the inverse situation: even with strong technical training programs and Smart Farmer multipliers, incomplete infrastructure, particularly the limited roll-out of laser land leveling services, constrained how widely and consistently practices could be adopted. In this case, infrastructure seems not a secondary consideration but a prerequisite for technical practice adoption.

3.3.4. Market Linkages and Value Chains

Both case studies revealed that while reduced input costs motivated initial adoption, sustained transition required demand-side mechanisms. For instance, VnSAT's contract farming arrangements and partnerships with lead firms created market pull for certified low-carbon rice, providing farmers with not just lower costs but higher revenues. By contrast, Thailand's voluntary TAS standard offered no price premium and limited buyer commitment, which reduced long-term incentive for continued adoption once project support ended. This distinction matters because it reveals that low-carbon transitions in rice are not purely technical or environmental shifts, but fundamentally economic transformations that require alignment between production practices and value chain structures.

What emerges from this cross-case analysis is that successful transitions are not driven by any single intervention but by the interaction of institutional structures, financial design, infrastructure capacity, and market integration. When these elements align, as they largely did in VnSAT, scaling accelerates. When any one of these dimensions is weak or misaligned, as occurred in various aspects of the Thai NAMA, the niche struggles to expand beyond protected project spaces.

Table 3. Enablers and Barriers to Scaling Low-Carbon Rice Programs

Dimension	Enablers	Barriers
Institutional Coordination	– Centralized oversight – Decentralized local execution – Capacity building – Multi-stakeholder committees integrating public and private actors	– Rigid program rules – Lack of central authority causing duplication and inconsistent actions
Financial Mechanism	– Blended public-private financing – Pre-financing and subsidies reducing adoption risks	– High co-funding obligations – Low uptake of financial instruments due to eligibility, delays, or mismatched targets
Integrated Infrastructure and Technical Support	– Small-scale infrastructure improvements (roads, irrigation, pumps, electricity) – Promotion of low-carbon practices – Demonstration plots and training	– Limited coverage of technical service providers or limited value chain involvement – Partial implementation of infrastructure and support
Market Linkage and Value Chain Development	– Contract farming and linkages with lead firms – Farmer multipliers for outreach – Improved market access	– Lack of price premiums – Market and infrastructure limitations

Source: Author's compilation based on the preceding analysis.

4. Cambodia's Low-Carbon Rice Context and Implications

4.1. Current Status of Low-Carbon Rice Cultivation in Cambodia

Cambodia is entering a critical transition phase in its rice sector, marked by growing policy attention to low-carbon and climate-resilient production. This shift reflects a broader national commitment to aligning agricultural development with climate objectives, innovative financing mechanisms, and evolving market requirements. Key national policies and technical frameworks, including Cambodia's NDCs, the Climate Change Strategic Plan (CCCSP), the Cambodia Sustainable Rice Platform (SRP) National Chapter, and related sectoral roadmaps, collectively emphasize the need to reduce GHG emissions, strengthen farm resilience, and integrate agriculture into emerging climate finance and market systems (DCC & MoE/RGC, 2025; NCSD, 2025; Swisscontact, n.d.). Together, these frameworks highlight priorities such as strengthening Monitoring, Reporting and Verification (MRV) systems, promoting climate finance instruments including carbon credits, scaling improved irrigation practices such as AWD, enhancing nutrient and water management, and fostering multi-stakeholder partnerships across government, farmers, the private sector, civil society, and development partners (DCC & MoE/RGC, 2025; NCSD, 2025; Swisscontact, n.d.).

Importantly, Cambodia is not starting from zero in this transition. Recent pilot initiatives, including Dei Meas, the Kanghot irrigation pilot, and the ThanksCarbon project, have demonstrated proof of concept across multiple dimensions of low-carbon rice production (ThanksCarbon, 2025; P. Vernet et al., 2025; P.-A. Vernet, 2023) (see Appendix B). These initiatives show that farmers can adopt improved practices, that MRV systems can function in the Cambodian context, and that institutional engagement is feasible. However, when Cambodia's current landscape is assessed against regional success factors, a more nuanced picture emerges. Progress is evident, but it remains uneven, and persistent structural constraints continue to limit scale and sustainability. Understanding these gaps is essential for determining where future policy attention and resources should be directed.

4.1.1. Institutional Coordination

The experience of the Dei Meas initiative highlights the catalytic role of government engagement. The participation of the Department of Agricultural Land Resources Management (DALRM) went beyond facilitating implementation; it enabled inter-

agency dialogue and created pathways for pilot-level learning to inform government planning (P.-A. Vernet, 2023). This suggests that institutional capacity and willingness to engage do exist within Cambodia's system. However, such engagement remains largely project-specific rather than systemic. Unlike Vietnam, which has a coordination structure led by its Ministry of Agriculture and Rural Development, Cambodia does not yet have a formal mechanism responsible for harmonizing technical standards, facilitating cross-project learning, or translating pilot evidence into national policy frameworks.

The absence of such coordination has practical consequences. Each pilot has generated valuable but siloed insights; for instance, Dei Meas on payment-for-practice models, Kanghot on infrastructure constraints, and ThanksCarbon on digital MRV systems (ThanksCarbon, 2025; P. Vernet et al., 2025; P.-A. Vernet, 2023). Yet these lessons remain largely confined to project channels rather than being systematically integrated into broader sectoral planning. Regional experience, particularly from Thailand, shows that without central coordination, duplication of effort, inconsistent protocols, and fragmented implementation can significantly slow progress (Yasarapu et al., 2024). Cambodia appears to be at a juncture where the foundations for stronger coordination exist, but the institutional architecture to leverage them at scale has not yet been established.

4.1.2. Financing Mechanisms

Cambodia's pilots have also demonstrated that well-designed financial incentives can change farmer behavior. Dei Meas showed that transparent annual payments for verified agroecological practices can motivate adoption even among smallholders with limited financial resources (P.A. Vernet, 2023). This confirms the viability of payment-for-practice models in the Cambodian context. However, the scale and structure of financing remain major constraints. Current initiatives rely heavily on donor and NGO funding and operate at scale sufficient for demonstration, but not for sector-wide transformation.

More critically, Cambodia has yet to develop a blended finance architecture comparable to Vietnam's VnSAT program, which mobilized USD 97 million by leveraging public funds to crowd in private capital (World Bank, 2023). While institutions such as the Agricultural and Rural Development Bank (ARDB) could potentially play a central role, their involvement in risk-sharing or wholesale financing mechanisms for low-carbon rice remains limited. Pilot-scale financing can

support experimentation and learning, but it cannot drive structural changes. The regional lesson is clear: scaling requires institutionalized financing mechanisms that combine concessional public finance with commercial lending to reduce risk and unlock private investment (World Bank, 2023; Yasarapu et al., 2024). Cambodia has demonstrated farmer responsiveness to incentives; what remains underdeveloped is the system to deliver those incentives beyond isolated projects.

4.1.3. Infrastructure and Technical Support

The Kanghot pilot brought Cambodia's physical constraints into sharp focus. Farmers attempting to implement AWD faced narrow and unreliable irrigation canals, malfunctioning drainage gates, and uneven fields that made controlled water management extremely difficult (P. Vernet et al., 2025) (see Appendix C). These constraints are not marginal; they directly undermine both practice adoption and the credibility of MRV systems. Where water levels cannot be controlled, AWD cannot be implemented consistently, and without consistent implementation, emission reduction claims lose integrity.

The project-bound limitations highlighted by early pilots are beginning to be addressed through commercial value-chain integration. Recent private sector-led initiatives in major production zones like Battambang Province are linking AWD protocols directly to international carbon credit markets via formalized contract farming networks. To mitigate the high operational costs and manual labor constraints identified in the Kanghot pilot, these modern initiatives integrate advanced technological tools specifically satellite remote sensing, IoT devices, and automated AI monitoring solutions like FieldSense—to establish scalable, cost-effective MRV frameworks that secure additionality compliance for smallholders (ThanksCarbon, 2025; P. Vernet et al., 2025).Vietnam's experience under VnSAT illustrates a contrasting approach, where infrastructure investment, including canal upgrades, improved field access, and mechanization, were integrated with farmer training (World Bank, 2023). This ensured that technical knowledge was matched by physical capacity. Cambodia's current situation more closely resembles constraints observed in parts of Thailand's Rice NAMA, where limited infrastructure restricted the spread of low-emission practices. While the ThanksCarbon pilot has demonstrated that digital MRV systems are technically feasible in Cambodia (ThanksCarbon, 2025), field evidence consistently points to infrastructure as the binding constraint. In effect, technical ambition has outpaced physical readiness.

4.1.4. Market Linkages and Value Chain Integration

Cambodia has begun to establish the foundations for market-linked sustainability. Dei Meas has supported farmers in building SRP certification capacity, and awareness is growing among exporters and processors that sustainability standards increasingly matter for market access (P.-A. Vernet, 2023). These developments represent important early steps in engaging the demand side of the value chain. However, they have not yet translated into robust contract farming arrangements or reliable price premiums for farmers.

By contrast, Vietnam's VnSAT benefited from strong buyer engagement and contract farming models that created clear market pull. Farmers understood the standards required, had assured buyers, and received tangible price incentives for compliance (World Bank, 2023). In Cambodia, certification processes are emerging, but downstream linkages—buyer commitments, contractual arrangements, and consistent price signals—remain weak. Thailand's experience with the TAS standard further illustrates that certification without economic incentives does not sustain adoption (Yasarapu et al., 2024). For low-carbon rice to scale, market linkages must be not only technically feasible but economically compelling.

In essence, these pilot initiatives demonstrate several important truths: institutional engagement can accelerate implementation; payment-based incentives coupled with MRV systems can change farmer behavior; and farmers can achieve sustainability certification. Yet Cambodia's low-carbon rice transition remains at a pilot-to-scaling threshold. Successes are largely confined within individual projects and have not yet overcome the structural barriers—fragmented coordination, limited financing scale, infrastructure deficits, and weak value chain integration—that separate niche experimentation from regime-level transformation.

Regional experience, particularly from Thailand, also cautions that even well-designed projects can struggle to scale when entrenched institutional and market structures remain unchanged. The critical question for Cambodia is therefore not whether low-carbon rice is technically or socially feasible, but whether forthcoming policy responses will explicitly address the specific institutional, financial, infrastructural, and market gaps identified above.

4.2. Policy Implications

Cambodia's emerging low-carbon rice agenda has moved beyond proof of concept and now faces the more complex challenge of system-wide scaling. Experiences

from recent pilots, when assessed alongside regional comparators, point to a consistent lesson: technical feasibility alone is insufficient. Scaling requires coordinated institutions, finance aligned with risk realities, infrastructure that enables practice adoption, market mechanisms that create demand pull, and supporting systems for MRV and extension. The following sections reorganize these challenges into coherent policy pillars, drawing explicit lessons from Cambodia, Vietnam, and Thailand to inform strategic next steps.

4.2.1. Strengthening Institutional Coordination and Policy Integration

Cambodia currently hosts multiple low-carbon rice initiatives operating in parallel. While each generates valuable insights, these lessons are not yet systematically integrated into sector-wide planning. Dei Meas initiative illustrates the benefits of direct government engagement: DALRM's involvement accelerated implementation and enabled institutional learning (P.-A. Vernet, 2023). However, this coordination remains informal and project-specific rather than institutionalized at the national level. In Vietnam's case, Ministry of Agriculture and Rural Development's role extended beyond oversight to include harmonizing technical standards, translating pilot evidence into policy, and aligning budget allocations with strategic objectives. This institutional architecture enabled scaling by supporting expansion beyond pilot regions (World Bank, 2023). Conversely, Thailand's experience offers a cautionary counterpoint. Despite multiple committees and technical working groups, unclear leadership led to coordination gaps, duplicated efforts, and inconsistent implementation, contributing to financing shortfalls (Yasarapu et al., 2024).

For Cambodia, this suggests that building on the positive experience with DALRM could involve formalizing the agency's coordinating role at a national level to harmonize standards and create pathways for pilot learnings to become sectoral policy. Strengthening efforts to formalize agency leadership will be critical for determining whether localized successes can become system-wide transformations.

4.2.2. Designing Financing Mechanisms Aligned with Risk and Scale Requirements

Cambodia's pilot proved that transparent payment-for-practice models work for Cambodian smallholders, overcoming behavioral and risk barriers. However, the scale of this financing remains constrained by its reliance on donor and NGO channels, and Cambodia has not yet developed a mechanism to leverage this proven model at a sector-wide scale (P.-A. Vernet, 2023). VnSAT's wholesale banking model provides a potential template. By using concessional finance as a first-loss

layer, the program reduced risk for private banks and agribusinesses, mobilizing large-scale investment across the rice value chain (World Bank, 2023). Meanwhile, lessons from the Thai Rice NAMA further indicate that financial instruments must be accessible and aligned with farmers' actual economic situations to avoid low uptake (Yasarapu et al., 2024).

For Cambodia, effective financing mechanisms must combine accessibility, scale, and risk reduction. Financial mechanisms such as blended finance facility, developed in partnership between development banks like the Agricultural and Rural Development Bank (ARDB), development partners, and the private sector, could build on the proven payment-for-practice model while incorporating wholesale finance structures. In this sense, the challenge is no longer farmer willingness, but institutional capacity to deliver incentives at scale.

4.2.3. Aligning Infrastructure Investment with Technical Ambition

Evidence from the Kanghot pilot identified infrastructure as the binding constraint on the implementation of AWD. Narrow canals, unreliable drainage systems, and uneven fields made water management inconsistent, undermining both practice adoption and MRV credibility (P. Vernet et al., 2025). These constraints reveal that training and incentives alone are insufficient when physical systems cannot support promoted practices. Regional experiences highlight that effective water management infrastructure is an essential foundation for the practical adoption of low-carbon rice practices. For instance, VnSAT integrated infrastructure upgrades with technical training, ensuring that farmers could implement new practices effectively.

In contrast, Cambodia's current situation resembles the constraints in Thailand, where technical ambition has outpaced physical capacity (Yasarapu et al., 2024). Hence, since Cambodia aims to promote large scale of AWD adoption in rice, irrigation upgrades must be planned concurrently with technical promotion rather than treated as a separate, sequential workstream (DCC & MoE/RGC, 2025; NCSD, 2025).

4.2.4. Building Market Linkages to Create Demand Pull

While Cambodia has made early progress on SRP certification through Dei Meas and related initiatives (P.-A. Vernet, 2023), certification alone does not drive sustained adoption; market linkages also play a crucial role. The success of VnSAT was driven by contract farming arrangements and buyer commitments that provided

clear price premiums and reduced market risk, creating a tangible market pull and making the transition economically rational for farmers (World Bank, 2023). Conversely, Thailand's TAS standard showed that voluntary certification without price incentives reduced the long-term incentive for continued adoption once project support ended (Yasarapu et al., 2024). For Cambodia, emerging certification efforts must therefore be linked to concrete value chain mechanisms, including contracts, buyer guarantees, and premium pricing. Market mechanisms must create pull for certified production, as adoption becomes self-reinforcing only when it is economically advantageous.

4.2.5. Investing in MRV Systems as Enabling Infrastructure

Regional experiences show that MRV systems function not merely as reporting tools, but as enablers of finance and market access. Vietnam and Thailand invested early in MRV to unlock results-based payments and carbon revenues. Cambodia's ThanksCarbon pilot confirms the technical feasibility of digital MRV systems (ThanksCarbon, 2025), but scale remains limited. Consequently, the implementation of a national MRV architecture must follow a structured institutional timeline. MAFF's strategic framework establishes a clear three-phase transition: a short-term readiness and piloting phase (1–2 years), a medium-term phase (2–5 years) focused on scaling proven practices and developing localized, Cambodia-specific (Tier 2) emission factors, and a long-term phase (5+ years) to fully mainstream low-emission rice into national planning. To operationalize this hierarchy, the General Directorate of Agronomy (GDA/MAFF) has proposed an integrated data monitoring protocol encompassing explicit reporting channels, quality assurance safeguards, and a digital MRV platform equipped with spatial visualization capabilities to track real-time rice production progress and verified mitigation outcomes (Sony, 2026). Basically, MRV should be treated as infrastructure and this requires standardized protocols, operational feasibility at farm level, and scalability beyond pilots. Investment in MRV capacity will reinforce financing mechanisms and credibility with international partners.

4.2.6. Institutionalizing Extension and Peer-Learning Models

Both Vietnam and Thailand found peer-based learning more effective than conventional extension. Smart Farmers, demonstration plots, and farmer groups accelerated adoption by building trust and practical understanding (World Bank, 2023; Yasarapu et al., 2024). Cambodia's pilots have applied similar approaches, but

they remain project-bound. Scaling adoption requires institutionalizing peer-learning within the national extension system. This involves reorienting extension agents toward facilitation, supporting local champions, and leveraging cooperatives and farmer organizations. Evidence suggests this shift significantly accelerates adoption when combined with supportive finance, infrastructure, and market incentives.

Table 4: Policy Priorities for Cambodia's Low Carbon Rice Transition

Policy Priority	What Works	Cambodia's Current State	Action Needed
Strengthening Institutional Coordination	Central authority enables harmonized standards and policy-level uptake of pilot learnings	Coordination is informal and project-specific	Formalize national-level coordinating role; create pathways for pilot findings to inform sectoral policy
Design Blended Finance	Wholesale banking model reduces risk for farmers, banks, and processors simultaneously	Payment-for-practice proven; scale remains constrained	Build blended finance facility; match financial instruments to farmer risk profiles
Align Infrastructure with Technical Practices	Infrastructure and technical support must be concurrent, not sequential (VnSAT model)	Infrastructure as binding constraint; uneven fields, narrow canals, unreliable gates prevent AWD	Synchronize irrigation system upgrades with technical promotion; target infrastructure in zones planned for AWD scaling
Build Market-Driven Value Chains	Contract farming and price premiums create pull for certified production	Certification capacity emerging; market linkages weak and inconsistent	Link SRP certification to contract farming pilots; engage international buyers; communicate market demand

Policy Priority	What Works	Cambodia's Current State	Action Needed
Scale MRV as Financial Infrastructure	Credible MRV enables climate finance access and results-based payments	Proves feasibility; not yet standard practice across initiatives	Standardize MRV protocols; scale digital/sensor-based systems; connect to climate finance flows
Institutionalize Farmer-Led Extension	Peer-to-peer learning and demonstration plots are more effective than classroom training	Pilots use farmer groups successfully; not yet integrated into broader extension system	Shift extension focuses toward facilitating farmer-to-farmer learning; support local champions as multipliers

Source: Author's compilation based on the preceding analysis.

5. Conclusion

The transition to low-carbon rice cultivation in Southeast Asia reveals a consistent pattern: success depends not on any single intervention but on the coordination of institutional structures, financial mechanisms, infrastructure capacity, and market linkages. Vietnam's VnSAT project achieved rapid scaling because these elements reinforced each other, where centralized policy coordination provided strategic direction, blended public-private financing reduced risk for all parties, targeted infrastructure improvements enabled practical adoption, and contract farming created reliable market demand. On the other hand, Thailand's Rice NAMA, while demonstrating that strong landscape pressures can drive innovation, encountered constraints when these elements remained misaligned, particularly in coordination architecture and financial design.

Cambodia stands at a critical juncture where pilot-scale initiatives have proven the technical and economic viability of low-carbon practices, but the transition from niche experimentation to sector-wide transformation requires deliberate action on four fronts: formalizing institutional coordination beyond project channels, scaling financial mechanisms from donor-dependent models to blended finance facilities, synchronizing infrastructure investment with technical promotion rather than treating them sequentially, and developing value chain linkages that create genuine

market pull for certified production. The evidence from regional cases suggests that without these structural supports, adoption will plateau at demonstration scale regardless of how effectively individual projects are implemented.

6. Future Research Agenda

This study is subject to several limitations that should be acknowledged to contextualize its findings and guide future research. First, the research relies primarily on publicly available secondary data, such as official reports and academic publications. While this approach allows for a broad comparative analysis, it inherently misses insights from unpublished documents or direct, on-the-ground experiences. Second, the paper's discussion of the Cambodian context is intentionally framed by the experiences of a few foundational pilot projects for which official reports were available. This approach is useful for drawing specific, targeted lessons, but it is important to acknowledge that these pilots represent a starting point, not the entire landscape of LCRC in the country. The resulting baseline, therefore, offers a strategic snapshot rather than a comprehensive national assessment, and the perspectives may not encompass all actors involved in Cambodia's evolving agricultural transition. Lastly, the focus on Thailand and Vietnam provides a valuable but not the whole picture of LCRC transitions in the region. The specific institutional and economic factors in other ASEAN countries could offer additional, different lessons that are beyond the scope of this paper.

To build upon this analysis, future research should aim to develop a more comprehensive picture of Cambodia's LCRC ecosystem. For instance, a broad-based study that maps all relevant projects (from small pilots to larger commercial ventures and other related initiatives) and identifies the full range of stakeholders involved would provide a more robust baseline for national strategy development. Moreover, future research could focus on the farmer's perspective through field interviews and surveys to better understand the direct costs, benefits, and practical barriers they face when adopting new techniques. Additionally, a detailed economic analysis, such as a cost-benefit study of LCRC adoption for smallholder farmers in different regions of Cambodia, would provide the quantitative evidence needed to design more effective and equitable financial support mechanism.

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Appendices

Appendix A

Rice Production and Management Practices Promoted by the Project

Three reductions, three gains (3R3G): 3R3G evolved from the promotion of 'integrated pest management' practices and aims to reduce input requirements without sacrificing yield. The three reductions encompass a reduction of seed rate, fertilizer use, and insecticide spraying. The three gains are an increase in yield, quality of farm produce, and net farm profit.

One Must Do, Five Reductions (1M5R): 1M5R is also an integrated technology package that aims to promote best management practices in lowland rice cultivation. It was developed using the requirements specified in the 3R3G practice, whereby the package promotes the use of certified seeds, which is the 'One Must Do' combined with five reductions, which encompass the reduction of seed rate, fertilizer use, pesticide use, water use, and post-harvest losses.

Source: World Bank, 2023

Appendix B

Initiatives	Implementers	Core Objective	Key Actors
Kanghot AWD	Swisscontact, CIRAD, WAT4CAM Phase 1	Test field-level AWD implementation	Farmers' Water User Community (FWUC); Department of Agricultural Land Resources Management (DALRM)
Dei Meas	Swisscontact, CIRAD, ASSET program	Develop transition pathways toward agroecological rice systems (including AWD)	DALRM/GDA; Provincial Department of Agriculture, Forestry and Fisheries (PDAFF); private finance partners
ThanksCarbon	ThanksCarbon; CPDD	Deploy satellite-based AWD monitoring linked to carbon-credit incentives	Coalition for Democratic Development (CPDD); provincial agriculture offices; local Farmers' Water User Community (FWUC)

Source: Author's conceptualization based on existing literature.

Appendix C

Key Lessons from Kanghot AWD Pilot and ThanksCarbon Pilot

In Battambang, two pilot projects tested different models for linking Alternate Wetting and Drying (AWD) with financial incentives. The Kanghot pilot offered direct payments of USD 20 per hectare to reward practice, aiming to support an agroecological transition and collective farming. The Thanks Carbon pilot emphasized rewards for results, demonstrating a 13.9 percent yield increase alongside methane reductions to establish the viability of large-scale carbon credit projects. Both showed that while AWD delivers tangible agronomic benefits such as stronger stems and reduced lodging, sustained farmer participation depends on combining technical guidance with financial incentives.

A critical lesson across both pilots was the need for robust Monitoring, Reporting, and Verification (MRV). Manual data collection proved too labor-intensive, pointing to the necessity of advanced tools such as remote sensing, IoT-based water sensors, and AI systems like FieldSense to ensure accuracy and keep costs manageable for carbon credit certification. Structural constraints, however, remain significant. In Kanghot pilot, uneven land levels, elevation differences, and uncontrolled "wild tubes" disrupted water control, adding pumping costs for some farmers. Baseline assessments also revealed widespread "Natural AWD," with fields below water level 37-53 percent of the time, raising concerns about meeting the additionality requirement that underpins carbon market credibility.

These experiences highlight both the promise and fragility of carbon-financed low-carbon rice transitions. For initiatives to scale, future projects will need careful baseline mapping, infrastructure improvements, and financial mechanisms that can deliver reliable credit revenues. Only with these safeguards can AWD adoption provide farmers with stable, long-term benefits while generating verifiable climate outcomes.

Source: ThanksCarbon, 2025; P. Vernet et al., 2025

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