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Assessing the Carbon Trading Potential and Economic Efficiency of Low-Emission Rice Farming in the Mekong Delta: Evidence from Thang Loi Cooperative

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List of Acronyms

AFOLU	Agriculture, Forestry and Other Land Use
AWD	Alternate Wetting and Drying
CGIAR	Consultative Group on International Agricultural Research
CH_4	Methane
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
ECD	Economics of Development
EKC	Environmental Kuznets Curve
GHG	Greenhouse Gas
GSO	General Statistics Office (Viet Nam)
GWP100	100-year Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
IRRI	International Rice Research Institute
ISS	International Institute of Social Studies
MAC	Marginal Abatement Cost
MARD	Ministry of Agriculture and Rural Development (Viet Nam)
MONRE	Ministry of Natural Resources and Environment (Viet Nam)
MRV	Measurement, Reporting and Verification
RBCF	Results-Based Climate Finance
RBP	Results-Based Payment
SSNM	Site-Specific Nutrient Management
tCO_2e	tonne of Carbon Dioxide Equivalent
UEH	University of Economics Ho Chi Minh City
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar
VCS	Verified Carbon Standard
VND	Vietnamese Dong

Abstract

This thesis examines whether low-emission rice production can simultaneously reduce greenhouse gas (GHG) emissions and increase agricultural incomes under real-world conditions for smallholder farmers, and how these results can be translated into carbon finance opportunities for the Vietnamese rice sector. The thesis analyzes a pilot model on an area of 43.1 hectares implemented by 20 households at Thang Loi Agricultural Cooperative (Lang Bien commune, Thap Muoi district, Dong Thap province) in the autumn-winter 2024 crop under the national program "One Million Hectares of High-Quality, Low-Emission Rice Sustainable Development Project linked to Green Growth in the Mekong Delta by 2030". The pilot model applies a bundle package of practices – alternate wetting and drying (AWD), site-specific nutrient management (SSNM), mechanical direct seeding with lower seed rates, short-duration varieties, and straw management – designed to reduce emissions intensity while improving production efficiency.

A before-after quasi-experimental design was combined with the 2019 IPCC Tier-2 rice methodology to estimate seasonal methane emissions, using national baseline emission factors and observed management measures. Cooperative accounting data were used to construct both an "engineering" marginal abatement cost (MAC, based on production costs) and a "private" MAC (based on net profits) for the bundled intervention. Results showed that the bundle packages reduced emissions by approximately 4.9 tCO_2 equivalent per hectare compared to continuous flooding and conventional straw burning, while simultaneously increasing yield, reducing production costs per unit of output, and increasing net profits per hectare. At the cooperative scale, the pilot project delivered approximately 212 tCO_2 equivalent mitigation over a season, providing a credible volume for participation in emerging carbon markets.

The estimated MACs are strongly negative, meaning that each tonne of CO_2 equivalent reduced is associated with cost savings and increased farm income, and this finding remains robust to careful sensitivity tests of productivity, costs, and global warming potential. Plotting the joint change in emissions and income in the Environmental Kuznets Curve (EKC) space reveals a clear "bend" towards higher incomes and lower emissions at relatively low income levels, emphasizing the role of targeted technological and institutional interventions rather than income growth alone. By integrating the Tier- 2 compatibility measure, empirical MAC estimates, micro EKC interpretations, and carbon price benchmarks, this thesis provides new evidence on the economics of emissions reductions from smallholder and offers specific design insights for results-based payment schemes and carbon trading programs in the rice sector in Vietnam.

Relevance to Development Research

This topic is highly relevant to Development Research as it addresses climate action including climate smart farming techniques and GHG emission reductions. Using the MAC framework, this thesis identifies low-emission rice farming bundle practice helps reduce CO_2 emissions while increasing farmers income through carbon trading scheme. By linking local farming practices with global climate finance, this thesis approaches to sustainable development which supports for a more climate-resilient and economically benefits for smallholder farmers. This aligns with key Sustainable Development Goals (SDGs), including Zero Hunger (SDG 2), Climate Action (SDG 13) and Economic Growth (SDG 8) (UN 2030 Agenda).

Keywords
Low-emission rice farming, carbon trading, emission mitigation, Marginal Abatement Cost (MAC), Environmental Kuznets Curve, Mekong Delta (Vietnam).

Chapter 1 Introduction

Internationally, Vietnam is recognized as one of the world's leading rice producers and exporters, a position that has played a central role in its rural development and food security strategies. In particular, the Mekong Delta plays an important role—contributing more than half of the country's total rice output and supplying approximately 90% of rice exports (GSO, 2023). Despite its achievements, the rice industry still faces challenges that need to be addressed.

Acccording to World Bank 2022, namely rice which is Vietnam's most important crop and grown on more than half of its agricultural land area, accounts for 48% of the agriculture sector's GHG emissions and over 75 percent of methane emissions (World Bank, 2022), with the Mekong Delta being the largest emitter. On the one hand, uncertain farming practices like continuous flooding (CF), high seed rates, improper pest management not only contribute greatly to the increase in production costs, causing waste, resource depletion, and negative impacts on the environment but also increasing GHG emissions. On the other hand, rice farmers' incomes remain disproportionately low relative to the price of rice due to small production scale, high input and production costs, inefficiencies in the rice value chain (including fragmentation and weak vertical coordination), and limited integration of farmers with agribusiness or cooperative organisations.For example, in the total cost of final rice products, farmers contributed the highest rates of 70% compared with traders is 17% and wholesalers 5%, respectively, while the profit-cost ratio (profit/cost) of the famers is the lowest with only 19% because of the cost of paddy production paid by farmers always the highest (Thang, 2017). Fragmented value chains and weak linkages with businesses further constrain farmers' ability to benefit from export or high-value markets (Do at el., 2018). These structural conditions raise significant concerns about the long-term sustainability of current production models, especially given Vietnam's ambitious climate-mitigation commitments. These trends raise important questions about the long-term sustainability of current production methods, especially in light of Vietnam's ambitious climate commitments.

In 2021, the Government committed to achieving net zero emissions by 2050, aligning its domestic policy framework with international climate targets under the Paris Agreement (Government of Vietnam, 2021). A key policy step towards this goal was the Prime Minister's approval in November 2023 of the "One Million Hectares of High-Quality, Low-Emission Rice Sustainable Development Project linked to Green Growth in the Mekong Delta by 2030". Supported by international development partners including the World Bank, IRRI and CGIAR, the initiative aims to transform rice farming in the Mekong Delta from a high-emission sector to one that is both climate resilient and carbon-credit ready (World Bank, 2023; IRRI, 2023).

While the technical potential of low-emission practices—such as alternate wetting and drying (AWD), site-specific nutrient management (SSNM), mechanised direct seeding, improved straw handling, and Integrated Pest Management (IPM) to Reduced Agro-chemical Usage — have been widely acknowledged in the Mekong Delta "Low Emissions and Climate Smart Farming Practices" (IRRI, 2019; CGIAR, 2023), there remains limited empirical evidence on two critical fronts.

First, although bundle climate-smart farming interventions are promoted in practice, few studies have measured the actual GHG emission reductions achieved under real smallholder conditions in the Mekong Delta. Most estimates are derived from model simulations or isolated trials, making it difficult to assess real-world performance. Second, and more critically, there is a lack of evidence on the marginal abatement cost (MAC) of these practices—that is, the additional cost or savings per tonne of CO_2-equivalent reduced when shifting from traditional to low-emission farming. Without such evidence, it is difficult to design effective carbon pricing schemes or results-based payment models that reward farmers for adopting these practices.

This study directly addresses these gaps by evaluating the pilot project as a bundle intervention, using actual field data on inputs, and CO_2-equivalent reductions from an actual site. Emissions are estimated using the Tier 2 methodology from the 2019 IPCC Refinement for Rice Systems. A Marginal Abatement Cost (MAC) is calculated for the bundle model by comparing the net benefit per hectare and emission reductions relative to a conventional rice farming baseline. Sensitivity analysis is conducted under different carbon price and cost/yield scenarios to test robustness. Where disaggregated data is unavailable, literature-based estimates are triangulated to contextualise findings.

In addition to the MAC framework, this research also applies the Environmental Kuznets Curve (EKC) as a broader analytical lens. The EKC hypothesises an inverted U-shaped relationship between environmental degradation and income: as incomes rise, environmental quality initially deteriorates, then improves after a turning point due to the adoption of cleaner technologies. This study examines whether low-emission rice farming—as bundle in the pilot—offers an early pathway to reduce emissions while increasing farm profitability, thus potentially "bending the curve" earlier than predicted by traditional EKC trajectories.

1.1 My research motivation and personal interests

Coming from an agricultural background, my family used to depend on rice farming to live. I am well aware of the challenges faced by rice farmers. Climate change, storms and floods have significantly affected agriculture in Vietnam, especially in the Mekong Delta, which is considered a vulnerable region to climate change. This research is motivated by the urgent need to develop empirical information on the performance and cost-effectiveness of low-emission rice cultivation in the Mekong Delta, Vietnam, which is important for national food security but also a major source of methane emissions. Although climate-smart techniques are widely recommended, few studies have quantified their actual GHG emission reductions under smallholder conditions, and even fewer have estimated their marginal mitigation costs. Without this information, it is difficult to develop effective carbon pricing or results-based payment mechanisms. This study bridges the gap by analyzing pilot-scale evidence from the Thang Loi Cooperative, which directly contributes to GHG emissions reductions and prepares Vietnam's carbon market (World Bank, 2023; Verra, 2023).

1.2 Novelty of the study and thesis structure

Using data from the Thang Loi Agricultural Cooperative under "One Million Hectares of High-Quality, Low-Emission Rice Sustainable Development Project linked to Green Growth in the Mekong Delta by 2030" Program, this thesis makes a novel contribution by empirically evaluating the economic efficiency and carbon trading potential of an integrated bundle low-emission farming model in the Mekong Delta. Unlike most studies that rely on simulation models or single field experiments, this study combines Tier 2 compatible emissions estimates, marginal abatement cost (MAC) analysis, and sensitivity testing into an integrated set of practices adopted by smallholder farmers. In this way, the thesis establishes a direct link between results-based climate finance design and carbon market development for rice and field-level mitigation outcomes.The thesis is organized into five chapters. The first chapter has explained the study problem, farming context, and research questions. Chapter 2 examines worldwide and Vietnamese literature on rice-sector emissions, MACs, carbon pricing, results-based payment systems, and agricultural transition theories to identify the gaps that this study fills. Chapter 3 describes the conceptual framework and methods, which include the emission estimating method, data sources, and MAC construction. Chapter 4 presents and examines empirical findings on emissions, costs, MACs, Environmental Kuznets Curve, and carbon trading potential on a cooperative scale. Chapter 5 concludes the thesis by synthesizing the key findings, explaining policy implications for Vietnam's rice sector, and proposing future study areas.

Chapter 2 Literature Review

2.1 Empirical GHG Reduction Evidence of Rice Cultivation in Mekong Delta

Across Southeast Asia, rice cultivation especially continuous irrigated paddy rice remains one of the largest agricultural GHG emissions sources. The IPCC finds that methane (CH_4) from continuously flooded paddy fields in Asian production systems is a major contributor to agricultural emissions globally (IPCC, 2022). Traditional rice cultivation practices in the Mekong Delta are characterised by prolonged flooding, high seeding rates and heavy use of nitrogen fertiliser. These conditions lead to oxygen poor (anaerobic) soils that produce large methane emissions, making rice farming is one of the sources of GHG in Vietnam's agriculture. As state at recent national GHG inventory reports and sectoral studies estimate that rice contributes approximately 48% of total agricultural GHG emissions, making mitigation efforts in the rice sector especially critical (MONRE, 2022).

Aside from the general scarcity of crop management data, the computation of national GHG emissions from rice production systems is hampered by a lack of GHG measurements to estimate country-specific emission factors (EFs) and research on EFs in Vietnam's rice systems reveals great diversity. For example, Vo et al. (2020) conducted a meta-analysis across 36 field locations spanning 73 cropping seasons and reported average CH_4 emission rates for late-season rice in southern Vietnam at around 3.58 kg CH_4 ha^{-1} day^{-1}. This amount significantly surpasses the Tier-1 defaults proposed by the Intergovernmental Panel on Climate Change (IPCC, 2019), highlighting the importance of locally-adapted Tier-2 emission variables. The meta-analysis highlights not only the volume of emissions from traditional continuous flooding, but also the sensitivity of EFs to water regime, organic amendments, and crop duration, all of which are precisely the levers targeted by climate-smart rice interventions.

Enhancing water management is one of the keys. According to International Rice Research Institute (IRRI), Alternate Wetting and Drying (AWD) is a simple and economical method of reducing water usage in rice production by 30%, allowing farmers to reduce production expenses while maintaining yield. AWD includes periodically draining the field to a specified level, usually 15 cm below the soil surface, and then re-flooding. A perforated tube inserted in the soil allows the farmer to monitor the water level beneath the soil surface and determine when to irrigate. The AWD system has also been shown to effectively reduce GHG emissions, notably CH_4 from rice production by 30-70% without reducing output (IRRI,2019). During the dry stages, methane-producing sources are suppressed, resulting in reduced GHG emissions. Multi-location field trials across Southeast Asia, including Sander et al. (2017) confirm substantial reductions in seasonal CH_4 under AWD and related water-saving regimes. Similarly, Shrestha, Sander and Babel (2020) find that AWD combined with improved nutrient management reduces both emissions and water use in irrigated systems, though the magnitude of benefits varies with local hydrology and fertiliser practices.

Despite these promising results, much of the evidence base still comes from researcher-managed trials. Many AWD and climate-smart rice experiments are conducted on small plots under close supervision, with controlled irrigation and fertiliser schedules that may not reflect the constraints of smallholder farmers (IRRI, 2019; Vo et al., 2020). In the Viet Nam context, Vo et al. (2020) note that Tier 2 emission factors largely pool data from experimental sites and short-term pilots, which are essential for inventory development but provide limited insight into how mitigation performance changes under real cooperative management, variable irrigation reliability and partial adoption.

Another gap concerns how climate-smart practices are implemented in combination. Most empirical studies examine single interventions—such as AWD, reduced nitrogen, straw incorporation or mulch—rather than the bundles of practices now promoted in programmes like Viet Nam's "One Million Hectares of High-Quality, Low-Emission Rice Sustainable Development Project linked to Green Growth in the Mekong Delta by 2030" initiative. Research on bundle packages that combine water management, site-specific nutrient management (SSNM), mechanised direct seeding, short-duration varieties and improved residue handling under genuinely smallholder management remains scarce (Nguyen et al., 2020; Richards et al., 2014). For example, Sander et al. (2017) report an approximately 25% reduction in combined CH_4 and N_2O emissions in a Cambodian rice case that adopted elements of AWD and improved residue management, but provide limited information on scale, cost structures or cooperative-level adoption conditions

When all of the evidence is taken into account, two major conclusions emerge. First, the technological mitigation potential of rice-sector activities in the Mekong region is well documented, especially for AWD and SSNM under controlled settings. Second, there is still a scarcity of pilot-scale, farmer-managed evidence on how bundle low-emission models function in the Mekong Delta in terms of emissions and financial consequences. This immediately prompts to the first research question: Can a bundle of climate smart practices, implemented by smallholder farmers under real conditions, significantly reduce GHG emissions and what is the magnitude of such reduction focus on the 43.1-hectare pilot at Thang Loi Agricultural Cooperative in Lang Bien commune, Thap Muoi district, Dong Thap province.

2.2 Marginal Abatement Cost Concept and Economic Efficiency in Agricultural Mitigation

The Marginal Abatement Cost (MAC) concept summarizes the cost of reducing an additional ton of GHG emissions and is widely used to compare mitigation options across sectors. In its simplest form, the MAC ranks measures by cost per ton of CO_2 equivalent and show their accumulative emission reduction potential. In agriculture, the MAC has been used to evaluate climate-smart interventions such as improved fertilizer management, manure treatment, and low-emission farming practices, and to identify "negative cost" options that both reduce emissions and increase profits (Bockel et al., 2012; Moran et al., 2011; Eory et al., 2018).

The IPCC report highlights that substantial mitigation in the Agriculture, Forestry and Other Land Use (AFOLU) sector can be achieved without reducing food production and with potential yield improvements, provided livelihoods and food security are safeguarded (IPCC, 2022). This implies that MAC estimates in agriculture therefore need to be interpreted jointly with agronomic feasibility, risk and distributional considerations, rather than as purely engineering numbers. In practice, this means that MAC analysis should be embedded in a broader assessment that considers extension systems, credit constraints, labour markets and the transaction costs of measurement, reporting and verification (MRV).

Despite a strong methodological foundation, empirical MAC applications in smallholder farmers remain limited. Eory et al. (2018), reviewing more than 60 agricultural MAC studies, find that fewer than 20% are based on farm-level primary data; most rely on simulation models, expert judgement or partial budget assumptions. They also found that agricultural MAC curves are highly sensitive to assumptions about adoption rates, labour costs, and commodity prices — variables that are typically volatile in developing economies. This sensitivity reinforces the importance of deriving MACs from real pilot data where possible, and of documenting the assumptions used in MAC construction transparently.

For irrigated rice, empirical MAC work is still relatively rare but provides important benchmarks. Shrestha, Sander and Babel (2020) analyse mitigation options in Thai rice systems and report negative MACs for AWD (around –USD 12 tCO_2e) and for SSNM (around –USD 4 tCO_2e), indicating that these practices reduce emissions while lowering production costs. By contrast, straw composting and some residue management options are associated with positive MACs in the range of USD 18–25 tCO_2e, suggesting that they are unlikely to be adopted at scale without carbon payments or other financial support. Similarly, the International Rice Research Institute (IRRI, 2019) found that combined adoption of AWD and precision nutrient management can achieve substantial emission reductions with modest net cost savings on research-managed demonstration farms, but emphasises that economic outcomes vary with local labour markets and input prices.

Recent contributions also point out the limitations of MAC curves when used in isolation. Richards, Wollenberg and van Asselt (2022) argue that MAC analysis often downplays real-world adoption frictions—such as risk perceptions, tenure insecurity and missing markets for services like straw collection or water scheduling—so that even "negative-cost" practices may diffuse slowly unless farmers have access to advisory support, finance and predictable incentives. In Viet Nam's rice sector, smallholder farmers typically face high transaction costs and depend on intermediaries such as cooperatives, traders and millers for information and market access (World Bank, 2022). As a result, headline negative MACs do not automatically translate into rapid adoption.

A cross-cutting limitation in the existing MAC and rice mitigation literature concerns the treatment of uncertainty. Many studies report point estimates of abatement and cost without systematically examining how results change when key assumptions are altered, such as baseline emission factors, yield responses, input prices or carbon prices. Where sensitivity analysis is conducted, it often focuses only on alternative carbon-price scenarios or single-parameter changes, rather than jointly testing the robustness of both baseline and mitigation scenarios under realistic smallholder conditions (Kesicki and Ekins, 2012; Bockel et al., 2012; Eory et al., 2018). Rice-sector work for Southeast Asia, including Sander et al. (2017) and Shrestha, Sander and Babel (2020), sometimes presents ranges of emission reductions, but rarely distinguishes clearly between uncertainties in the conventional baseline and those in the pilot interventions.

This thesis addresses these gaps by developing MAC estimates of both engineering costs and private net returns (net profits) for low-emission rice at the Thang Loi Cooperative. This analysis links IPCC Tier-2 methane emissions calculations with actual plot-level cost and revenue data from the pilot,and then embeds these results in a results-based sensitivity framework. Key parameters such as yield, output price, and carbon price are varied within realistics ranges to test how robust the MAC outcomes are (IPCC, 2019; Eory et al., 2018). In this way, the thesis aims to provide a transparent, data-driven representation of MAC that reflects the variability observed in empirical studies of rice farming, while still being directly interpretable to policymakers designing incentive programs and to cooperatives considering carbon market participation.

2.3 Carbon Pricing, Results-Based Payments, and Climate Finance

As Vietnam step by step enters to implement Nationally Determined Contributions (NDCs) under the Paris Agreement, carbon pricing and results-based payment (RBP) mechanisms have gained prominence to incentives mitigation beyond the energy and industrial sectors. The World Bank's "State and Trends in Carbon Pricing 2023" report said that carbon taxes, emissions trading systems (ETS), and crediting mechanisms together cover about 23% of global GHG emissions, with annual revenues from carbon taxes and ETS amounting to nearly US$95 billion (World Bank, 2023). Within this context, irrigated rice emerges as a promising but under-exploited candidate for carbon finance: irrigated rice is highly emission-intensive, mitigation options are quite vary, and many can be applied at scale if the right institutional and financial structures are in place.

Recent developments in international and domestic carbon market are opening new revenues opportunity for agricultural mitigation. Under Article 6 of the Paris Agreement, countries can transfer emission reductions through Internationally Transferred Mitigation Outcomes (ITMOs), subject to robust accounting and "corresponding adjustments" to avoid double counting (UNFCCC, 2022). For Viet Nam, this raises the prospect that verified emission reductions from low-emission rice systems could be sold to international buyers, provided that MRV systems are compatible with national inventory methods and that double counting is avoided. Parallel to this, voluntary standards such as Verra's Verified Carbon Standard (VCS) and the Gold Standard have developed methodologies for improved agricultural land management (e.g. VM0042 methodology) that include rice-sector interventions.

In Vietnam, carbon pricing mechanisms are at an early stage but progressing rapidly. Decree 06/2022/ND-CP on greenhouse gas mitigation and ozone layer protection outlines the roadmap for establishing a domestic carbon market by 2028, with pilot phases scheduled between 2025 and 2027. Under this framework, agriculture especially rice farming is identified as a priority sector for emission reduction (MONRE, 2022). Meanwhile, the World Bank's Emission Reduction Payment Agreements (ERPAs) under the BioCarbon Fund and the Forest Carbon Partnership Facility (FCPF) have begun exploring agricultural linkages, particularly in Southeast Asia. These instruments adopt results-based payment (RBP) structures, whereby verified emission reductions could generate financial returns.

In addition, results-based payments (RBPs) and results-based climate finance (RBCF) apply a similar logic at the project or programme level: payments are made after verification against emissions reductions or other performance indicators, such as the number of hectares managed under climate-smart management or the number of tonnes of CO_2 equivalent reduced. Porras, Vorley and Amrein (2021) show that RBPs can help shift climate finance from traditional donor-driven projects to more performance-oriented mechanisms, but only when robust monitoring, reporting and verification (MRV) is feasible and not costly. They also point out that agriculture receives only a small share of overall climate finance, owing to high MRV costs and dispersed emission sources that make it harder to structure bankable RBP schemes than in the energy sectors.

From an analytical viewpoint, carbon pricing and RBP mechanisms are directly linked to the marginal abatement cost framework. For any measure with a given MAC value, adding a carbon price P (or an equivalent RBP level per tonne) shifts the private net return by P times the verified abatement. If a practice has a negative private MAC – meaning it is already profitable without credits – then any positive carbon price or results-based payment increases net gains further. Conversely, for positive-cost measures, a sufficiently high carbon price can move the option from loss-making to break-even or profitable. (Kesicki and Ekins, 2012; Eory et al., 2018; World Bank, 2023) In this thesis, I execute this relationship by overlaying plausible carbon price levels onto the Thang Loi cooperative's MAC estimates. For a given mitigation measure with cost C per tCO_2e (MAC) and a carbon price P per tCO_2e, the net return increases by P for each tonne of verified abatement. Thus, if a practice has a negative private MAC (already profitable without credits), any positive carbon price simply adds to its profit. Contrary, if a practice has a positive MAC (a net cost), a sufficiently high carbon price can tip it into profitability (Kesicki and Ekins, 2012; Eory et al., 2018; World Bank, 2023).

From a development economics perspective, result-based payment (RBPs) offer a way to shift climate finance from donor-driven to market-driven mechanisms (Porras et al., 2021). However, their success depends on whether the payments exceed the MAC of bundle practices. For example, if a bundle of AWD, SSNM, and straw collection yields 2.3 tonnes of CO_2-eq reduction per hectare per season at a cost of USD 15, then a carbon price of USD 20 would generate net benefits making it financially attractive for farmers. Conversely, at the carbon price is only USD 5, the bundle would require additional subsidy or co-benefits like yield gains or labour savings.

In sum, the carbon pricing and RBP literature provides a framework for interpreting the economic value of the Thang Loi pilot's emission reductions under potential crediting schemes. However, most existing empirical work focuses on national or sectoral carbon pricing, or on large-scale forestry and energy projects, rather than on smallholder rice cooperatives in the Mekong Delta. This study therefore contributes by combining farm-level MAC estimates with a simple, transparent overlay of carbon price scenarios, grounded in Viet Nam's emerging carbon market regulations (e.g., Decree 06/2022/ND-CP) and Article 6 of the Paris Agreement guidance, to explore the feasibility and implications of linking low-emission rice pilots to results-based payments.This thesis integrates these economic instruments into its analytical framework by assessing the cost per tCO_2e abated, comparing this against current voluntary and projected compliance carbon prices. It also examines how bundle practices affect the viability of participating in carbon schemes—both as part of national climate finance portfolio and as independent cooperative-based projects. In doing so, it links local farming decisions to global climate finance mechanisms, a connection rarely addressed in conventional rice-farming economics.

2.4 The Environmental Kuznets Curve (EKC) Framework in Low-Emission Rice Farming

The Environmental Kuznets Curve (EKC) hypothesis posits an inverted U-shaped relationship between environmental degradation (e.g., pollution or emission) and income per capita. Initially proposed by Grossman and Krueger (1995), the EKC suggests that as a country develops, environmental degradation increases due to industrialisation and resource extraction, but eventually declines after a certain income threshold as technological improvements, institutional capacity, and environmental awareness rise. EKC analysis has been widely applied to air pollutants such as SO_2 and CO_2 in industrial and energy sectors, but applications to agricultural systems and to methane-intensive rice in particular remain limited.

Stern (2004) argues that many EKC regressions suffer from unstable econometric specifications, omitted variables and short time series, so that the "inverted U-shape" often reflects structural, regulatory, and technological change rather than a simple "grow first, clean up later" law. Despite high income levels, many economies have yet to reach a clear turning point for GHGs such as CO_2 due to their long atmospheric lifetime and reliance on fossil fuels (Stern, 2004; Leal and Marques, 2022). This insight is particularly relevant to rice farming in the Mekong Delta, where productivity gains have been linked to high-emission practices such as year-round flooding, overuse of nitrogen fertilisers, and unmanaged residue burning. Without targeted intervention, increases in rice income risk locking farmers into high-emission production systems, potentially delaying or even preventing a turning point in the emissions trajectory.

In agriculture, the EKC literature is more scattered. Cross-country evaluations generally suggest that agricultural growth and conventional intensification increase emissions in low- and middle-income countries, particularly if production is based on fossil fuels, synthetic fertilizer, and ruminant livestock (Raihan, 2023; IPCC, 2019). According to Raihan (2023), increasing agricultural value added can improve environmental quality by reducing net CO_2 emissions through effective production and land management. This is consistent with sector-specific EKC trends, which show that the "turning point" is driven by technologies that reduce emissions intensity per unit of output rather than shrinking the agricultural sector. In rice-based systems, where CH_4 from flooded paddies is a major source of agricultural GHGs, EKC-style analyses remain scarce. Most evidence comes from mitigation potential studies and technology assessments rather than macro-EKC regressions (IPCC, 2019; Antle and Valdivia, 2018).

Empirical EKC work for Viet Nam's agricultural sector provides mixed but instructive evidence. Nguyen et al. (2020) use provincial panel data to estimate a statistically significant inverted U-shaped relationship between agricultural GDP per capita and GHG emissions find an inverted-U for Vietnam's agricultural sector with a turning point around VND 50 million per capita. However, reaching this turning point requires structural shifts towards greener technologies and supportive policies. In rice farming, this suggests that climate-smart bundles and carbon finance might "bend the curve" earlier-allowing farmers to achieve higher incomes with lower emissions before reaching the income levels observed in historical EKC studies.

The bundle low-emission rice farming model implemented in Thang Loi Cooperative offers a micro-level test of this idea. Over one season, the bundle low-emission model—combining AWD, SSNM, mechanised seeding, short-duration varieties and straw removal/composting—reduced emissions by approximately 4.92 tCO_2e per hectare while increasing profit by about 179.2 USD/ha relative to the baseline. In EKC income–emissions space, this corresponds to a movement from the origin (no change) to a point in the "north-west" quadrant: lower emissions with higher income. The slope of this movement (ΔProfit/ΔEmissions) is numerically equal to the private MAC in absolute value—about 36.4 USD of additional profit per tonne of CO_2-eq reduced in this case. This provides a concrete, farm-level illustration of how mitigation can coincide with income gains under coordinated interventions, rather than being a short-run trade-off.

Policy and institutional conditions are central to this micro-EKC transition. The Thang Loi pilot benefited from factors like cooperative coordination, extension support and record systems, which lowered transaction costs and enabled the bundle to be implemented as a package. This aligns with Antle and Valdivia's (2018) argument that enabling conditions secure land tenure, access to credit, functioning value chains and supportive public–private partnerships can accelerate the EKC transition by lowering the income level at which green technologies become attractive.

In this thesis, the EKC is not estimated econometrically but used as a conceptual lens for interpreting the empirical results. It complements the MAC analysis by situating farm-level cost-effectiveness within broader development trajectories: if scaled, negative-cost mitigation bundles like the Thang Loi model could contribute to a "green growth" path in which rice incomes increase and emissions decline simultaneously, rather than following the classic pattern of "grow now, clean up later".

2.5 Synthesis and Limitations

The literature reviewed in this chapter highlights significant progress in understanding GHG emissions and mitigation options in rice systems, but it also reveals four persistent gaps that motivate the present study.

First, although individual mitigation practices such as AWD, SSNM and improved residue management are well documented, there is limited evidence on how bundle, climate-smart packages perform on smallholder farmer fields in the Mekong Delta under cooperative management. Most empirical studies involve researcher-managed plots or short-term trials, leaving questions about performance, compliance and variability in farmer-managed remains unanswered (Vo et al., 2020; IRRI, 2019; Sander et al., 2017).

Second, MAC frameworks are widely discussed in the agricultural mitigation literature, but farm-level MAC estimates that combine real production costs with Tier 2 methodology emission calculations remain rare in smallholder rice systems. Existing MAC studies for rice in Southeast Asia largely rely on simulations or partial budget assumptions and seldom consider bundle interventions or cooperative-level implementation (Eory et al., 2018; Shrestha et al., 2020).

Third, carbon pricing and results-based payments are often proposed to support low-emission rice in Viet Nam. Yet these proposals are seldom grounded in actual cooperative data on mitigation volumes, MACs, MRV requirements and transaction costs. Policy documents and international reports outline potential carbon market pathways, but they rarely provide micro-evidence on whether prevailing carbon prices would cover costs and create meaningful incentives for farmers and cooperatives (MONRE, 2022; Newell et al., 2021; World Bank, 2023; Porras et al., 2021).

Finally, applications of the EKC to agriculture in Viet Nam exist, but they are typically based on provincial-level data and do not integrate micro-level MAC evidence from specific farming systems such as irrigated rice. As a result, we know relatively little about how farm-scale mitigation interventions, when implemented through cooperatives, might affect the trajectory of emissions relative to income growth in practice (Nguyen et al., 2020; Antle and Valdivia, 2018).

By focusing on a 43.1-hectare, pilot at Thang Loi Cooperative, this thesis responds directly to these gaps. It provides empirical evidence on GHG reductions from a bundle low-emission rice model under real smallholder conditions; pilot-based engineering and private MAC estimates aligned with Tier 2 inventory methods; an assessment of how these MACs compare to current and plausible carbon-price ranges; and a micro-EKC interpretation of the joint income and emissions outcomes. Chapter 3 now sets out the methodological framework used to generate and interpret this evidence.

Chapter 3 Methodology

This chapter explains how this thesis evaluates the carbon-mitigation performance and economic efficiency of a bundle low-emission rice model under real smallholder conditions in the Mekong Delta. This thesis adopts a predominantly quantitative, case-study design with a quasi-experimental before–after comparison between conventional practice and the low-emission pilot bundle implemented at Thang Loi Agricultural Cooperative during the 2024 autumn–winter season. Greenhouse-gas emissions are estimated using a Tier 2-compatible framework aligned with national inventory practice, while detailed production-cost and revenue data are used to compute both engineering and private MAC indicators at cooperative scale. These MACs are then linked to carbon-price scenarios and interpreted through an Environmental Kuznets Curve (EKC) lens to examine whether emissions can fall while farmer income rises.

Methodologically, the chapter operationalises the MAC framework for climate-smart agriculture (Bockel et al., 2012; Eory et al., 2018) and the EKC perspective on growth–environment dynamics (Grossman and Krueger, 1995; Stern, 2004) by applying them to a concrete cooperative-level pilot. Section 3.1 describes the study area and case study context. Section 3.2 explains the research design, data sources and evaluation strategy. Section 3.3 details the Tier 2 greenhouse-gas emission estimation and parameterisation. Section 3.4 outlines the construction of engineering and private MACs and the linkage to carbon-price scenarios. Section 3.5 integrates the MAC results into a micro-EKC interpretation. Section 3.6 sets out the sensitivity analysis, while Section 3.7 discusses ethical considerations and methodological limitations. Section 3.8 clarifies the restricted, transparent use of digital tools and generative AI, in line with ISS guidelines.

3.1 Study Area and Case Study Context

Project " One Million Hectares of High-Quality, Low-Emission Rice Sustainable Development Project linked to Green Growth in the Mekong Delta by 2030" is an important project in the orientation of transforming sustainable rice cultivation methods in the Mekong Delta to increase the value of Vietnam's rice industry, improve income and living standards for farmers, adapt to climate change and reduce GHG emissions, contributing to the implementation of Vietnam's international commitments. The project is divided into two phases:

Phase 1 (2024-2025): Focus on 200,000 hectares with favorable conditions for production infrastructure and the capacity of cooperatives in production and consumption linkage with enterprises to achieve the criteria of high-quality, low-emission rice.

Phase 2 (2026-2030): Focus on investing in completing infrastructure and continuing to improve the capacity of the entire system to expand an additional 800,000 hectares of high-quality, low-emission rice.

This thesis will focus on phase 1 of the project, which centers on a pilot project launched in Thang Loi Co-operative (Lang Bien commune, Thap Muoi district, Dong Thap province. The pilot was implemented in the 2024 autumn-winter season, spanning 43.1 hectares and involving 20 smallholder farmers the project aims to assess the considerations of scaling climate-smart rice farming practices under real-world conditions (Tri Tue, 2024). During the Autumn–Winter 2024 season, the Thang Loi pilot implemented a bundle low-emission package combined alternate wetting and drying (AWD) irrigation; site-specific nutrient management (SSNM) with reduced nitrogen rates; mechanised direct seeding with lower seed rates; short-duration OM18 rice seed ; and off-field straw collection and composting instead of open burning. This package is consistent with technical guidance of the national programme and regional climate-smart agriculture recommendations for the Mekong Delta (IRRI, 2019; Tri Tue, 2024).

According to reports from Dong Thap's Crop Production and Plant Protection Sub-department and the Institute of Agricultural Environment, the Thang Loi pilot reduced seeding rates from 150 kg/ha to 70 kg/ha, nitrogen application from 100 kg N/ha to 65 kg N/ha, and pesticide sprays from six to three per season compared to conventional fields. At the same time, average yields reached about 6.1 t/ha, production costs fell by more than 1.6 million VND/ha, net profits increased by nearly 4.3 million VND/ha, and seasonal greenhouse-gas emissions declined by approximately 4.92 tCO_2e/ha—a reduction of about 43.4% compared to traditional practice (Dang, 2024; Tri Tue, 2024). Cooperative-level production and accounting records for this season is the core empirical dataset used in this thesis.

To define the conventional baseline, this thesis draws on a meta-analysis of 36 field sites across Vietnam (Vo et al., 2020). In contrast to the bundle low-emission package, the field in conventional baseline did not employ this new farming technology, and still remained uncertain farming practices. Vo et al. (2020) report average late-season methane emission factors (EFs) for southern Vietnam of around 3.58 kg CH_4 ha^{-1} day^{-1}, substantially higher than IPCC Tier-1 defaults, underscoring the importance of using Tier-2, country-specific parameters for both inventories and project-level assessments. These baseline factors provide the reference point against which the Thang Loi pilot's mitigation performance is evaluated. The analysis in later sections will utilize the Thang Loi pilot's own records (on input, cost, yields…) and monitoring reports from this pilot as a secondary data.

3.2 Research Design and Evaluation Approach

This study adopts a quasi-experimental before–after design within Thang Loi Agricultural Cooperative to quantify how a bundle package of climate-smart practices performs under real smallholder conditions. Baseline conditions for conventional rice farming are reconstructed from pre-pilot practice in the cooperative and from published evidence on typical Mekong Delta rice systems while post-intervention outcomes were collected during the 2024 pilot implementation at Thang Loi Cooperative. This approach allows me to assess the difference in both GHG emissions and economic returns attributable to the adoption of bundled low-emission practices. Although a before–after design may not fully control for externalities or time-variant factors, it provides a practical and feasible design in the absence of multi-year panel data or controlled randomised trials. Limitations are acknowledged and mitigated through the triangulation of literature, pilot records, and cross-validated emission coefficients.

This research design has three important features that help explain the results clearly. First, the pilot uses all practices together as one package: alternate wetting and drying; site-specific nutrient management; mechanised direct seeding; short-duration rice seed ; and off-field straw collection and composting. This matches how Viet Nam's "One Million Hectares of High-Quality, Low-Emission Rice Sustainable Development Project linked to Green Growth in the Mekong Delta by 2030" programme promotes climate-smart rice and responds to a gap in the literature, where most studies look at only one practice at a time and often under researcher-managed conditions rather than real farmer bundles (IRRI, 2019; MARD, 2023; Sander et al., 2017; Richards et al., 2022). Second, the bundle is implemented by farmers themselves, under cooperative coordination. Farmers decide on irrigation timing, how to handle straw and other daily operations within the normal limits of smallholder farming. This makes the pilot different from tightly controlled field experiments and improves the external validity of the results (Vo et al., 2020; León and Izumi, 2022). Third, the analysis relies on existing records instead of new field measurements. It uses cooperative data on inputs, yields, costs and revenues, together with official pilot summaries and published emission factors and scaling parameters for rice in Viet Nam, rather than household surveys or direct measurements (Vo et al., 2020; IPCC, 2019; MONRE, 2022).

To enhance validity, the pilot outcomes are compared with reference emissions and cost structures drawn from a meta-analysis of 36 rice-growing sites in Vietnam, reported by Vo et al. (2020), and IPCC Tier 2 methodology guidelines. Although the lack of a control group or randomisation poses internal validity concerns, this thesis compensates through empirical consistency and the integration of multiple sources.

3.3 GHG Emission Estimation: Tier 2 IPCC Framework

3.3.1 Rationale for using Tier 2

Methane emissions from flooded rice fields in this study are estimated using the IPCC Tier 2 methodology for rice cultivation (IPCC, 2019). Tier 2 is chosen instead of Tier 1 for several reasons. First, it relies on country-specific baseline emission factors derived from Vietnamese field measurements (Vo et al., 2020), rather than global averages, so the estimates better reflect conditions in the Mekong Delta. Second, Tier 2 allows emissions to change in response to management practices through scaling factors for water regime, pre-season water status and organic amendments. These are exactly the aspects targeted in the Thang Loi pilot, where alternate wetting and drying, straw removal and shorter crop duration are central elements of the bundle. Third, Tier 2 takes into account the actual length of the crop cycle. This matters because the use of short-duration varieties in the pilot shortens the flooding period and therefore reduces the time during which methane is produced.

By contrast, Tier 1 would apply a similar emission factor to fields that are continuously flooded and to fields managed under AWD, and it would not capture the effect of removing straw from the field. For a pilot that seeks to quantify mitigation from specific management changes, and to remain compatible with national inventory practice and potential carbon-credit methodologies, Tier 2 is therefore the appropriate choice (MONRE, 2022; IRRI, 2019).

3.3.2 Core equations

This study estimates seasonal methane emissions from flooded rice using the IPCC Tier-2 framework, which adjusts a country or region-specific baseline daily emission factor by field conditions actually observed during the season (IPCC, 2019; MONRE, 2022). The adjusted daily emission factor EFadj is

$$EFadj = EFc \times SFw \times SFp \times SFo \ [\text{kg } CH_4 \text{ ha}-1 \text{ day}-1]$$

where:

- EFc is the baseline daily emission factor for continuously flooded fields without organic amendments
- SFw is the scaling factor for the in-season water regime (≈ 1.0 for continuous flooding; < 1.0 for AWD, depending on the frequency and depth of drying);
- SFp is the scaling factor for pre-season water status (e.g. flooded vs dry soil prior to planting);
- SFo is the scaling factor for organic amendments, which adjusts for the rate and type of residues or other organic inputs applied.

In other words, the baseline emission factor is multiplied by adjustment factors for water regime, pre-season flooding, and organic amendments to reflect the field conditions. To be able to compare baseline and pilot, we continue to convert.

Seasonal methane emissions per hectare, in tonnes of CH_4, are then:

$$CH_{4,season} = EF_{adj} \times t \times 10^{-3}$$

where t is the number of cultivation days from sowing to harvest, and the factor 10^{-3} converts kilograms to tonnes. To express emissions in CO_2-equivalent, the methane total is multiplied by the 100-year global warming potential (GWP100) for CH_4:

$$E_{CO_2e} = CH_{4,season} \times GWP_{100}(CH_4)\ (\mathrm{tCO_2e\ ha^{-1}})$$

Consistent with the IPCC's Sixth Assessment Report (AR6), seasonal methane emissions are expressed in carbon-dioxide-equivalent terms using the 100-year global warming potential for methane, $GWP_{100}(CH_4)$. The central calculations adopt $GWP_{100}(CH_4) = 27.2$, meaning that one tonne of CH_4 is treated as equivalent to 27.2 tonnes of CO_2 (IPCC, 2021).

3.3.3 Parameterisation for baseline and pilot

For late-season irrigated rice in southern Viet Nam, Vo et al. (2020) report an average Tier-2 baseline daily emission factor is 3.58 kg CH_4 ha^{-1} day^{-1}. Denoting this as $EF_{base,L}$, the baseline factor is:

EFbase,L=3.58 kg CH_4 ha−1 day−1.

This value already reflects typical conventional management in the Mekong Delta: continuous flooding during the crop period and some in-field residue presence under real farming conditions. In Tier-2 mechanics , this can be interpreted as the adjusted baseline factor $EF_{adj,base}$ for late-season rice when the in-season water scaler is close to unity for continuous flooding $(SF_w \approx 1)$ and the pre-season and organic scalers (SF_p, SF_o) are either embedded in the country/season factor or set to one for reporting clarity (IPCC, 2019; MONRE, 2022).

For the pilot, parameter values are taken from the cooperative's observed management rather than idealised textbook assumptions. The water-regime scaler SF_w is inferred from Thang Loi 's irrigation and drainage logs, which document alternate wetting and drying (AWD) cycles. Under farmer-managed AWD, SF_w is below one (reflecting reduced flooding) but generally higher—that is, less strongly mitigating—than the lowest values sometimes reported for perfectly implemented AWD in researcher-managed plots. The pre-season scaler SF_p is set using information on canal and field conditions at sowing (wet versus dry soil). The organic scaler SF_o is based on residue handling: in the pilot, straw is removed from the field and composted off-site, so there is no additional in-field organic amendment that would increase CH_4 emissions. Crop duration D (days from sowing to harvest) is taken from the cooperative's calendars; short-duration varieties in the pilot shorten D compared with the conventional baseline (IRRI, 2019; IPCC, 2019; Vo et al., 2020).

To check that the observed abatement is consistent with Tier-2 mechanics under this baseline factor, a simple back-calculation can be performed. The seasonal methane emissions per hectare in the baseline are:

$$E_{base} = \frac{EF_{base,L} \times D_{base} \times GWP_{100}(CH_4)}{1000} [tCO_2e\ ha^{-1}],$$

where D_{base} is the number of cultivation days and $GWP_{100}(CH_4)$ is the 100-year global warming potential for methane. Using the AR6 central value $GWP_{100}(CH_4) = 27.2$ (IPCC, 2021), this becomes:

$$E_{base} = \frac{3.58 \times D_{base} \times 27.2}{1000} = 0.097376 \times D_{base}[tCO_2e\ ha^{-1}].$$

The Thang Loi pilot is observed to reduce seasonal emissions by $\Delta E = 4.92\ tCO_2e/ha$ relative to this conventional baseline. Thus:

$$E_{pilot} = E_{base} - \Delta E.$$

The implied adjusted daily factor for the pilot, $EF_{adj,pilot}$, can be obtained by inverting the Tier-2 seasonal formula:

$$EF_{adj,pilot} = \frac{E_{pilot} \times 1000}{GWP_{100}(CH_4) \times D_{pilot}} = \frac{(E_{base} - \Delta E) \times 1000}{27.2 \times D_{pilot}},$$

where D_{pilot} is the pilot's crop duration. Substituting $E_{base} = 0.097376\ D_{base}$ gives:

$$EF_{adj,pilot} = \frac{(0.097376\ D_{base} - 4.92) \times 1000}{27.2\ D_{pilot}}.$$

It is useful to express the ratio of pilot to baseline daily factors:

$$\frac{EF_{adj,pilot}}{EF_{base,L}} = \frac{E_{base} - \Delta E}{E_{base}} \times \frac{D_{base}}{D_{pilot}} = (1 - \frac{\Delta E}{0.097376\ D_{base}}) \times \frac{D_{base}}{D_{pilot}}.$$

With $\Delta E = 4.92$, $\Delta E/0.097376 \approx 50.52$, so this simplifies to:

$$\frac{EF_{adj,pilot}}{EF_{base,L}} = \frac{D_{base} - 50.52}{D_{pilot}}.$$

This expression depends only on the baseline and pilot crop durations. For representative late-season calendars in the Mekong Delta—baseline late-season rice around 100–105 days, and short-duration pilot varieties around 90–95 days—the ratio falls within a narrow range:

If D_"base" =100 and D_"pilot" =95: (100-50.52)/95≈0.52.
If D_"base" =105 and D_"pilot" =95: (105-50.52)/95≈0.57.
If D_"base" =100 and D_"pilot" =90: (100-50.52)/90≈0.55.

In other words, under realistic crop calendars

$$EFadj,pilot \approx (0.52\text{–}0.57) \times EFbase,L.$$

With EFbase,L=3.58 kg CH_4 ha−1 day−1 so this implies

$$EFadj,pilot \approx 1.9\text{–}2.0 \text{ kg } CH_4 \text{ ha}^{-1} \text{ day}^{-1}$$

In sumary, the Tier 2 framework predicts that the pilot's adjusted emission factor would be roughly half of the baseline's (≈1.9–2.0 vs 3.58 CH_4 ha−1 day−1), given the shortened season and improved practices. A reduction in the adjusted daily factor of roughly 40–50%, combined with the shorter crop duration in the pilot, is fully consistent with the observed seasonal abatement of 4.92 tCO_2e/ha. The magnitude of this reduction sits comfortably within the range expected for farmer-managed AWD with straw removal and short-duration varieties, and is more conservative than the strongest mitigation effects reported from tightly controlled demonstration plots (IRRI, 2019; IPCC, 2019; Vo et al., 2020).

3.4 Marginal Abatement Cost and Carbon Credit Valuation

3.4.1 MAC construction from farmer-managed results

The MAC analysis uses the measured emissions abatement and observed economic outcomes to derive two complementary indicators: an engineering MAC and a private (net-return) MAC. Both are calculated for the cooperative-scale bundle, reflecting the fact that AWD, short-duration varieties, mechanised seeding, site-specific nutrient management and straw removal/composting were implemented jointly on all 43.1 ha, rather than as separate options. This study constructs two complementary MAC measures for the Thang Loi bundle: an engineering MAC based solely on production costs, and a "private" MAC based on net profit, which farmers actually experience.

Relative to the reconstructed conventional baseline, the Thang Loi bundle reduced seasonal GHG emissions by 4.92 tCO_2e/ha, achieved a yield of 6.1 t/ha, lowered total production costs by approximately 1.6 million VND/ha and increased profit by around 4.3 million VND/ha. In unit terms, the model reduced production costs by about 399 VND/kg of paddy and the crop was sold at a contract price of 8,300 VND/kg (Dang, 2024). These figures align with the results reported for Đồng Tháp's high-quality, low-emission rice model. For readability, monetary values are expressed in US dollars using an exchange rate of 24,000 VND/USD.

The engineering MAC is defined as the change in production cost per tonne of CO_2-equivalent abated,

$$MAC_{\text{eng}} = \frac{\Delta Cost}{\Delta E},$$

- where ΔCost is the per-hectare cost difference relative to the baseline and ΔE is the abatement in tCO_2e/ha. Given profit increases by 4.3 million VND/ha → $\Delta\pi = +4{,}300{,}000$ VND/ha and cost falls by 1.6 million → $\Delta\text{Cost} = -1.600.000$ VND/ha then engineering MAC is:

$$MAC_{\text{eng}} = \frac{-1.600.000 \text{ VND/ha}}{4.92 \text{ tCO}_2\text{e/ha}} \approx -325.200 \text{ VND/tCO}_2\text{e} \approx -13.6 \text{ USD/tCO}_2\text{e}.$$

Thus, each verified tonne of abatement is associated with a cost saving of about 13.6 USD on the production side.

The private (net-return) MAC reflects what farmers experience once yield and price effects are included.

$$\Delta\pi = 4.300.000 \text{ VND/ha}$$

$$\Delta\text{Cost} = -1.600.000 \text{ VND/ha}$$

Continuing per tonne of abatement:

- Cost saving per tCO_2e:

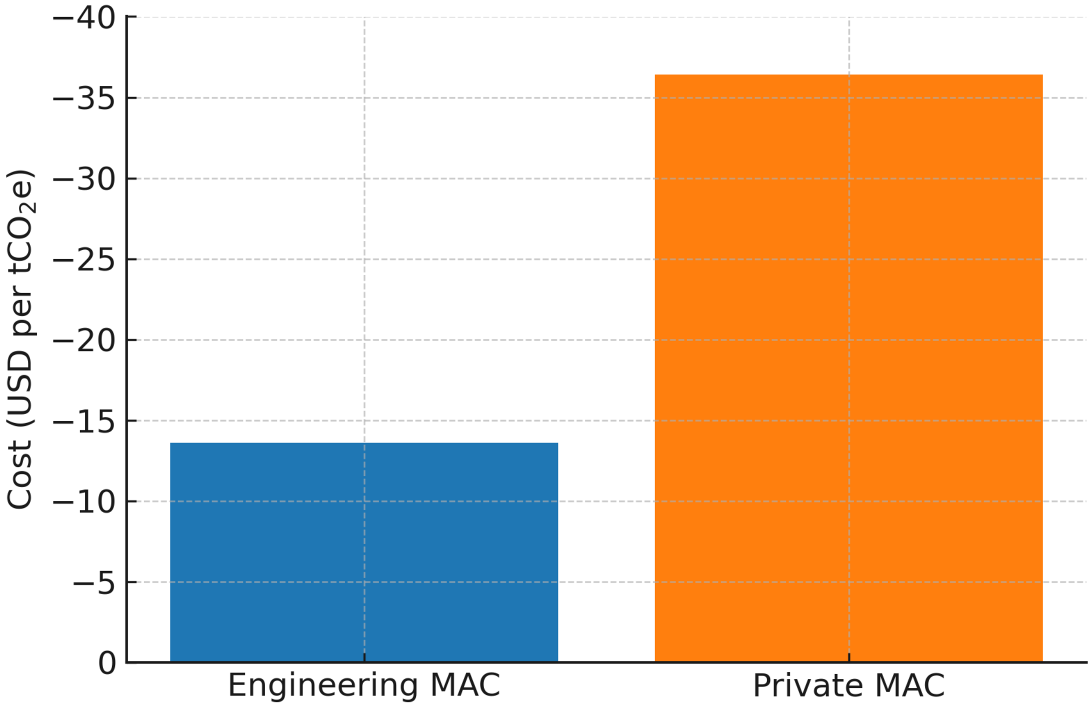
$$\frac{-\Delta\text{Cost}}{\Delta E} = \frac{1.600.000}{4.92} \approx 325.200 \text{ VND/tCO}_2\text{e} \approx 13.6 \text{ USD/tCO}_2\text{e}.$$

Then MAC private is

$$MAC_{\text{priv}} = -\frac{\Delta\pi}{\Delta E} = -\frac{4.300.000 \text{ VND/ha}}{4.92 \text{ tCO}_2\text{e/ha}} \approx -874.800 \text{ VND/tCO}_2\text{e} \approx -36.4 \text{ USD/tCO}_2\text{e}.$$

Interpreted per tonne, the bundle therefore delivers roughly 13.6 USD of production-cost savings and 22.9 USD of additional revenue, for a total profit gain of about 36.4 USD for every verified tCO_2e reduced. The engineering MAC is approximately –13.6 USD/tCO_2e, while the private MAC is around –36.4 USD/tCO_2e. Figure 1 compares the engineering and private MACs side-by-side.

Figure 1 The engineering and private MACs for Thang Loi bundle

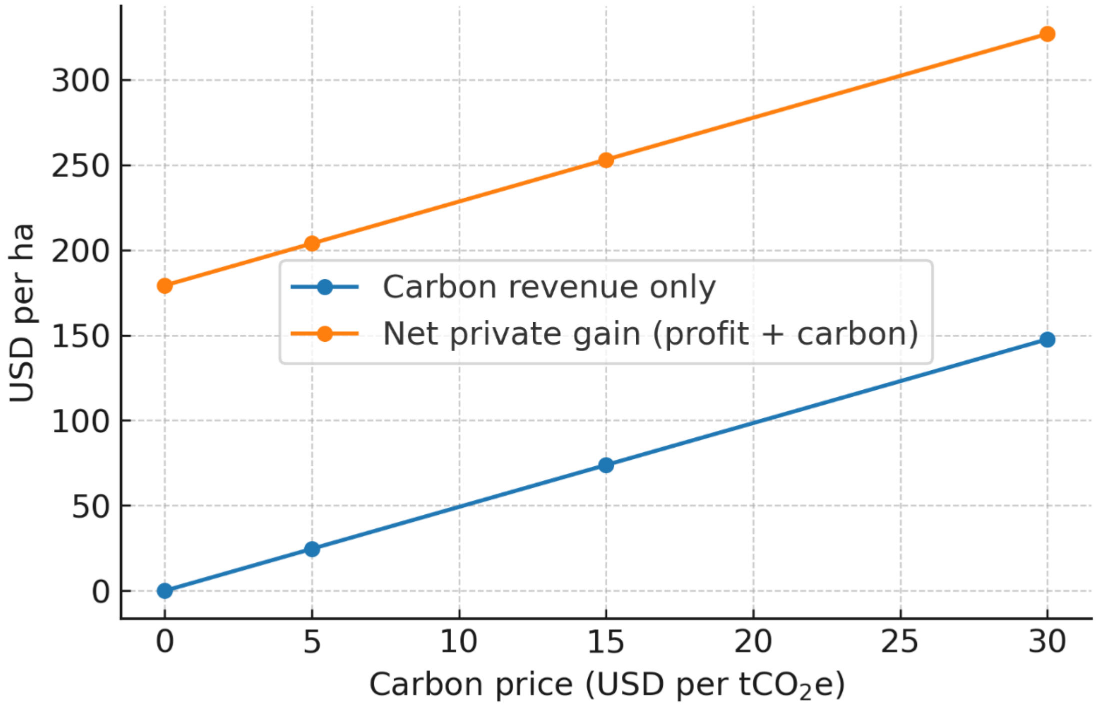


Source: Author's elaboration

3.4.2 Carbon credit valuation

By convention, MAC values exclude policy payments. To value credits without conflating metrics, overlay a carbon price P (USD/tCO_2e) on the measured abatement. Per-hectare carbon revenue is $4.92 \times P$ USD. At 5, 15 and 30 USD/t, revenue equals 24.6, 73.8 and 147.6 USD/ha, respectively. Since the bundle already raises farm profit by 4.3 million VND/ha ≈ 179.2 USD/ha before any credits, net private gains with carbon become ≈ 203.8, ≈ 252.9 and ≈ 326.8 USD/ha at those prices. Figure 2 shows different price points translate into cooperative economic gain.

Figure 2 Net private gain per hectare under alternative carbon prices in Thang Loi Cooperative



Source: Author's elaboration

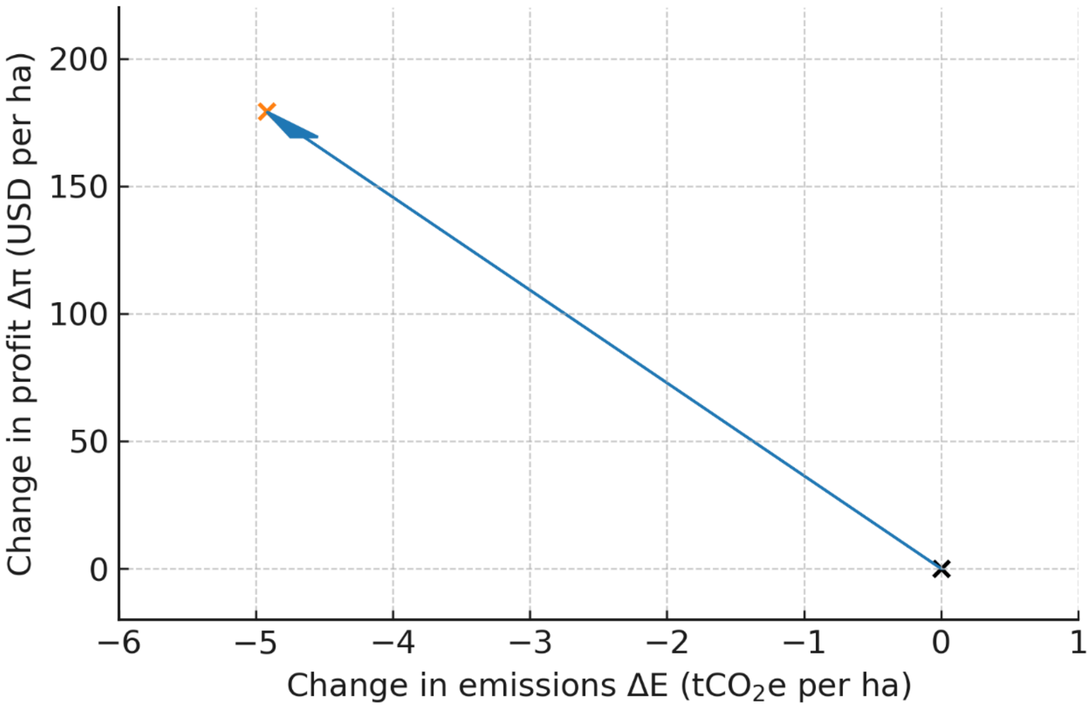
It can be easily seen from the chart that the application of bundle of emission reduction rice cultivation brings significant benefits in emission reduction and conversion of carbon credits into economic benefits under different carbon price scenarios as 179.2, 203.8, 252.9 and 326.8 USD/ha, respectively.

3.5 EKC Framework Integration Based on the MAC

The Environmental Kuznets Curve (EKC) is typically used to describe an inverted-U relationship between environmental pressure and income over the course of development (Stern, 2004). In farm-level applications, this concept can be made operational by mapping how income and emissions move jointly when a new technology package is adopted. The marginal abatement cost (MAC) framework provides the per-tonne economics of mitigation (Kesicki and Ekins, 2012; Eory et al., 2018). Integrating EKC with MAC is straightforward in a pilot setting: compute the change in emissions per hectare (ΔE) and the change in profit per hectare ($\Delta\pi$) between baseline and treatment; plot the directional movement in "delta space"; and relate its slope to the private MAC. If ΔE is negative (emissions fall) while $\Delta\pi$ is positive (profit rises), the farm-system moves down in emissions and up in income—a local bend of the EKC achieved through technology adoption rather than through structural income growth alone.

The Thang Loi co-operative bundle delivers a verified seasonal abatement of $\Delta E = 4.92$ tCO_2e/ha, a profit increase of $\Delta\pi = 4.3$ million VND/ha, a total cost reduction of 1.6 million VND/ha, and a revenue increase of 4,3 million VND/ha, with realized yield 6.1 t/ha at 8,300 VND/kg. Expressing profit in US dollars at 24,000 VND per USD gives $\Delta\pi \approx 179.2$ USD/ha. In the EKC plane with the origin at baseline, the pilot is represented by the vector from $(0,0)$ to $(-4.92, 179.2)$, measured in (tCO_2e/ha, USD/ha). Figure 3 plots this directional movement: the shift is leftward (emissions down) and upward (income up), i.e., a clear EKC-consistent bend at farm scale.

Figure 3 Directional change in emissions and profit in Environmental Kuznets Curve (EKC) for Thang Loi bundle



Source: Author's elaboration

The slope of this vector is $\Delta\pi/\Delta E$ in USD per abated tonne. Using values,

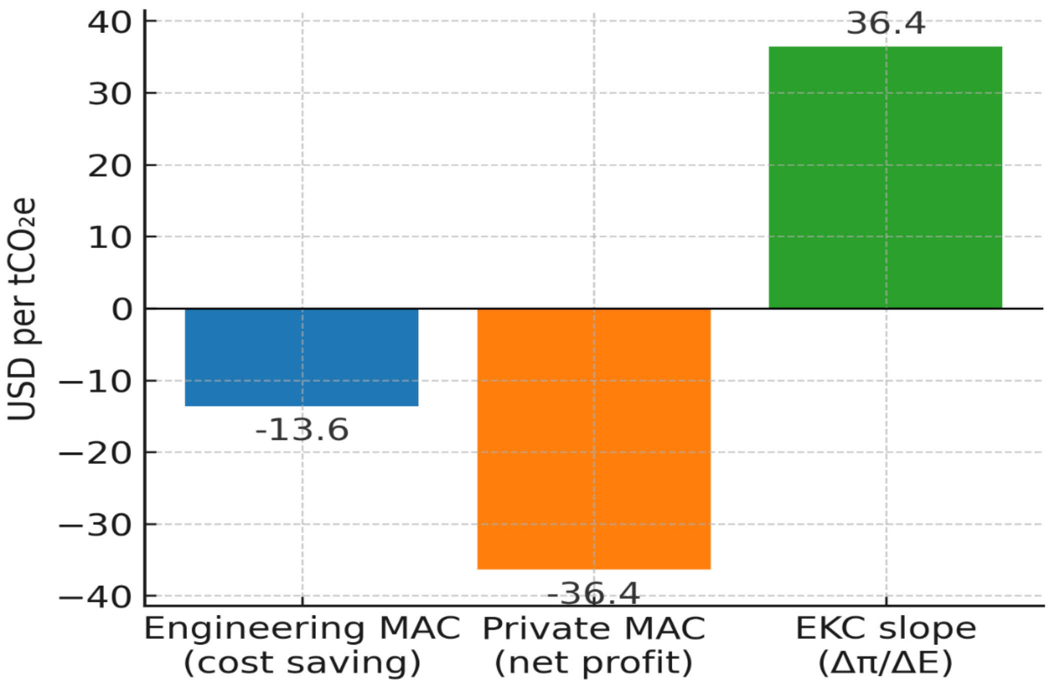
$$\frac{\Delta\pi}{\Delta E} = \frac{179.2}{-4.92} \approx -36.4 \text{ USD/tCO}_2\text{e}.$$

This slope is numerically equal to the absolute value of the private MAC, because by definition

$$\text{MAC}_{\text{private}} = \frac{\Delta\text{Cost} - \Delta\text{Rev}}{\Delta E} = -\frac{\Delta\pi}{\Delta E}.$$

My earlier MAC calculations showed $\text{MAC}_{\text{private}} \approx -36{,}4$ USD/tCO_2e, so the EKC slope derived from field data is 36.4 USD per tCO_2e, exactly mirroring the private per-tonne gain. In other words, every verified tonne corresponds to ≈ 36.4 USD of incremental net farm income in this pilot. Figure 4 visualises the link between the two MACs and the EKC slope

Figure 4 Comparison of engineering MAC, private MAC and EKC slope (USD per tCO_2e) for Thang Loi bundle



Source: Author's elaboration

This figure compares three per-tonne indicators from the Thang Loi pilot. The engineering MAC is approximately -13.6 USD/tCO_2e, which represents production cost savings per tonne of reduced emissions. The private MAC is approximately -36.4 USD/tCO_2e, reflecting the whole net-return effect after accounting for yield and price variations. The EKC slope, $\Delta\pi/\Delta E$ in the income-emissions plane, has a magnitude of about 36.4 USD/tCO_2e - equal to the absolute value of the private MAC. This demonstrates that each verified tonne of abatement correlates to roughly 36.4 USD of higher farm income in this pilot.

3.6 Sensitivity analysis and robustness checks

Because the pilot is based on a single cooperative and one season, the thesis employs a basic, transparent sensitivity analysis to see whether its primary conclusions are robust plausible variation in key parameters

3.6.1 Emission factor sensitivity

The per-hectare abatement $\Delta E = 4.92$ tCO_2e/ha depends on the choice of baseline emission factor and management scalers. To reflect the variability in daily emission factors reported by Vo et al. (2020), two alternative scenarios are considered:

- A low-abatement scenario, where the baseline emission factor and thus baseline emissions are 20 % lower than in the central case, while pilot emissions remain unchanged.
- A high-abatement scenario, where the baseline emission factor and baseline emissions are 20 % higher.

In terms of per-hectare abatement:

$$\Delta E^{low} = 0.8 \times 4.92 = 3.936 \text{ tCO}_2\text{e/ha}$$
$$\Delta E^{high} = 1.2 \times 4.92 = 5.904 \text{ tCO}_2\text{e/ha}$$

Under these emission scenarios, the engineering MAC becomes: (1 USD = 24000 VND)

$$MAC^{eng}_{low} = \frac{-1{,}600{,}000}{5.904} \approx -271{,}000 \text{ VND/tCO}_2\text{e } (\approx -11.3 \text{ USD/tCO}_2\text{e})$$
$$MAC^{eng}_{high} = \frac{-1{,}600{,}000}{3.936} \approx -406{,}504 \text{ VND/tCO}_2\text{e } (\approx -16{,}9 \text{ USD/tCO}_2\text{e})$$

Even in the low-abatement case (ΔE reduced by 20 %), the engineering MAC remains strongly negative, between roughly –11.3 and –16.9 USD/tCO_2e.

3.6.2 Cost and profit sensitivity

To reflect uncertainty in cost and revenue data, a simple ±20 % sensitivity is applied to the central profit change $\Delta\pi = 4.3$ million VND/ha. This captures potential errors in cost allocation, price fluctuations or yield measurement.

Define:

$$\Delta\pi^{low} = 0.8 \times 4.3 = 3.44 \text{ million VND/ha}$$
$$\Delta\pi^{high} = 1.2 \times 4.3 = 5.16 \text{ million VND/ha}$$

Using the central abatement $\Delta E = 4.92$ tCO_2e/ha, the private MAC in these scenarios becomes.(1 USD = 24.000 VND)

$$MAC^{priv}_{low} = \frac{\Delta\pi^{low}}{\Delta E} = \frac{3.440.000}{4.92} \approx 700.000 \text{ VND/tCO}_2\text{e } (\approx 29{,}2 \text{ USD/tCO}_2\text{e})$$
$$MAC^{priv}_{high} = \frac{\Delta\pi^{high}}{\Delta E} = \frac{516.000.000}{4.92} \approx 1.049.000 \text{ VND/tCO}_2\text{e } (\approx 43{,}7 \text{ USD/tCO}_2\text{e})$$

Even if the profit gain is 20% lower than the central estimate, each tonne of CO_2-equivalent lowered corresponds to about 29 USD of additional profit. If the profit gain is 20% greater, this jumps to over 43 USD/tCO_2e. Even in low-profit cases, each tonne of CO_2-equivalent reduced still associated with a significant positive income gain for farmers, showing the robustness of the "win-win" situation.

3.6.3 Carbon-price and service budget scenarios

Finally, the thesis explores how sensitive cooperative-level incentives are to carbon prices. Per-hectare carbon revenue R_c at price P (USD/tCO_2e) is:

$$R_c = P \times \Delta E$$

Using $\Delta E = 4.92$ tCO_2e/ha, carbon revenues per hectare are:

- At $P = 5$ USD/tCO_2e:

$$R_c = 5 \times 4.92 = 24.6 \text{ USD/ha}$$

- At $P = 15$ USD/tCO_2e:

$$R_c = 15 \times 4.92 = 73.8 \text{ USD/ha}$$

- At $P = 30$ USD/tCO_2e:

$$R_c = 30 \times 4.92 = 147.6 \text{ USD/ha}$$

Adding these to the underlying profit gain of approximately 179.2 USD/ha gives total net gains per hectare of roughly:

- 203.8 USD/ha at 5 USD/tCO_2e;
- 253 USD/ha at 15 USD/tCO_2e;
- 326.8 USD/ha at 30 USD/tCO_2e.

For service budgets, the break-even carbon price P^* required to fund a cooperative-level service cost B (USD/ha) is:

$$P^* = \frac{B}{\Delta E}$$

For example, if the cooperative needs 25 USD/ha for AWD scheduling, straw logistics and MRV:

$$P^* = \frac{25}{4.92} \approx 5.1 \text{ USD/tCO}_2\text{e}$$

If it needs 50 USD/ha:

$$P^* = \frac{50}{4.92} \approx 10.2 \text{ USD/tCO}_2\text{e}$$

These figures are within or below many documented voluntary carbon pricing ranges, implying that realistic carbon prices could cover cooperative service expenses while still providing farmers with a significant portion of the profits.

3.7 Ethical Considerations and Methodological Limitations

Ethical and methodological constraints shape both what this thesis can claim and how its results should be interpreted. No primary data were collected directly from farmers through surveys or interviews; instead, the analysis relies on cooperative records and extension reports. Ethical approval was therefore not required for human-subject research, but confidentiality was maintained by working only with anonymised, aggregated data and by not disclosing any information that could identify individual households.

Several limitations warrant caution. First, the evaluation covers a single late-season crop in one year at one cooperative. The results cannot be assumed to generalise automatically to other seasons, cooperatives or regions with different hydrological conditions, institutional capacities or market access. Second, the emissions analysis focuses on CH_4 from flooded rice fields and does not include full life-cycle emissions for inputs such as fertilisers or fuel; nor does it consider possible changes in nitrous-oxide emissions. While this is consistent with national inventory practice for rice (MONRE, 2022; IPCC, 2019), it means the MACs relate to a defined subset of emissions rather than the entire supply chain. Third, the data are aggregated at cooperative level, which precludes disaggregating MACs by individual practice or farmer type; this is a deliberate choice to reflect programme reality but limits analysis of intra-cooperative distributional effects.

Finally, the EKC-informed interpretation is illustrative and case-based rather than econometric. It shows a directional "bend" in the emissions–income plane for one cooperative bundle, but it does not estimate formal EKC turning points or elasticities for Viet Nam's agricultural sector. Future work could extend this micro-EKC approach by constructing a panel of cooperative-level pilots across the Mekong Delta, applying harmonised Tier 2 methods and household surveys to explore heterogeneity in adoption and benefit distribution.

3.8 Use of digital tools and generative AI

In accordance with ISS guidelines for the responsible use of artificial intelligence, this research article discloses how digital technologies, including generative AI, were utilized during the research and writing process. I used OpenAI's ChatGPT as a support tool for four primary reasons: (i) brainstorming and refining the formulation of research questions, section headings, and thesis structure; (ii) receiving help to clarify and rephrase complex theoretical concepts (for example, the Marginal Abatement Cost framework, carbon-pricing mechanisms, and Environmental Kuznets Curve interpretations); (iii) improving English expression, including grammar, academic tone, and coherence of paragraphs that I had drafted myself; and (iv) receiving suggestions on how to link my empirical results to the existing literature and to policy debates in Viet Nam.

Generative AI was not utilized to produce empirical data, make statistical or numerical calculations, fabricate results, or select sources to quote. All quantitative data, including Tier 2 emission estimates, cost and income numbers, and marginal abatement cost (MAC) calculations, are derived from my own analysis of cooperative records,goverment papers, and published literature, as indicated in Sections 3.1-3.5. When ChatGPT provided formulations of concepts, probable references, or example sentences, I critically analyzed, modified, and changed the language, validated the underlying sources as needed, and confirmed coherence with my actual dataset and research strategy.

I am completely and totally responsible for the content of this research work. This includes ensuring that equations, numerical results, and citations are correct, as well as correcting any biases or mistakes that may show in AI-assisted drafts. The final text is based on my own judgment and interpretation, and any errors or omissions are my responsibility.

Chapter 4 Results and Discussions

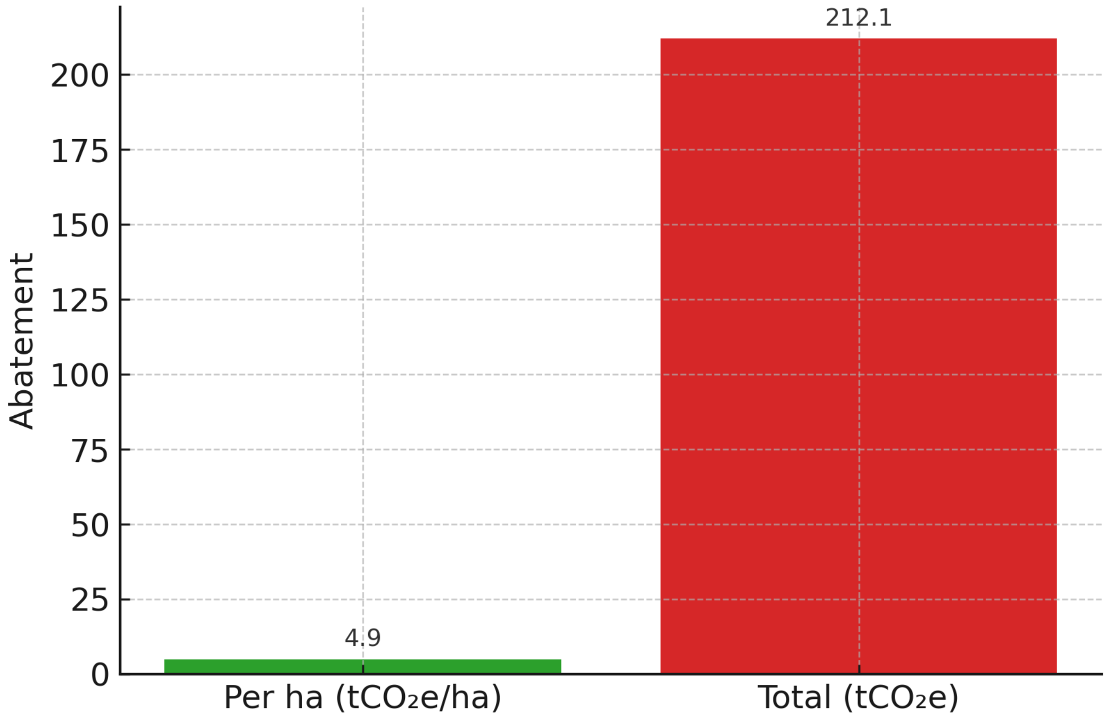
This chapter directly addresses the two core evidence gaps articulated in the introduction. The first is whether bundle climate-smart practices materially reduce GHG emissions in real smallholder conditions in the Mekong Delta, rather than only in simulations or isolated field trials. The second is whether these reductions are achieved at positive cost or at negative cost, i.e., what the marginal abatement cost (MAC) actually is when moving from conventional to low-emission rice farming under real farm-gate prices and services. Using the Tier-2 rice methodology from the 2019 IPCC Refinement and the pilot's verified activity and accounting data from the 2024 Autumn–Winter season at Thang Loi Agricultural Cooperative, I quantify the realised emissions outcome, compute the empirical, package-level MAC, and then test robustness under carbon-price and cost/yield sensitivities. Where the bundle's aggregate activity data preclude exact per-practice allocation, I keep attribution conservative and triangulate with literature to interpret magnitudes. The discussion closes by reading these results through the Environmental Kuznets Curve (EKC) lens to ask whether the bundle provides an early "bend" toward lower emissions at higher farm income.

4.1 Measured performance of the bundle intervention under cooperative management

As stated with the first research whether a bundle of climate-smart rice practices could achieve measurable GHG mitigation under real smallholder conditions in the Mekong Delta, as opposed to researcher-managed trials or model simulations. The pilot results indicate that yes, using the Tier 2 methodology described in chapter 3; the cooperative's data show a per-hectare emission reduction of 4.92 tCO_2e/ha between the conventional baseline and the bundle, and a total seasonal abatement of roughly 212 tCO_2e over 43.1 ha. On the economic side, production costs fall by about 1.6 million VND/ha while net profit rises by around 4.3 million VND/ha, equivalent to 179.2 USD/ha at 24,000 VND/USD. This means the bundle simultaneously delivers substantial mitigation and a sizeable income gain under farmer-managed conditions.

Figure 5 illustrates the per-hectare abatement (4.92 tCO_2e/ha) and the implied total seasonal abatement (212 tCO_2e) as two bars. The figure emphasises that the same per-hectare performance, when aggregated, generates mitigation volumes that are meaningful in the context of both national climate targets and carbon market transactions.

Figure 5 Comparing the total seasonal abatement of Thang Loi bundle



Source: Author's elaboration

The magnitude of this reduction is broadly consistent with field evidence from AWD and straw-management interventions in the Mekong Delta which often report methane reductions on the order of 30–50% relative to continuous flooding under similar conditions. Here, the reduction is achieved under farmer-managed, cooperative-coordinated conditions rather than in researcher-managed plots, which gives the result particular policy relevance.

4.2 Marginal abatement costs and carbon-price overlays

The second research question concerned the farm-level marginal abatement costs (MACs) of the Thang Loi bundle when estimated from real farmer-managed data rather than simulations. Using the Tier 2 abatement estimate of 4.92 tCO_2e/ha and the cooperative's cost and revenue records, two complementary MACs are obtained: an engineering MAC and a private (net-return) MAC. Both are calculated at the level of the cooperative-scale bundle, because AWD, short-duration varieties, mechanised seeding, site-specific nutrient management and straw removal/composting were implemented jointly on all 43.1 ha rather than as separate options.

With a cost reduction of −1.6 million VND/ha and an abatement of 4.92 tCO_2e/ha**,** the per-tonne cost saving is:

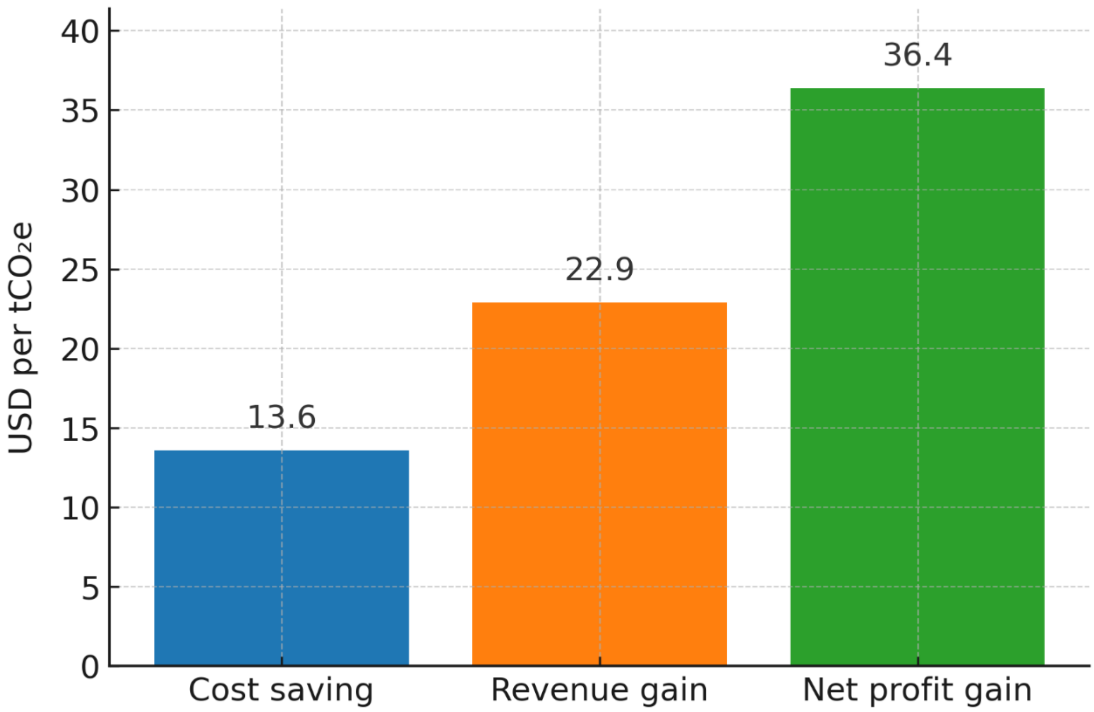
$$MAC_{\text{eng}} = \frac{-1.600.000 \text{ VND/ha}}{4.92 \text{ tCO}_2\text{e/ha}} \approx -325{,}200 \text{ VND/tCO}_2\text{e} \approx -13.6 \text{ USD/tCO}_2\text{e}.$$

The private MAC reflects the change in net profit per abated tonne once yield and price effects are included. Profit per hectare is defined as revenue minus cost, so the change in profit can be written **as** $\Delta\pi$ =4.3 million VND/ha . The private MAC is then:

$$MAC_{\text{priv}} = -\frac{\Delta\pi}{\Delta E} = -\frac{4.300.000 \text{ VND/ha}}{4.92 \text{ tCO}_2\text{e/ha}} \approx -874{,}800 \text{ VND/tCO}_2\text{e} \approx -36.4 \text{ USD/tCO}_2\text{e}.$$

Interpreted per tonne, the bundle therefore delivers roughly 13.6 USD of cost saving and 22.9 USD of additional revenue, for a total profit gain of about 36.4 USD for every verified tCO_2e reduced. At cooperative scale, aggregate abatement equals ΔE_total = 4.92 × 43.1 ≈ 212.1 tCO_2e, so on a MAC curve the Thang Loi bundle appears as a single bar whose width is ~212 tCO_2e and whose height is the engineering MAC of about −13.6 USD/tCO_2e.

Figure 6 USD per tCO_2e benefits from Thang Loi bundle: cost saving, revenue gain and net profit gain



Source: Author's elaboration

At cooperative scale, the single-season mitigation volume is given by area times abatement:

$$\Delta E_{\text{total}} = 43.1 \text{ ha} \times 4.92 \text{ tCO}_2\text{e/ha} \approx 212.1 \text{ tCO}_2\text{e}.$$

On a MAC curve, the Thang Loi bundle is therefore represented as a single bar because the practices are implemented as a package whose width equals approximately 212 tCO_2e and whose height equals the engineering MAC of about −13.6 USD/tCO_2e.

The cooperative dataset also permits a simple sensitivity analysis based on alternative accounting conventions for cost. Holding abatement fixed at 4.92 tCO_2e/ha, the change in unit cost per kilogram of paddy can be multiplied by the observed yield to derive an alternative engineering MAC. Using this unit-cost method yields a slightly larger cost saving per hectare and an implied engineering MAC of around −13.6 USD/tCO_2e. Reporting −13.6 USD/tCO_2e as the central value and –11.3 and –16.9 USD/tCO_2e as a sensitivity (low abatement scenerios) illustrates that the sign and order of magnitude of the negative MAC are robust to reasonable cost-accounting choices. The private MAC remains about −36.4 USD/tCO_2e, because it is determined by the observed profit change and abatement rather than by how costs are allocated.

By convention, MAC calculations exclude policy payments. To explore how carbon finance might interact with these farmer-managed economics without conflating the metrics, the analysis overlays carbon prices on the measured abatement. Per-hectare carbon revenue at price P (USD/tCO_2e) is:

$$R_c = P \times 4.92.$$

At prices of 5, 15 and 30 USD/tCO_2e, this yields additional revenues of 24.6, 73.8 and 147.6 USD/ha respectively. When added to the underlying profit gain of 179.2 USD/ha, total net gains per hectare become approximately 203.8, 253.0, 326.8 USD/ha. A simple linear relationship between carbon price and net gain can thus be read directly from a price overlay graph (Figure 7 in section 4.3.3).

The same overlay provides an operational formula for break-even pricing for service budgets. If an aggregator must finance M USD/ha for AWD coordination, monitoring and MRV, the per-tonne break-even price is:

$$P^* = \frac{M}{4.92}.$$

For example, if $M = 10$ USD/ha, $P^* \approx 2.0$ USD/tCO_2e; if $M = 25$ USD/ha, $P^* \approx 5.1$USD/tCO_2e; and if $M = 50$ USD/ha, $P^* \approx 10.2$ USD/tCO_2e. Because the private MAC is already strongly negative, these payments do not need to buy down a farm-level cost penalty; they can instead be directed at the institutional functions that maintain adoption quality and keep Tier 2 evidence audit.

4.3 Sensitivity analysis: Cost, profit and carbon prices scenarios

Given that the Thang Loi pilot is based on one season and one cooperative, it is important to test whether the main conclusions hold under plausible variation in key parameters. This section reports a simple scenario-based sensitivity analysis**,** aligned with the methodological design in Chapter 3.

4.3.1 Cost and profit sensitivity

The second set of sensitivity tests concerns the economic side**.** To capture possible variation in input prices, yield, or cost allocation, the net income change $\Delta\pi$ is varied by ±20 percent around the central value of 4,3 million VND/ha:

$$\Delta\pi^{low} = 0.8 \times 4.3 = 3{,}44 \text{ million VND/ha}$$
$$\Delta\pi^{high} = 1.2 \times 4.3 = 5{,}16 \text{ million VND/ha}$$

Using the central abatement $\Delta E = 4.92$ tCO_2e/ha, the private MAC becomes:

$$MAC_{low}^{priv} = \frac{3.440.000}{4.92} \approx 700.000 \text{ VND/tCO}_2\text{e } (\approx 29.2 \text{ USD/tCO}_2\text{e})$$
$$MAC_{high}^{priv} = \frac{5.160.000}{4.92} \approx 1.049000 \text{ VND/tCO}_2\text{e } (\approx 43.7 \text{ USD/tCO}_2\text{e})$$

Despite these fluctuations, one tonne of CO_2-equivalent reduced still gain additional profit from 29-43 USD. The result that the Thang Loi bundle therefore robust to reasonable changes in cost and profit assumptions.

Table 1 Sensitivity of MAC values to abatement and profit assumptions (tCO_2e)

Scenario	ΔE (tCO_2e/ha)	ΔCost (million VND/ha)	Δπ (million VND/ha)	MAC_eng (USD/tCO_2e)	MAC_priv (USD/tCO_2e)
Central case	4.92	-1.6	+4.30	-13.6	-36.4
Low abatement (−20%)	3.94	-1.6	+4.30	-16.9	-45.5
High abatement (+20%)	5.90	-1.6	+4.30	-11.3	-30.3
Low profit (Δπ −20%)	4.92	-1.6	+3.44	-13.6	-29.2
High profit (Δπ +20%)	4.92	-1.6	+5.16	-13.6	-43.7

Note: USD values are obtained by dividing VND/tCO_2e by an exchange rate of 24.000 VND/USD.

Even in a low-abatement case (where we only achieve 80% of the measured reduction), the cost per tonne is still around 17 USD/tCO_2e. And even if the profit benefit were 20% lower than observed, the bundle still yields about 29 USD/tCO_2e. In other words, under resonable certaintainties, one tonne of CO_2e reduced still adds a net profit for the farmer- the negative-cost outcome is robust.

4.3.2 Carbon-price scenarios

Finally, the implications of different carbon prices for farmers and the cooperative are explored. With abatement of 4.92 tCO_2e/ha, the per-hectare carbon revenue R_c at price P (USD/tCO_2e) is:

$$R_c = P \times 4.92$$

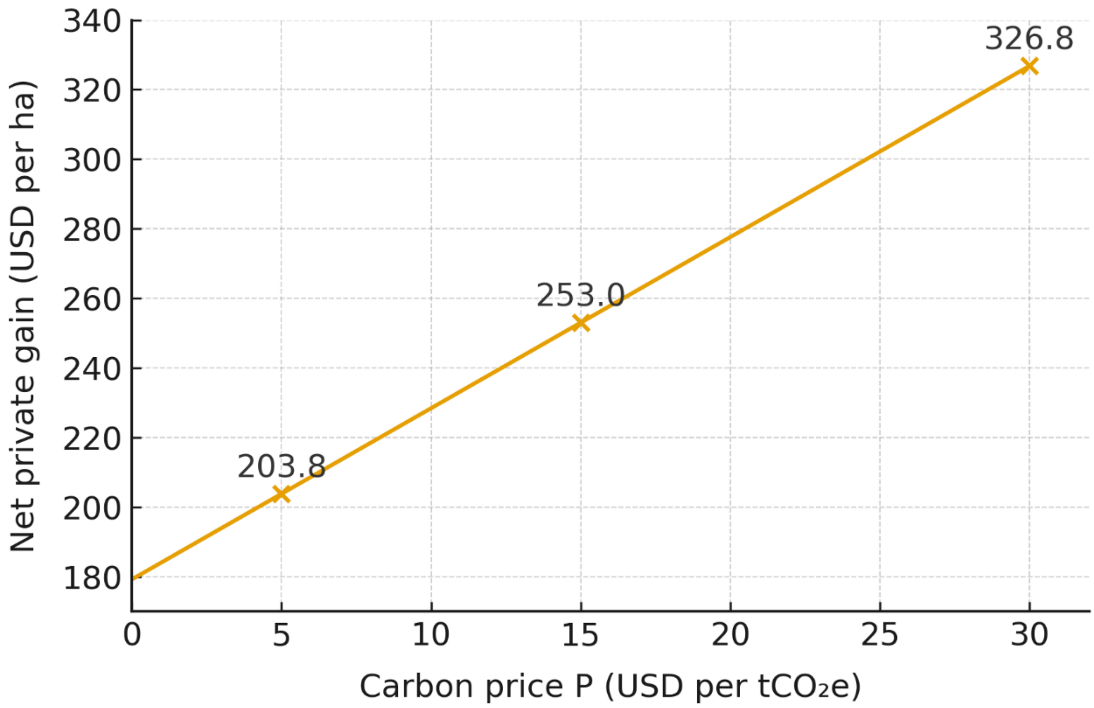
For $P = 5{,}15{,}30$ USD/tCO_2e:

- 5 USD/tCO_2e → $R_c = 24.6$ USD/ha;
- 15 USD/tCO_2e → $R_c = 73.8$ USD/ha;
- 30 USD/tCO_2e → $R_c = 147.6$ USD/ha.

Accumulating to the underlying profit gain $\Delta\pi_{\text{USD}} \approx 179.2$ USD/ha yields so total net gains per hectare of approximately

- 203.8 USD/ha at 5 USD/tCO_2e;
- 253 USD/ha at 15 USD/tCO_2e;
- 326.8 USD/ha at 30 USD/tCO_2e.

Figure 7 Net private gain per hectare under alternative carbon prices (0–30 USD/tCO_2e)



Source: Author's elaboration

The graph depicts the correlation between the carbon price P and net private benefits from the Thang Loi bundle, with an abatement of 4.92 tCO_2e/ha. Without credits, the bundle already increases agricultural profit by around 179.2 USD per hectare. This suggests that if Vietnam implements rice carbon crediting under Article 6, even a low carbon price (say 5 USD) might augment farmers' income, whereas larger prices (15-30 USD, which are within the range of several compliance markets) could significantly enhance profitability.Importantly, because the pilot case is already profitable, carbon finance can be directed to cover coordination and MRV costs rather than subsidizing farmers' losses.

4.4 EKC-informed interpretation

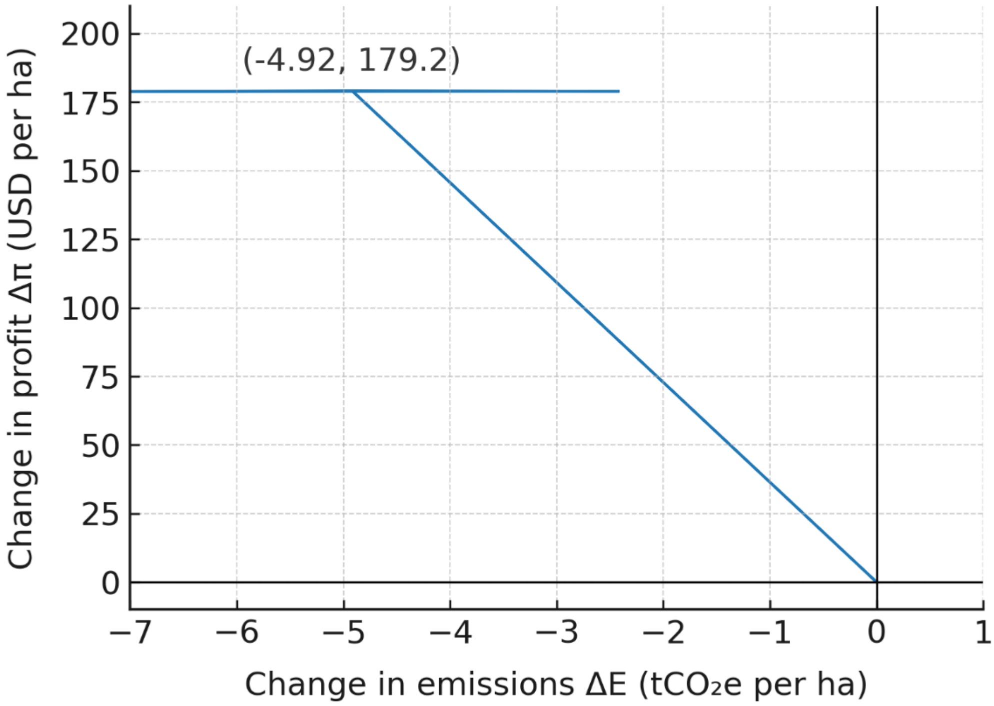
The Introduction proposed using the Environmental Kuznets Curve (EKC) as an interpretive lens to ask whether, under a realistic adoption model, emissions can fall while farm income rises effectively "bending the curve" earlier than a conventional trajectory would suggest. Rather than estimating a macro-level EKC from time-series data, this study uses the micro-level of a single cooperative to examine whether a low-emission bundle can reduce emissions and increase income.

Using the baseline as the origin, the pilot's per-hectare movement is given by the observed change in emissions and profit:

$$(\Delta E_{\mathrm{EKC}}, \Delta\pi_{\mathrm{USD}}) = (-4.92,\ 179.2)$$

where $\Delta E_{\mathrm{EKC}} = E^{pilot} - E^{baseline}$ is negative because emissions fall, and $\Delta\pi_{\mathrm{USD}}$ is the net income gain of approximately 179.2 USD/ha. The resulting vector runs from (0, 0) to roughly (–4.92, 179.2) and lies in the north-west quadrant of the EKC plane: emissions decrease, income increases. Figure 8 shows this directional shift.

Figure 8 Micro-EKC "bend": change in emissions and net income per hectare for Thang Loi bundle



Source: Author's elaboration

The slope of this EKC vector is:

$$\frac{\Delta\pi_{\text{USD}}}{\Delta E_{\text{EKC}}} \approx \frac{179.2}{-4.92} \approx -36.4\ \text{USD/tCO}_2\text{e}$$

From this point, we can see the vector's slope is equal to the absolute value of the previously derived private MAC. In other words, each verified tonne of abatement corresponds to about 36.4 USD of additional net farm income in this pilot. The EKC "bend" is thus measured directly in per-tonne and linked to observed accounts rather than to a growth path.

In contrast to the usual EKC where turning points occur only after substantial income growth (Nguyen et al., 2020), our micro-level result presents a simultaneous improvement. This is consistent with previous research that suggests targeted interventions compress the EKC (Antle and Valdivia, 2018) in part by facilitating decoupling at an earlier stage. This finding is encouraging as it indicates that an increase in farmer income (increase in economic opportunity) need not be associated with a net increase in emissions, at least in this particular case. With appropriate interventions, the relationship can even be moved downward now.

4.5 Implications for carbon-trading design, a lesson for future work

The results have direct implications for carbon-trading readiness and results-based finance in smallholder conditions. Because the engineering MAC is negative and the private MAC is strongly negative, credit revenues should be targeted to enablement, not to offset an intrinsic production penalty that does not exist in this setting. In practice, that means contracting for AWD scheduling services, water-level monitoring, straw logistics, and Tier-2 record-keeping at the cooperative level, with payment per verified tonne and clearly defined roles for the aggregator and the buyer. The break-even rule $P^* = M/4.92$ makes it easy to convert service budgets into per-tonne price targets.

Uncertainties remain and should be acknowledged to guide future work. The present chapter reports one season of farmer-managed evidence in a single cooperative. Time-varying shocks and inter-seasonal changes in water availability or pest dynamics could alter ΔE and the profit increment. Extending the record to a second season or adding a matched-commune comparison would strengthen internal validity. Tier-2 already incorporates key field conditions, but further micro-data on N_2O and on upstream energy for pumping would refine the inventory boundary and may slightly adjust the per-tonne economics, though the sign is unlikely to flip given the observed margin on CH_4. The unit-cost versus total-cost accounting difference is resolved with the sensitivity analysis reported here; adopting a standardised cost template across cooperatives would streamline future MAC reporting and reduce scepticism about accounting choices. Finally, the EKC interpretation in this chapter is directional and case-based; it does not estimate a formal econometric EKC with turning points. That is appropriate for a pilot designed to produce policy-usable per-tonne numbers, but it leaves open the possibility of a later, larger panel study that would locate turning points across communes and seasons.

Despite these caveats, the core quantitative findings are strong and policy-relevant. The Thang Loi bundle abates ≈ 4.92 tCO_2e per hectare under farmer management while delivering 179.2 USD/ha in profit gains before any credits. The engineering MAC sits -13.6 USD/t , and the private MAC is −36.4 USD/t. At the cooperative level, the one-season volume is 212 tCO_2e. At 5–30 USD/t, carbon revenues add 25–148 USD/ha on top of the observed profit change, enough to finance the coordination/MRV commons that keep the bundle durable and the tonnes auditable. The EKC bend is unambiguous in directional space and its magnitude equals the farmer's per-tonne gain, thereby connecting the abstract concept of decoupling to the concrete realities of contracting in results-based finance.

Chapter 5 Conclusion and Policy Implications

5.1 Summary of this thesis

This thesis set out to assess whether a bundle package of low-emission rice farming practices could simultaneously reduce greenhouse-gas emissions and improve farm economics under real smallholder conditions in Viet Nam's Mekong Delta. Against the backdrop of Viet Nam's net-zero by 2050 pledge and the "One Million Hectares of High-Quality, Low-Emission Rice Sustainable Development Project linked to Green Growth in the Mekong Delta by 2030" initiative, this thesis examined a pilot implemented at Thang Loi Agricultural Cooperative in Lang Bien commune, Thap Muoi district, Dong Thap province during the 2024 Autumn–Winter season. The bundle combined alternate wetting and drying (AWD) irrigation; site-specific nutrient management (SSNM) with reduced nitrogen rates; mechanised direct seeding with lower seed rates; short-duration OM18 rice seed ; and off-field straw collection and composting instead of open burning on 43.1 hectares managed by 20 smallholder famers.

Rather than treating mitigation options in isolation, this thesis evaluated the bundle as it is actually implemented: alternate wetting and drying, mechanised direct seeding, adjusted fertiliser use, shorter-duration varieties and improved straw handling were coordinated across all participating plots through the cooperative. Emissions and economic outcomes were then compared with a reconstructed baseline that reflects local conventional practice. The findings in Chapters 3 and 4 show that the bundle can achieve substantial reductions in methane emissions from rice fields and enhance the financial position of participating farmers. In other words, for this cooperative in this season, emissions intensity falls and net income increases at the same time. In terms of empirical outcomes, seasonal paddy-field emissions were reduced by approximately 4.92 tCO_2e per hectare, while farmers' net profit increased by about 4.3 million VND per hectare (179.2 USD) relative to the baseline. These figures translate to a 5–10% increase in yield and a 3–5 million VND/ha profit gain, as also reported by Vietnamese authorities for this model. The pilot therefore offers real-world evidence that climate-smart rice practices can achieve "win win" in mitigation and livelihoods under smallholder conditions.

The thesis has also shown that these outcomes can be interpreted in a structured way using marginal abatement cost (MAC) analysis and an Environmental Kuznets Curve (EKC) lens. The MAC estimates derived from farmer-managed data confirm that the bundle is a negative-cost mitigation option. When recast in an income–emissions plane, the cooperative's trajectory is clearly towards lower emissions and higher income, with a slope that corresponds to the farmer's gain per tCO_2e reduced. This micro-level EKC "bend" is not the result of abstract income growth but of a specific combination of technology and cooperative organisation.Taken together, these findings indicate that the low-emission rice model supported in the national program can be more than just a technological demonstration. Under the appropriate conditions, it can serve as the foundation for a development pathway that aligns productivity, farmer welfare, and climate ambition. The remainder of this chapter analyzes how these findings address the research question, what contributions they make to the literature, and what they imply for policy and future research.

5.2 What we learn on research questions

The first research question investigated whether a bundle set of climate-smart practices can result in measurable GHG reductions in the Mekong Delta under farmer-managed conditions. The results indicate that they can. The Thang Loi bundle reduced seasonal emissions by 4.92 tCO_2e per hectare compared to conventional baseline. This result is obtained directly by applying the Tier 2 equations to observed water management, residue handling, and crop cycles, rather than by using idealised compliance assumptions. In other words, the GHG impacts was measured under realistic field conditions, not just researcher-managed plots. The observed emissions reduction (on the order of 40–50% lower adjusted methane emission factor) is consistent with expectations for AWD combined with straw removal and short-duration varieties, and and is more conservative than the strongest mitigation effects reported from tightly controlled demonstration plots. This confirms that even under typical smallholder practices and constraints, a well-coordinated bundle can deliver significant GHG abatement.

The second research question concerned the MAC of the bundle practices-essentially,the economic cost or benefit per unit of emissions reduced. Here the findings are equally important: the bundle does not impose a cost penalty on farmers; instead, it generates net savings and higher returns. Total production costs per hectare fall while yields and revenues rise, so the engineering MAC defined as the change in cost per tCO_2e abated is clearly negative, in the range of about –11.3 and –16.9 USD per tCO_2e (the range reflecting different cost conventions used in sensitivity analysis). When changes in revenue are included, the private MAC is even more negative. In the base scenerio, each tonne of verified emissions reduction corresponds to roughly 36 USD of additional net profit for farmers (4.3 million VND gain over 4.92 tCO_2e). Under various sensitivity tests (e.g. varying yields, prices, or global warning potential) , the private MAC benefits remained robusly positive, with plausible values in the 15–22 USD/tCO_2e band under the sensitivity tests. At cooperative scale, the one-season mitigation volume was about 212 tCO_2e (43.1 ha × 4.92 tCO_2e/ha). This shows that even a single cooperative pilot can generate a non-trivial volume of mitigation and do so at negative cost. In sumary, the bundle climate-smart practices economically co-benefits where farmer were financially benefits even before accouting for any carbon payments.

A third set of findings derives from integrating MAC results with the EKC perspective. In income-emission plot (EKC space), the Thang Loi bundle shifts the system from a baseline point to a new point with lower emissions and higher income. The vector representing this change lies firmly in the "north-west" quadrant: emissions decline while profits rise. The slope of this vector is numerically equivalent to the increase in profit per unit of abatement(the absolute value of the private MAC), providing a concise measure of how much farm income increases per tCO_2e mitigated. This demonstrates, in a concrete case, that it is possible to "bend the curve" at farm scale through targeted technological and institutional interventions, rather than waiting for income growth alone to deliver environmental improvements.

Finally, an additional insight comes from overlaying carbon price scenarios onto the results. The analysis showed that the bundle would remain privately attractive even in the absence of carbon credits, given its nagative MAC. Any carbon revenue at prices in the range of about 5–30 USD/tCO_2e would therefore represent additional gain that could be strategivally used. In practical terms, this finding provides an empirical basis for designing RBP schemes and intergrating smallholder rice mitigation into emerging carbon markets. In sum, the Thang Loi pilot's outcomes on emissions, economics, and their intersection (through MAC/EKC analysis) collectively demonstrate affirmative answers to the research questions and highlight a viable path for sustainable rice intensification that alighns with both climate mitigation and rural development goals.

5.3 Contributions to literature and methodology

The thesis offers several contributions to existing research on climate-smart agriculture, carbon markets and development transitions.

First, it adds to the relatively sparse empirical literature on GHG mitigation in rice under smallholder conditions. Much of the evidence base for rice mitigation in Southeast Asia comes from researcher-managed trials or model simulations. By contrast, this study uses farmer-managed, cooperative-level field data and applies Tier 2 IPCC methodology consistent with the national inventory. This enhances the external validity of the results and provides a more realistic sense of what can be achieved when mitigation practices are implemented through existing local institutions. Thang Loi's pilot case thus contributes a data point from real-world practice that can inform both the academic understanding and the practical of climate-smart farming.

Second, the study contributes to the methodological development of marginal abatement cost analysis in agriculture. It operationalises the distinction between engineering and private MACs in a smallholder conditions, explicitly incorporating yield and farm-gate price effects into the latter, while aligning the former with standard cost only conventions. The approach shows how MAC estimates can be made more relevant to farmer's (through the private MAC) and to policy makers (through the engineering MAC). Moreover, this thesis demonstrates how to construct a pilot-based MAC from integrated cost and emissions data, and how to conduct straightforward but informative sensitivity analysis around cost accounting conventions and GHG. This responds directly to calls in the literature for more transparent, empirically grounded agricultural MAC studies.

Third, the thesis innovatively links MAC analysis with EKC theory at the micro scale. Rather than treating the EKC as a purely macro concept, it shows how changes in emissions and income at farm level can be represented in EKC space and directly related to per-tonne economic gains from mitigation. This opens a pathway for future work to connect micro-level technological adoption with macro-level structural change. In particular, it suggests a way to rethink the timing of EKC "turning points" in low- and middle income agrarian settings - indicating that proactive technology and policy interventions might accelerate the transition to declining emissions intensities, rather than waiting passively for income growth to drive that change.

Finally, by overlaying MAC results with carbon-price scenarios and RBP design principles, the study offers an integrated perspective that bridges agronomy, environmental economics and climate-finance practice. It provides concrete per-hectare and per-tonne numbers (e.g. USD of profit gain per tCO_2e, cost savings per tCO_2e, revenue for coordination per tCO_2e) that can be used by policymakers and carbon market actors to benchmark programme design in Viet Nam's rice sector.s

5.4 Policy implications for Viet Nam's rice sector

The findings have several implications for the design of sustainable rice policies and carbon-finance instruments in Viet Nam:

A first implication is that bundle, cooperative-level interventions should be prioritised over isolated, practice-by-practice promotion. The Thang Loi experience suggests that AWD, improved nutrient management, mechanised seeding, residue management and shorter-duration varieties interact in ways that jointly shape both emissions and costs. Treating them as a package reduces the risk of double-counting or undercounting of mitigation when scaling up, and it reflects the reality of how farmers adopt technologies (often as part of a system, not one practice in islation). For the "One Million

Hectares of High-Quality, Low-Emission Rice Sustainable Development Project linked to Green Growth in the Mekong Delta by 2030" programme, this points towards designing and financing integrated, cooperative-centred packages rather than separate, closely coordinated projects on water, fertiliser and straw.

A second implication concerns the strategic use of carbon finance and RBPs in scaling up low-emission rice farming**.** Because the bundle is already privately profitable, carbon payments do not need to serve as a subsidy to compensate for a net imcome loss (as it may be the case for other mitigation options). Instead, carbon revenue can be deployed to finance the common goods that are essential for high-quality mitigation like cooperative management of AWD schedules, water-level monitoring, straw collection and transport, and Tier 2-compatible data collection and archiving required for credible MRV. This suggests a financing model in which a significant share of carbon revenue flows to the cooperative as an aggregator to fund these enabling services, while farmers continue to capture the underlying production gains from the technology package.

The third implication is the results underline the importance of robust measurement, reporting and verification (MRV) systems. The credibility of Tier 2 estimates (and any resulting carbon credits) depends on accurate records of water management regime, crop duration, residue handling and input use. Scaling the Thang Loi pilot model to hundreds or thousands of hectares in the future will require investment in simple but reliable MRV tools, staff training, and clear protocols for data validation. Embedding these systems within local instituitions -e.g. cooperative management boards, provincial extension services, and digital platforms- would support both carbon market participation and improvement in national GHG inventories under Decree 06/2022/ND-CP.

The fourth implication suggests that rice mitigation can contribute meaningfully to Viet Nam's climate and rural-development objectives without sacrificing smallholder farmers welfare**.** The strongly negative private MAC indicates that, under the right conditions, low-emission rice practices can increase farmer income while reducing emissions- a win-win scenerio. This finding challenges the view that climate mitigation in agriculture necessarily entails trade-offs (for example, cutting emission would required yield penalties or expensive inputs). On the contrary, the Thang Loi pilot bundle case reinforces the idea that climate smart agriculture can advance livelihoods, supporting calls to mainstream such practices into broader rural development and poverty reduction strategies. For policymakers, this means that innitiatives like "One Million Hectares of High-Quality, Low-Emission Rice Sustainable Development Project linked to Green Growth in the Mekong Delta by 2030" program should be viewed not only as environmental project but as dual-benefit development projects

Finally, we have to leverage the EKC insight in long term planning , that is , the EKC informed interpretation of the results carried strategic implications for long-term agricultural development planning. The Thang Loi pilot showed that with targeted interventions, the "turning point" for emissions intensity- the point at which emissions begin to decline as income rises- can be brought forward to a much lower income level than classic economic theory might predict. In plainer terms, deliberate policy choices and technology packages can bend the EKC earlier, rather than assuming that pollution must worsne until a country becomes wealthier. Incorporating such insights into regional planning could help avoid lock-in to high-emission cultivation systems and reduce the cost of later transitions. It also supports Vietnam's broader climate commitments by showing that agricultural mitigation can happen now, driven by innovation and policy support, rather than waiting for the economic growth to hopefully deliver environmental benefits later.

5.5 Limitations and directions for future research

Several limitations must be recognised when interpreting these findings, and they suggest avenues for futute research:

First, the empirical analysis is based on a single cooperative and a single season**.** Although the results are internally consistent and grounded in real farm management data, they may not capture inter-seasonal variability in factors like weather (e.g flood or drought conditions), pest or disease pressures, and fluctuating market price. Futhermore, the Mekong Delta has diverse agroecological conditions and cropping calendars across its provinces. Thus, a priority for future work is to extend the analysis over multiple seasons and across additional cooperatives in different regions of the Mekong Delta.

Second, this thesis focuses primarily on methane emissions from paddy fields, as captured by the Tier 2 rice methodology. It does not comprehensively account for other GHG or emission sources such as nitrous oxide (N_2O) emissions that might arise from fertiliser use (especially under intermittently wet soils), and carbon dioxide (CO_2) from on-farm energy use (e.g. fuel for irrigation pumps) or from the production of inputs like fertiliser. Including these components in future work would refine the emissions profile of low emission rice farming practices and possibly adjust the per-tonne economics, although the strong negative MAC observed for methane suggests that the overall sign is unlikely to change.

Third, the available data in Thang Loi's pilot were aggregated at cooperative level**,** which means the analysis treated the bundle as a single combined intervention and evaluated outcomes in agggregate. This precludes disaggregation of results by individual practice or by household. While treating the bundle as a unified package is methodological defensible (since the practices were implemented together) and aligns with programmatic implimentation, it would be valuable to know how benefits and risks are distributed among different farmers and which components of the bundle contribute the most. Future studies could combine plot-level data (e.g. emissions, yield, input use measured per field or a whole farm) with household survey data to explore heterogeneity.

Fourth, the EKC analysis presented here is case-based and directional, rather than a formal econometric estimation. It illustrates an instance of bending the income-emission curve at the farm scale, but it does not establish a generalizable functional relationship or "turning point" income level for agricaltural emissions in Vietnam. In essence, while this thesis provides a proof of cencepts of micro level EKC bending, a more rigorous macro-level analysis is needed to inform long term policy targets (e.g. determining realistic emission reduction trajectories for the agricultural sector as income grow)

Given these limitations, several avenues for further research emerge. One priority is to develop a panel of cooperative-level pilots across the Mekong Delta (and possibly other rice farming regions in Vietnam) that implement similar low-emission bundle. By using consistent measurement methods, this would enable comparative analysis and even meta-analysis of mitigation potential and costs saving. Another is to experiment with different carbon finance mechanisms and adoptions—for example, pilot test various models of credit revenue sharing between famers and cooperatives, or performance based grants from government or international funds. Last but not lease, incorporate climate risk ans adaption metrics into the analysis of mitigation options. The Mekong Delta faces rising threars from flooding, salinity intrusion, and extreme weather. Future research could ebaluate how the low emission practices intersect with adaption benefits- for instant, do shorter-duration varieties or AWD also reduce drought risk or avoid late season flood? It is still need us to explore more.

In conclusion, this thesis presents a successful example of emissions reduction and revenue increases in smallholder rice cultivation, giving evidence to improve Vietnam's climate-smart agriculture strategies. Future work can build on this foundation by addressing the research gaps and constraints mentioned above, driving the continuous improvement of sustainable rice models and supporting Vietnam's journey toward climate-resilient, low-carbon agriculture.

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