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From fragmented farms to verified mitigation: rice clusters as infrastructure for smallholder carbon neutrality

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ABSTRACT

Low-emission rice practices are implemented on individual fields, but their feasibility often depends on shared irrigation, machinery, information and finance. This perspective paper develops a conditional model of the rice cluster as carbon infrastructure. Its contribution is not the claim that collective farming is new, but the specification of when an organization becomes carbon-ready: it must connect a hydrologically meaningful boundary, coordinated mitigation, a common measurement, reporting and verification protocol, transparent cost accounting, and enforceable benefit-sharing. Clustering is justified only when savings in measurement and transaction costs exceed the additional costs of coordination, governance and collective action. Evidence from studies of alternate wetting and drying and cooperative upgrading in Vietnam, together with the emerging rice-cluster architecture in the Philippines, shows both the potential and limits of aggregation. This aper proposes differentiated co-financing in which public funds support shared infrastructure and fixed measurement costs, farmers or value-chain actors co-invest in productive assets according to capacity and expected benefit, and verified-performance payments are distributed under disclosed rules. The appropriate near-term objective is verified emission reduction; carbon neutrality remains a whole-system, long-term claim requiring complete accounting of residual emissions and credible balancing.

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1 The coordination gap in low-emission rice

Rice mitigation is commonly presented as a menu of field practices: alternate wetting and drying (AWD), improved nitrogen management, low-emission straw handling, efficient machinery and lower-carbon energy. However, adoption is not determined by technical performance alone. AWD may reduce water use and methane, but outcomes vary with drying intensity, soil and management[1]. Recent economic analysis shows that field leveling and irrigation upgrading can require carbon prices or other support high enough to challenge farm-level viability[2]. Farmers also need reliable control over the timing of water delivery, which is frequently governed beyond a single plot[3].

The resulting problem is institutional. Per-plot monitoring is costly, irrigation decisions are interdependent, and machinery or residue services often operate across farms. Aggregation can pool fixed costs, but it can also add meetings, enforcement, elite capture and delays. The relevant question is therefore not whether clusters are inherently superior, but under what conditions a cluster creates a net advantage for verifiable mitigation.

2 What is new beyond a cooperative

Cooperatives already coordinate services, investment and marketing, and recent evidence from Vietnam shows both their potential and the limits of upgrading them into investment platforms[4]. The proposed carbon-ready cluster is not a replacement legal form and need not be a cooperative. It is an operational layer that can be attached to a cooperative, irrigation association, farmer organization or network of organizations.

Its distinctive feature is the simultaneous alignment of five boundaries: membership, hydrology, mitigation operations, greenhouse-gas accounting and financial responsibility. A standard cooperative may aggregate inputs or output without mapping fields, coordinating drainage, maintaining an emissions baseline, accepting a common verification protocol or disclosing carbon revenues. A carbon-ready cluster must do all five. This distinction makes the framework falsifiable: an organization that cannot define the relevant fields and water relationships, document agreed practices, assign data responsibility, account for costs and distribute benefits should not be treated as a carbon project.

The Philippine case provides emerging institutional evidence, although not yet proof of emission outcomes. Department of Agriculture Memorandum Circular No. 49 establishes recognized rice clusters, assessment, organizational records, cluster development plans and time-bound recognition[5]. These elements can supply identity and governance foundations. They do not themselves establish mitigation additionally, emission reductions or financial viability; those require a separate carbon-readiness layer and evaluation.

3 A conditional seven-function model

The seven functions, viz. organize, diagnose, decarbonize, digitize, verify, finance and share, are best understood as a linked decision system rather than a list of familiar practices. Table 1 states what each function adds beyond ordinary aggregation and the condition that must be met before proceeding. Failure at one stage can invalidate later claims: weak water control undermines AWD; weak records undermine verification; and opaque cost deductions undermine consent and participation.

4 When clustering produces net benefits

Clustering is economically justified only when avoided atomization costs exceed new collective costs. In compact form, the net cluster advantage is positive when savings in individual monitoring, reporting, and verification (MRV), contracting, training and shared-service costs are greater than cluster coordination, governance, enforcement and residual

Table 1 Conditional functions of a carbon-ready rice cluster

Function	Distinct carbon-readiness requirement	Proceed only if
Organize	Map members, fields, water links, authority and consent	Boundary and decision rights are credible
Diagnose	Establish a stratified emissions and feasibility baseline	Material sources and constraints are known
Decarbonize	Select a coordinated, locally feasible practice portfolio	Water and services can support compliance
Digitize	Link activity evidence to fields and accountable data stewards	Farmers can access and correct records
Verify	Apply proportionate sampling, modelling and independent checks	Uncertainty and cost meet the use case
Finance	Separate public goods, private assets and performance payments	Expected funding covers total delivery cost
Share	Disclose deductions and apply agreed distribution safeguards	Net benefits and grievance rights are acceptable

verification costs. This is a decision rule, not an empirical estimate. Each pilot should measure staff time, meeting and dispute costs, infrastructure and equipment costs, monitoring and verification fees, yield and input changes, and farmer payments under both clustered and plausible unclustered delivery.

The expected advantage is greatest where farms share a controllable irrigation unit, mitigation actions are standardized, fields are sufficiently contiguous for stratified sampling, and an organization already performs credible service and accounting functions. It may be negative where boundaries are dispersed, water cannot be jointly controlled, participation is unstable or a new organization must be created solely to obtain carbon revenue. Break-even analysis should test the minimum participating area, adoption rate and carbon or results-based payment needed to cover fixed and variable costs[2]. Carbon revenue should be presented as an uncertain supplement, not a guaranteed business case.

5 Differentiated finance and equitable allocation

A practical financing arrangement should separate public-good, productive and performance components. Public finance can cover baseline development, hydrological mapping, registry interoperability, extension, shared irrigation improvement and the fixed cost of an initial MRV system. Farmers, cooperatives, buyers or lenders can co-invest in productive assets, such as field leveling, pumps, machinery and dryers, when they receive identifiable private benefits. Carbon-market, supply-chain or public results-based payments should reward verified outcomes only after transparent deductions and reserves. Existing rice methodologies offer quantification rules, but do not remove the need to test local profitability and distribution[6].

Support should not be divided equally by default. Eligibility can consider incremental cost, mitigation potential, control over water, farm size, tenure, capacity to pre-finance investment and climate vulnerability. Higher grants may be justified for tenants and resource-poor farmers facing binding constraints; commercially viable assets may warrant loans or matching contributions. Recent work on government-led low-emission rice finance emphasizes that farmers face heterogeneous constraints and need differentiated support[7]. Safeguards should include published criteria, informed consent, a grievance mechanism, independent audit, caps on management deductions, disclosure of gross and net revenue, and a rule preventing exclusion solely because a farmer is costly to serve.

6 Verified mitigation before carbon neutrality

The immediate cluster objective should be verified mitigation, not a declaration of carbon neutrality. Methane reduction is important, but whole-system claims must also consider nitrous oxide, energy-related carbon dioxide, input production, residue pathways and defensible soil-carbon change[8–10]. Straw management, for example, can move emissions between burning, incorporation, transport and alternative use[11].

Carbon neutrality is retained only as a long-term direction governed by a mitigation hierarchy: define the boundary, measure material sources, reduce avoidable emissions, report absolute and yield-scaled results separately, and address residual emissions only with additional and durable removals without double counting. A cluster may make this accounting more feasible, but aggregation cannot substitute for evidence. Claims should advance through carbon-readiness levels, from recognized organization and baseline, to coordinated practice, independent verification and only then any transaction or neutrality claim.

7 Research and policy priorities

Philippine pilots should compare clustered and unclustered delivery using prespecified indicators: adoption and persistence of AWD, methane and nitrous oxide estimates, irrigation reliability, yield, water and energy use, total program and farmer cost, cost per tonne of carbon dioxide equivalent, distribution of net benefits, participation by tenants and women, and dispute frequency. Mixed-method evaluation should combine activity records and representative measurement with interviews on trust, workload and exclusion. International guidance on AWD can inform practice design, but local hydrology and governance remain decisive[12].

The testable proposition of the framework is therefore conditional: rice clusters improve smallholder decarbonization

only when boundary alignment and shared services reduce verification and implementation costs by more than the costs of collective action, while financing rules keep participation worthwhile and equitable. Demonstrating that proposition, not labelling existing organizations as carbon neutral, is the next research task.

Compliance with ethics guidelines

Rey S. Amante declares that there are no conflicts of interest or financial conflicts to disclose. This article does not contain any studies with human or animal subjects performed by the author.

Declarations

The author used OpenAI ChatGPT (GPT-5, accessed August–September 2026) for preliminary literature identification, language drafting, structural organization, and citation formatting, but not for data analysis. The author independently verified all sources, critically revised the AI-assisted material, approved the final manuscript, and accepts full responsibility for its content.

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