

Greenhouse Gas Emission Reduction in Rice Production in the Red River Delta: Current Status and Proposed Management Solutions

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Abstract: Rice production in the Red River Delta plays an important role in food security, farmers' livelihoods, and socio-economic development, but it is also a significant source of greenhouse gas emissions. A synthesis of field studies shows that methane (CH₄) emissions from rice production in the Red River Delta should be prioritized for emission control. Emission levels vary considerably by soil type, cropping season, water regime, nitrogen fertilizer management, and crop-residue management. Emission reduction should therefore be pursued through integrated soil-water-nutrient-residue management rather than through a single measure. The article proposes several directions for state management, including zoning priority areas for emission reduction, community-scale water management, improving fertilizer-use efficiency, managing crop residues according to circular-economy principles, developing a measurement, reporting and verification (MRV) system, and progressively improving databases and emission factors to support low-emission rice production and the carbon market.

Keywords: Greenhouse gas emissions; rice production; Red River Delta; water management; measurement, reporting and verification (MRV).

JEL Classification: Q54; Q15; Q58.

1. Introduction

The Red River Delta is one of Viet Nam's major rice-producing regions. Rice production not only meets a significant share of food demand but is also closely linked to the livelihoods of millions of people and to the maintenance of socio-economic systems in rural areas. However, flooded rice cultivation is also a significant source of greenhouse gas emissions in agriculture. Frequently inundated paddy fields promote methane

(CH₄) formation, while nitrogen fertilizer management and changes in soil-water status are closely associated with nitrous oxide (N₂O) emissions.

The current challenge is not merely to quantify emissions, but more importantly to identify where emissions arise, which factors determine their magnitude, and at which stages of the production process management authorities can intervene.

Studies in the Red River Delta show substantial variation in emissions across soil types and cropping seasons. This has important policy implications: a uniform greenhouse gas mitigation measure cannot be applied across the entire delta. Instead, management should shift toward an approach tailored to ecological characteristics, cropping seasons, and production conditions.

This article synthesizes and analyzes research findings on greenhouse gas emissions from rice production in the Red River Delta, focusing on three issues: (1) The magnitude and composition of emissions; (2) The factors governing emissions under different soil, seasonal, and farming conditions; and (3) The implications for state management. On this basis, the study proposes an integrated approach to emission reduction and emphasizes the need to differentiate measures by production conditions rather than applying a uniform approach across the entire region.

2. Research methods

This study reviews and synthesizes relevant studies to examine greenhouse gas (GHG) emissions from rice production in the Red River Delta (RRD). The evidence base consists primarily of field studies conducted under different soil, seasonal, and farming conditions in the RRD, with particular attention to methane (CH_4) and nitrous oxide (N_2O) emissions. Studies from elsewhere in Viet Nam and relevant international research provide comparative and supporting evidence for interpreting relationships between emissions and water management, nitrogen fertilizer use, and crop-residue management.

The reviewed evidence is organized around the main factors associated with variation in GHG emissions from rice cultivation,

including soil type, cropping season, water regime, nitrogen fertilizer management, and crop-residue practices. Findings across studies are compared to identify recurring emission patterns and differences among production conditions. This provides the basis for examining why mitigation measures may need to be differentiated rather than uniformly applied across the RRD.

Because the reviewed studies differ in study location, experimental design, production conditions, and measurement methods, the emission ranges reported in this article represent the variation observed in the available field studies. They should not be interpreted as uniform emission factors or statistically representative estimates for the entire Red River Delta. Instead, the synthesized evidence identifies major emission sources and their associated drivers and, on that basis, discusses mitigation directions and their implications for state management in the region.

3. Sources and magnitude of greenhouse gas emissions from rice production

3.1. Methane (CH_4) as the dominant emission source

In flooded rice production systems, prioritize controlling CH_4 . When soils remain inundated for long periods, oxygen availability declines, creating anaerobic conditions in which organic matter decomposes and CH_4 forms. CH_4 emissions depend on the duration of flooding, temperature, soil characteristics, the amount of organic matter and crop residues incorporated into the field, and water-management practices.

A study conducted on four paddy soil types in the Red River Delta recorded cumulative CH_4 emissions ranging from 74.4 to

698.51 kg CH₄/ha/season. The lowest level occurred on grey soil in the spring season, whereas the highest was recorded on alluvial soil in the summer/rainy season (Bui Thi Thu Trang et al., 2021).

When considered alongside other studies in Viet Nam, these findings indicate that CH₄ emissions are jointly influenced by water regime, soil type, cropping season, organic materials, and fertilizer application practices (Pandey et al., 2014; Nguyen Le Trang et al., 2018; Nguyen Van Thiet et al., 2019; Bui Thi Phuong Loan et al., 2019; Chu Sy Huan et al., 2020; Trinh et al., 2017).

Accordingly, CH₄ control should be a central priority for reducing emissions from rice cultivation. However, interventions should be tailored to soil conditions, cropping season, and water-management regime rather than applied uniformly across the region.

3.2. Nitrous Oxide (N₂O) in relation to nitrogen fertilizer and water management

Although N₂O emissions are smaller in mass than CH₄ emissions, N₂O has a high global warming potential. N₂O emissions are closely linked to the amount and timing of nitrogen fertilizer application, as well as soil-water conditions.

The same study of four paddy soil types in the Red River Delta reported N₂O emissions ranging from 0.3 to 1.19 kg N₂O/ha/season, with more notable emissions during the spring season and on grey and alluvial soils (Bui Thi Thu Trang et al., 2021).

From a management perspective, CH₄ mitigation should not be pursued independently of N₂O management. Drainage can reduce anaerobic conditions and thereby lower CH₄ emissions, but dry-wet transitions,

particularly when they coincide with nitrogen fertilizer application, can alter N₂O emissions. Water and nitrogen management should therefore be designed as an integrated package of measures (Pandey et al., 2014; Trinh et al., 2017; Jiang et al., 2019).

3.3. Overall greenhouse gas emissions

The reviewed studies indicate that CH₄ is the dominant greenhouse gas emitted from rice cultivation at the study sites. However, because conversion methods and experimental conditions differ across studies, this article does not apply a single CO₂-equivalent range to the entire region.

Thus, for overall climate impact, controlling CH₄ remains a priority, but N₂O management must be integrated to avoid reducing one gas while increasing another. This provides the basis for shifting from a “single-emission-source reduction” perspective to managing total emissions from the production system.

4. Key factors affecting greenhouse gas emissions in rice production in the Red River Delta

Greenhouse gas emissions from rice production in the Red River Delta are influenced by interactions among water management, soil characteristics, cropping seasons, nitrogen fertilizer use, and crop-residue management. The field evidence reviewed in Section 3 indicates substantial variation in CH₄ and N₂O emissions across soil types and seasons. These differences suggest that factors driving emissions should be examined in relation to the RRD’s specific production conditions rather than treated as uniform across the region.

4.1. Water management

Water regime is a major factor affecting

CH₄ emissions from flooded rice fields. Continuous flooding maintains anaerobic soil conditions that favor CH₄ formation, whereas mid-season drainage and alternate wetting and drying (AWD) increase soil aeration and can reduce CH₄ emissions. However, the effectiveness of these practices depends on the timing and intensity of drainage; moderate and controlled drying is generally more appropriate than excessive drying (Carrijo et al., 2017; Jiang et al., 2019).

This relationship is particularly relevant to the Red River Delta because water management is not determined solely at the individual farm level. Farmers within the same production area commonly depend on shared irrigation and drainage systems. Consequently, the timing and duration of flooding and drainage depend on irrigation infrastructure capacity and coordination among farming households, cooperatives, and irrigation-management entities. The feasibility of AWD in the RRD therefore depends not only on its technical effectiveness but also on the capacity to regulate water collectively within a production area.

The observed differences in CH₄ emissions among soil types and cropping seasons further indicate that water-management practices should be adapted to specific production conditions. In particular, the relatively high CH₄ emissions observed on alluvial and saline soils during the summer/rainy season suggest a greater need to consider controlled water regimes under these conditions. At the same time, because changes between wet and dry soil conditions can affect N₂O emissions, water management should be coordinated with nitrogen fertilizer management rather than implemented as an isolated mitigation measure.

4.2. Soil type and cropping season

Soil characteristics influence water retention, organic-matter availability, and soil redox conditions and therefore contribute to differences in CH₄ and N₂O emissions. Evidence from the Red River Delta shows that these differences are also associated with cropping seasons. CH₄ emissions tend to be higher on alluvial and saline soils, particularly during the summer/rainy season, whereas N₂O emissions require greater attention on grey and alluvial soils during the spring season (Bui Thi Thu Trang et al., 2021).

These findings indicate that the Red River Delta should not be treated as a homogeneous rice-production area from an emission-management perspective. Differences among soil and seasonal conditions can alter both the magnitude and composition of emissions and, consequently, the relative importance of individual mitigation measures. Conditions associated with higher CH₄ emissions require greater attention to water and crop-residue management, whereas those associated with relatively higher N₂O emissions require closer consideration of nitrogen fertilizer use and its interaction with soil-water conditions.

Soil type and cropping season therefore provide an important basis for differentiating emission-reduction measures within the RRD. This does not imply that a single mitigation measure can be assigned mechanically to each soil type or season; rather, these factors should be used to identify groups of production conditions with different emission profiles. Such differentiation provides the analytical basis for developing context-specific mitigation packages in Section 5.

4.3. Nitrogen fertilizer management

Nitrogen fertilizer is essential for maintaining

rice productivity but is also closely associated with N₂O emissions. The amount of nitrogen applied, application timing, fertilizer type, and soil-water conditions can all influence nitrogen transformations and losses. Improving nitrogen-use efficiency therefore requires attention not only to fertilizer quantity but also to how fertilizer application is coordinated with crop demand and water management.

For the Red River Delta, this interaction is important because field evidence shows variation in N₂O emissions across soil types and cropping seasons. N₂O emissions were more notable during the spring season and on grey and alluvial soils in the reviewed field evidence (Bui Thi Thu Trang et al., 2021). Under these conditions, nitrogen management requires particular attention to application timing and its relationship with changes in soil moisture.

This issue also illustrates the potential trade-off between CH₄ and N₂O mitigation. Drainage can reduce anaerobic conditions and thereby suppress CH₄ formation, but dry-wet transitions can alter N₂O emissions, particularly when they occur around the time of nitrogen fertilizer application (Pandey et al., 2014; Trinh et al., 2017; Jiang et al., 2019). In the RRD, nitrogen fertilizer management should therefore be considered together with irrigation and drainage schedules. The relevant objective is not simply to reduce nitrogen application, but to improve nitrogen-use efficiency while minimizing the risk that measures targeting CH₄ lead to higher N₂O emissions.

4.4. Rice straw and crop-residue management

Rice straw is an important source of organic matter and nutrients for agricultural soils,

but residue management can substantially influence emissions from rice-production systems. Incorporating large quantities of fresh rice straw under flooded conditions increases the availability of organic carbon for anaerobic decomposition and can promote CH₄ formation. By contrast, open-field burning generates greenhouse gas and air-pollutant emissions and results in the loss of some nutrients contained in crop residues. Evidence from India, for example, shows that open-field rice-straw burning can generate substantial CO₂ emissions and adverse environmental and health effects (Bhattacharyya et al., 2021).

For the Red River Delta, the relationship between crop-residue management and water regime is particularly relevant. Where rice straw is returned to the field, its effect on CH₄ emissions depends partly on the timing of incorporation and subsequent flooding. Incorporating large quantities of fresh residues shortly before prolonged inundation can create conditions favorable to CH₄ formation. Crop-residue management should therefore be considered in conjunction with irrigation and drainage practices rather than as a separate component of rice cultivation.

At the same time, the evidence reviewed in this article does not provide a sufficiently consistent basis for quantifying open-field residue-burning emissions specifically for the Red River Delta. Accordingly, this study does not use national-scale residue-burning estimates as proxies for the RRD. Instead, the available evidence supports a more limited conclusion: reducing open-field burning and developing feasible alternatives for rice-straw collection, reuse, processing, or appropriately timed incorporation into soils are relevant components of emission management in the region. More detailed RRD-specific activity

data are needed to quantify the contribution of open-field residue burning and compare alternative residue-management pathways.

Taken together, the evidence shows that water regime, soil type, cropping season, nitrogen fertilizer use, and crop-residue management interact in shaping greenhouse gas emissions from rice production in the Red River Delta. These interactions make it difficult to identify a single mitigation measure appropriate across the entire region. Instead, the evidence supports developing differentiated combinations of measures based on production conditions, as examined in the following section.

5. Mitigation directions tailored to rice production conditions in the Red River Delta

The evidence presented in Sections 3 and 4 indicates that greenhouse gas mitigation in rice production in the Red River Delta should not be based on a uniform technical package. Differences in soil type, cropping season, water regime, nitrogen fertilizer management, and crop-residue practices result in different emission profiles across production conditions. Mitigation measures should therefore be combined and differentiated based on dominant emission sources and the practical capacity to manage water, nutrients, and crop residues.

5.1. Integrated management of water, nutrients, and crop residues

An integrated approach is necessary because measures targeting one emission source can influence another. Water management is particularly important in this regard. Reducing the duration of continuous flooding through controlled drainage or alternate wetting and drying (AWD) can suppress CH₄

formation, but changes in soil moisture may also affect N₂O emissions, particularly around the time of nitrogen fertilizer application. Similarly, incorporating fresh rice straw can increase the availability of organic carbon for CH₄ formation when fields are subsequently flooded.

For rice-production conditions in the Red River Delta, water, nitrogen fertilizer, and crop-residue management should therefore be treated as interdependent components of the same mitigation package. Where water can be effectively controlled, AWD or controlled mid-season drainage can be combined with fertilizer application according to crop demand and growth stage. Coordinate nitrogen application with irrigation and drainage schedules to reduce the risk of unfavorable dry-*et* transitions after fertilizer application. Crop residues returned to the field should likewise be managed in relation to the timing of subsequent flooding, avoiding the incorporation of large quantities of fresh straw immediately before prolonged inundation.

The appropriate combination of these measures will depend on local production conditions. In areas with limited control over irrigation and drainage, for example, AWD's effectiveness may be constrained regardless of its technical mitigation potential. Similarly, residue incorporation may require different timing where cropping intervals are short. The objective should therefore not be to maximize the adoption of any single technique, but to identify combinations of practices that can reduce overall greenhouse gas emissions while maintaining rice productivity and economic viability.

5.2. Differentiating mitigation packages by soil type and cropping season

Field evidence from the Red River Delta provides a basis for distinguishing production conditions according to their dominant emission characteristics. In particular, higher CH₄ emissions have been observed on alluvial and saline soils during the summer/rainy season, whereas N₂O emissions require greater attention on grey and alluvial soils during the spring season (Bui Thi Thu Trang et al., 2021). These differences suggest that mitigation priorities should vary across soil-season combinations.

For alluvial and saline soils during the summer/rainy season, mitigation should emphasize CH₄ control. Where irrigation and drainage conditions permit, this implies reducing unnecessary periods of continuous flooding through controlled water management. Crop-residue management should be coordinated with these water regimes, particularly by avoiding the incorporation of large quantities of fresh straw immediately before prolonged flooding. Nitrogen management remains relevant, but under these conditions the principal mitigation objective is to reduce the anaerobic conditions that favor CH₄ formation.

For grey soils during the spring season, the mitigation package should focus more on N₂O and nitrogen-use efficiency. Fertilizer application should be closely coordinated with changes in soil-water conditions, particularly around drainage and rewetting periods. The objective is not simply to reduce fertilizer application, but to improve the timing and efficiency of nitrogen use while maintaining crop nutrient requirements. Water management under these conditions should therefore be designed not only to control CH₄

but also to avoid creating conditions that may increase N₂O emissions.

Alluvial soils require particular attention because the reviewed evidence suggests that they may be relevant to both emission pathways under different seasonal conditions: relatively high CH₄ emissions during the summer/rainy season and notable N₂O emissions during the spring season. This illustrates why mitigation measures should not be assigned solely based on soil type. When selecting water, fertilizer, and crop-residue management practices, consider the interaction between soil and cropping season.

5.3. Matching mitigation measures to water-control capacity and production organization

The technical suitability of a mitigation measure does not necessarily imply that it can be implemented effectively under all production conditions in the Red River Delta. This is particularly evident for AWD, whose effectiveness depends on the ability to control irrigation and drainage. Where farmers rely on shared irrigation systems, they cannot always manage water levels independently at the household level.

Accordingly, production areas with relatively reliable irrigation and drainage control are more suitable for the initial application of water-management-based mitigation packages. In areas where water cannot yet be adequately regulated, applying AWD mechanically may produce inconsistent results and may risk crop performance. Under such conditions, mitigation efforts may need to emphasize measures that can be implemented within existing production constraints while improvements in water-control capacity are pursued.

Production organization is also relevant

because several mitigation practices require coordination beyond individual farms. Irrigation schedules, synchronized drainage, crop-residue collection, and consistent recording of farming practices become more feasible when production is organized at the field, cooperative, or concentrated production-area scale. Thus, selecting mitigation packages in the RRD should consider not only biophysical conditions but also the organizational conditions under which the measures will be implemented.

5.4. Linking emission reduction with productivity and economic viability

Emission reduction should not be considered independently of rice productivity and farmers' economic interests. Measures that reduce greenhouse gas emissions but significantly reduce yields, increase production risks, or impose costs that farmers cannot absorb are unlikely to be sustained in practice.

For the Red River Delta, mitigation packages should therefore be evaluated against multiple criteria, including their effects on CH₄ and N₂O emissions, rice yields, water use, fertilizer-use efficiency, crop-residue management costs, and overall production efficiency. This is particularly important when comparing alternative combinations of AWD, nitrogen management, and residue treatment because their environmental and economic effects may vary across production conditions.

The appropriate direction is therefore to move from promoting individual "low-emission techniques" toward developing context-specific low-emission production packages. Such packages should specify the production conditions under which they apply and balance emission reduction with productivity,

economic efficiency, and production stability. This differentiated approach provides the technical basis for the state-management arrangements discussed in Section 6.

6. Implications for state management of low-emission rice production in the Red River Delta

The differentiated mitigation approach proposed in Section 5 has important implications for state management. Because greenhouse gas emissions vary across soil types, cropping seasons, water-management conditions, and production systems, state intervention should move beyond promoting individual technical practices toward establishing a coordinated management framework for low-emission rice production in the Red River Delta. Such a framework requires clear responsibilities across levels of government, appropriate policy and planning instruments, coordination with irrigation and production organizations, a credible measurement, reporting, and verification (MRV) system, and mechanisms to mobilize and target implementation resources.

Translating differentiated mitigation measures into practice requires a clear allocation of responsibilities among state-management actors and effective coordination with implementation and supporting actors. Based on the evidence synthesized in this study and the management requirements discussed above, *Table 1* proposes a state-management framework for low-emission rice production in the Red River Delta. The framework distinguishes state-management responsibilities from implementation and supporting functions and links each actor to relevant instruments, coordination requirements, and expected management outputs.

Table 1. Proposed state-management framework for low-emission rice production in the Red River Delta

Actor	Core responsibility	Management/implementation instruments	Coordination requirements	Expected output
State-management actors				
<i>Central government</i>	Establish a consistent national policy and methodological framework for low-emission rice production	Policy guidance; common MRV requirements; methodological standards; guidance on emissions data and emission factors	Provincial authorities and relevant specialized agencies	Consistent national framework and methodological requirements
<i>Provincial authorities in the RRD</i>	Translate the national framework into differentiated implementation according to local production conditions	Priority zoning; provincial implementation programs; resource allocation; provincial emissions and MRV databases	Commune-level authorities, irrigation-management entities, cooperatives, and relevant specialized agencies	Priority mitigation areas, implementation plans, resource allocation, and monitoring arrangements
<i>Commune-level authorities</i>	Connect state-management requirements with field-level implementation and data collection	Identification of participating areas and producers; confirmation and cross-checking of production and implementation data	Cooperatives, farmers, irrigation-management entities, and provincial specialized agencies	Verified local implementation and production data
Implementation and supporting actors				

Actor	Core responsibility	Management/ implementation instruments	Coordination requirements	Expected output
<i>Irrigation- management entities</i>	Enable coordinated implementation of water-management requirements	Irrigation and drainage schedules; water-regulation and operating procedures	Provincial and commune authorities, cooperatives, and farmers	Water regimes compatible with differentiated mitigation packages
<i>Cooperatives</i>	Organize collective implementation at the production-area level	Production coordination; farmer record-keeping; coordination of water and crop-residue management	Farmers, commune authorities, irrigation-management entities, and enterprises	Coordinated implementation and consolidated production records
<i>Enterprises</i>	Provide technology, services, and market linkages that support low-emission production	Digital solutions; monitoring equipment; residue-utilization services; production and market linkages	Cooperatives, producers, and relevant authorities	Technical and market support for implementation
<i>Independent verification bodies</i>	Independently verify methodologies, data, and mitigation outcomes where required	Validation and verification procedures	Program participants and competent authorities	Transparent and credible verification of mitigation outcomes

Note: Proposed by the authors based on the evidence synthesis and state-management analysis developed in this study. MRV-related elements are informed by the pilot MRV framework for high-quality, low-emission rice cultivation issued by the Ministry of Agriculture and Environment (2025).

Source: Authors' compilation (2026).

As shown in *Table 1*, the proposed framework places state-management responsibility primarily at the central, provincial, and commune levels, while cooperatives, irrigation-management entities, enterprises, and independent verification bodies handle implementation, coordination, service provision, or verification functions. This

distinction matters because low-emission rice production requires collective action but does not mean all participating actors exercise state-management authority. Within this framework, the central level sets common policy and methodological requirements; provincial authorities play the key role in adapting and organizing implementation to production conditions in the RRD; and commune-level authorities link these requirements to field-level implementation and data collection. Non-state and supporting actors complement this management structure through production coordination, water regulation, technology and service provision, and independent verification. The following subsections elaborate on these responsibilities and the institutional mechanisms required to operationalize the proposed framework.

6.1. Clarifying state-management responsibilities across levels of government

At the central level, the primary role should be to establish a consistent policy and methodological framework for low-emission rice production. This includes providing common guidance for greenhouse gas mitigation and MRV, developing methodological requirements for emissions data and emission factors, and establishing principles for recognizing mitigation outcomes. A common national framework matters because incompatible local methods would reduce data comparability and complicate the aggregation and verification of emission reductions.

Within this common framework, provincial authorities in the Red River Delta should assume the principal responsibility for translating national requirements into territorially differentiated implementation. Their role should include identifying priority rice-production areas, integrating emission-

reduction objectives into agricultural and relevant sectoral plans, organizing implementation programs, coordinating irrigation and agricultural agencies, developing provincial databases, and monitoring implementation outcomes. The evidence in this study suggests that provincial planning should distinguish production areas by soil type, cropping season, emission profile, water-control capacity, and production organization, rather than treating rice-growing areas as homogeneous.

Commune-level authorities should primarily support implementation and field-level data management. Their functions may include identifying participating production areas and households, coordinating with cooperatives and irrigation organizations, supporting the verification of cultivated area and farming practices, and facilitating the collection and cross-checking of information required for monitoring. This creates a vertical management chain in which the central level establishes common rules, the provincial level organizes and coordinates implementation, and the commune level connects the management system with actual production practices.

6.2. Using spatial planning and differentiated management as core policy instruments

The variation in emissions identified across production conditions implies that spatial differentiation should become an important management instrument in the RRD. Rather than setting a uniform requirement for all rice-growing areas, provincial authorities should progressively identify and classify production zones according to factors such as soil characteristics, cropping season, observed emission patterns, irrigation and drainage capacity, and the organizational conditions of production.

Such classification would allow management authorities to distinguish between areas where mitigation measures can be implemented immediately and areas where enabling conditions must first be improved. For example, areas with relatively high CH₄ emissions and adequate water-control capacity may be prioritized for coordinated water-management interventions, whereas areas with weak irrigation control may require infrastructure and organizational improvements before water-based mitigation measures can be implemented effectively.

This approach also provides a basis for more targeted public support. Pilot programs, technical assistance, infrastructure investment, and monitoring resources can be concentrated in areas where mitigation potential and implementation feasibility are both relatively high. As evidence and implementation capacity improve, the approach can then be extended to other production areas. State management would then shift from uniform dissemination of technical measures to differentiated planning based on production conditions and mitigation potential.

6.3. Establishing coordination mechanisms among state agencies and production actors

Low-emission rice production involves responsibilities that extend across administrative and sectoral boundaries. Water management involves irrigation authorities and service providers; agricultural practices involve specialized agricultural agencies and extension systems; production organization depends substantially on cooperatives and farmers; crop-residue utilization may require enterprises and markets; and MRV requires interaction among producers, local authorities, technical agencies, and independent verification bodies. Effective

implementation therefore requires an explicit coordination mechanism rather than parallel interventions by individual organizations.

At the provincial level, coordination is particularly important between agricultural management agencies, irrigation-management entities, local authorities, and cooperatives. Irrigation schedules, for example, need to be compatible with the low-emission production packages applied within a production area. A technically appropriate AWD schedule cannot be implemented effectively if irrigation operations are planned independently of production requirements. Similarly, residue-management programs are unlikely to be sustainable if collection is promoted without linkages to enterprises or other users capable of creating demand for the residues.

Cooperatives should be treated as implementation partners rather than as substitutes for state-management agencies. They can coordinate participating farmers, organize common production schedules, facilitate water management, support record-keeping, and aggregate information required for MRV. Enterprises can contribute technologies, monitoring equipment, digital solutions, residue-utilization services, and market linkages. The State's role is to establish the rules, incentives, coordination arrangements, and accountability mechanisms within which these actors participate.

6.4. Developing an integrated MRV and emissions-data system for the Red River Delta

A credible MRV system is necessary both to evaluate public mitigation programs and to support any future connection between low-emission rice production and carbon-finance mechanisms. The pilot MRV procedure for high-quality, low-emission rice cultivation provides a useful institutional reference

by identifying information such as field-water conditions, drainage periods, fertilizer application, crop-residue management, cultivated area, and yield that can be monitored in practice (Ministry of Agriculture and Environment, 2025).

For the Red River Delta, MRV should be developed as part of the state-management information system rather than as a stand-alone reporting exercise. Farmers and cooperatives can generate and record primary production data; commune-level authorities can support verification and cross-checking; provincial specialized agencies can manage databases, conduct quality control, aggregate results, and report according to common methodological requirements. Where emission reductions are to be independently recognized or used for carbon-credit mechanisms, appropriately independent entities should validate or verify them.

Data standardization is particularly important. Provinces should not develop incompatible indicators, reporting templates, or calculation methods. A common methodological framework is needed to enable comparison across production areas and aggregation across the RRD. At the same time, the database should retain sufficient detail on soil type, cropping season, water regime, fertilizer management, and crop-residue practices to reflect the heterogeneity demonstrated by the field evidence.

In the longer term, accumulating field-level data through MRV can also help improve emission factors for the RRD. Rather than relying indefinitely on generalized factors, a sufficiently robust longitudinal database could support the progressive development of emission factors differentiated by major production conditions. MRV should therefore serve two related purposes: verifying the

implementation and outcomes of mitigation programs and strengthening the evidence base for future state management.

6.5. Aligning public resources and incentives with mitigation priorities

The transition toward low-emission rice production requires resources beyond those available to individual farming households. Public intervention is particularly relevant where mitigation depends on collective infrastructure, monitoring systems, initial transition costs, or activities that generate environmental benefits not fully captured by individual producers.

Public resources should therefore be targeted according to the differentiated management framework proposed above. Priority investment may be required for irrigation and drainage infrastructure in areas where improved water control can enable effective mitigation; for digital infrastructure and data systems supporting MRV; and for technical and organizational capacity at the provincial, commune, and cooperative levels. Support should be linked to clearly identified production areas and measurable implementation requirements rather than distributed uniformly.

Policy incentives should also address the costs of changing production practices. Where farmers or cooperatives incur additional costs for monitoring, record-keeping, residue collection, or coordinated water management, appropriate support mechanisms may be necessary during the transition. At the same time, public support should avoid creating permanent dependence on subsidies. Its longer-term purpose should be to establish production systems in which lower input costs, improved resource-use efficiency, market opportunities, and, where feasible, carbon-related revenues help sustain

mitigation practices.

Resource allocation should also be linked to monitoring and evaluation. Areas receiving public support should generate sufficient information to assess not only emission reductions but also effects on yield, production costs, water use, and implementation feasibility. This would allow management authorities to determine which interventions to expand, modify, or discontinue.

6.6. Establishing an adaptive management framework for the Red River Delta

The available evidence does not support applying a single emission factor or mitigation package across the entire Red River Delta. State management should therefore be adaptive: policies and programs should be progressively adjusted as better field data, MRV results, and implementation experience become available.

An appropriate sequence would be to identify priority production conditions, implement differentiated mitigation packages in selected areas, monitor both environmental and production outcomes, and use the resulting evidence to refine technical guidance, targeting criteria, and support mechanisms before wider scaling. This approach would reduce the risk of expanding measures whose effectiveness has not been demonstrated under specific RRD conditions.

Accordingly, the central state-management challenge is not simply to promote the adoption of low-emission farming techniques. It is to establish an institutional system capable of differentiating production conditions, assigning responsibilities, coordinating relevant actors, directing public resources, generating verifiable data, and adjusting interventions based on evidence. Such a shift would move greenhouse gas mitigation

in rice production in the Red River Delta from a predominantly technical agenda to an integrated, evidence-based state-management framework.

7. Conclusion

Rice production in the Red River Delta offers considerable potential for greenhouse gas mitigation, although the available field evidence indicates substantial variation in emissions across soil types, cropping seasons, and production conditions. Among the greenhouse gases examined, methane (CH_4) emerges as a major mitigation priority. In a field study covering four paddy soil types in the region, Bui Thi Thu Trang et al. (2021) reported CH_4 emissions ranging from 74.4 to 698.51 kg CH_4 /ha/season and N_2O emissions ranging from 0.3 to 1.19 kg N_2O /ha/season. The broader evidence reviewed in this study further suggests that CH_4 mitigation deserves particular attention on alluvial and saline soils during the summer/rainy season, whereas N_2O management requires closer coordination between nitrogen fertilizer application and water regimes, particularly under soil and seasonal conditions associated with higher N_2O emissions.

These differences confirm that greenhouse gas mitigation in the RRD should not be based on a single technical measure or a uniform production protocol. Water management, nitrogen fertilizer use, and crop-residue management interact in determining emission outcomes, and measures targeting CH_4 may also affect N_2O . Mitigation strategies should therefore be designed as integrated packages and differentiated according to soil type, cropping season, water-control capacity, and production organization. Such differentiation is necessary not only to improve mitigation effectiveness but also to maintain rice productivity, economic viability, and

production stability.

From a state-management perspective, the central challenge is to move beyond promoting individual low-emission farming techniques toward an integrated institutional framework for low-emission rice production in the Red River Delta. The central level should provide a consistent policy, methodological, and MRV framework, while provincial authorities should translate this framework into spatially differentiated programs based on local production conditions and mitigation potential. Commune-level authorities, cooperatives, irrigation-management entities, enterprises, and independent verification bodies should participate within clearly defined implementation and coordination arrangements. In this framework, cooperatives and other non-state actors serve as implementation partners, not substitutes for state-management responsibilities.

A credible MRV and emissions-data system is particularly important for this transition. Standardized data on water regimes, fertilizer use, crop-residue management, cultivated area, yields, and other relevant production conditions would enable management authorities to monitor implementation, compare mitigation outcomes across production areas, and progressively strengthen the evidence base for emission factors specific to the RRD. Public investment and support mechanisms should likewise target production areas where mitigation potential, water-control capacity, and implementation feasibility justify intervention, with results evaluated in terms of both emission reductions and production performance.

The study nevertheless has limitations. The available field studies differ in location, experimental design, production conditions, and measurement methods; therefore, the

emission ranges synthesized in this article should not be interpreted as statistically representative estimates or uniform emission factors for the entire Red River Delta. In addition, the available evidence remains insufficient to quantify open-field crop-residue burning consistently across localities, cropping seasons, and residue-management practices within the region. Further research should therefore expand long-term, spatially differentiated field data; improve measurement consistency and emission-factor development; and jointly assess greenhouse gas emissions, rice yields, water and fertilizer use, and production costs.

Overall, reducing greenhouse gas emissions from rice production in the Red River Delta requires more than adopting individual mitigation technologies. It requires an adaptive state-management system that can differentiate production conditions, coordinate actors and resources, generate verifiable data, and progressively adjust interventions based on evidence. Establishing such a system would provide a more credible foundation for scaling up low-emission rice production while simultaneously supporting agricultural productivity, resource-use efficiency, and the longer-term development of carbon-related mechanisms in the sector.

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