

LESSONS FROM 20 YEARS OF INWEPF: PADDY IRRIGATION AND DRAINAGE SYSTEMS AS FOUNDATIONS OF AGRO-ECOLOGICAL TRANSITION UNDER CLIMATE CHANGE

LEÇONS TIRES DE 20 ANS D'INWEPF : LES SYSTÈMES D'IRRIGATION ET DE DRAINAGE DES RIZIÈRES COMME FONDATION DE LA TRANSITION AGRO-ÉCOLOGIQUE DES RIZIÈRES FACE AU CHANGEMENT CLIMATIQUE

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ABSTRACT

Under climate change, paddy irrigation and drainage systems are increasingly expected to contribute not only to agricultural production but also to ecosystem sustainability and rural resilience, exposing the limitations of conventional, efficiency-oriented approaches to water management. While water use efficiency has long been emphasized as a key performance indicator in irrigation planning and evaluation, such a single-dimensional approach often fails to capture the broader ecological and social functions inherent in paddy irrigation and drainage systems, tending to undervalue paddy farming due to its high water volume requirement and low relative economic gross value added (GVA). In particular, the roles of water storage, groundwater recharge, biodiversity conservation, and landscape management have long been present in paddy-based agricultural systems but remain insufficiently recognized or systematically evaluated within efficiency-oriented frameworks. This paper reviews lessons from 20 years of activities of the International Network on Water and Ecosystem in Paddy Fields (INWEPF), with a specific focus on how paddy irrigation and drainage systems have evolved to support agro-ecological transition under climate change. Rather than treating the agro-ecological transition as the introduction of entirely new practices or infrastructures, this review adopts the view that it can be advanced by reinterpreting and revaluing ecological and hydrological functions already embedded in existing irrigation and drainage systems. Drawing on symposium proceedings, working group reports, and country case studies accumulated between 2004 and 2024, the review traces a gradual conceptual and practical shift from recognizing the multifunctionality of paddy fields toward managing irrigation and drainage systems as nature-based solutions (NbS) that generate ecosystem services at field, irrigation-system, and landscape scales. The review identifies four major phases in the evolution of INWEPF activities: the initial phase emphasizing the multifunctionality of paddy fields; a shift toward water-saving practices and integrated water resources management (IWRM); an emphasis on climate adaptation and resilience, incorporating traditional irrigation and landscape-based flood management; and recent explicit alignment with the Sustainable Development Goals (SDGs). Beyond technical outcomes, the paper highlights partnership (SDG 17) as a critical institutional condition underpinning the scaling of agro-ecological practices across diverse contexts.

Keywords: paddy irrigation and drainage systems; ecosystem services; multifunctionality of paddy fields; agro-ecological practices; flood management.

RESUME

Dans le contexte du changement climatique, il est, de plus en plus, attendu que les systèmes d'irrigation et de drainage des rizières contribuent non seulement à la production agricole, mais aussi à la durabilité des écosystèmes et à la résilience rurale, mettant ainsi en lumière les limites des approches conventionnelles axées sur l'efficacité en matière de gestion de l'eau. Alors que depuis longtemps

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l'accent était mis sur l'efficacité de l'utilisation de l'eau comme un indicateur clé de la performance dans la planification et l'évaluation de l'irrigation, une telle approche unidimensionnelle ne parvient pas à saisir les fonctions écologiques et sociales plus larges inhérentes aux systèmes d'irrigation et de drainage des rizières. Cette approche tend ainsi à sous-évaluer la riziculture en raison de ses besoins élevés en volume d'eau et de sa faible valeur ajoutée brute (VAB) économique relative. En particulier, le stockage de l'eau, la recharge des eaux souterraines, la conservation de la biodiversité et la gestion des paysages ont longtemps joué un rôle important dans les systèmes rizicoles mais restent insuffisamment reconnus ou systématiquement évalués dans des cadres orientés vers l'efficacité. Cet article passe en revue les leçons tirées de 20 années d'activités menées par le Réseau international pour l'eau et l'écosystème dans les rizières (INWEPF), avec un accent particulier sur la façon dont les systèmes d'irrigation et de drainage des rizières ont évolué pour soutenir la transition agro-écologique face au changement climatique. Plutôt que de traiter la transition agro-écologique comme l'introduction de pratiques ou d'infrastructures entièrement nouvelles, cette revue adopte le point de vue qu'elle peut être avancée grâce à une réinterprétation et une revalorisation des fonctions écologiques et hydrologiques déjà intégrées dans les systèmes d'irrigation et de drainage existants. En s'appuyant sur les actes du symposium, les rapports des groupes de travail et les études de cas par pays recueillies entre 2004 et 2024, la revue retrace une évolution conceptuelle et pratique progressive, passant de la reconnaissance de la multifonctionnalité des rizières à la gestion des systèmes d'irrigation et de drainage en tant que solutions fondées sur la nature (NbS) qui génèrent des services écosystémiques à l'échelle de la parcelle, du système d'irrigation et du paysage.

L'étude identifie quatre grandes phases dans l'évolution des activités de l'INWEPF : la phase initiale mettant l'accent sur la multifonctionnalité des rizières; une transition vers des pratiques d'économie d'eau et la gestion intégrée des ressources en eau (GIRE); un accent sur l'adaptation au climat et la résistance, l'intégration de l'irrigation traditionnelle et de la gestion des inondations basée sur le paysage; et l'alignement explicite récent avec les Objectifs de développement durable (ODD). Au-delà des résultats techniques, le document met l'accent sur le partenariat (ODD 17) comme une condition institutionnelle essentielle pour mettre à l'échelle des pratiques agroécologiques dans divers contextes.

Mots-clés : Systèmes d'irrigation et de drainage des rizières; Services écosystémiques; Multifonctionnalité des rizières; Pratiques agroécologiques; Gestion des inondations.

1. INTRODUCTION

Global agricultural systems face the unprecedented challenge of ensuring food security while mitigating and adapting to climate change. In Monsoon Asia and other rice-producing regions, paddy field agriculture serves as the primary source of nutrition and livelihoods for billions of people. Paddy irrigation and drainage systems, developed over centuries, are not merely engineered infrastructures for water delivery; they are complex socio-ecological systems deeply embedded in local hydrological cycles and cultural landscapes. However, conventional irrigation planning, management, and evaluation frameworks have heavily prioritized narrow engineering efficiency, often measured by crop yield per unit volume of water or by economic value generated per drop. This efficiency-oriented paradigm is exemplified by the United Nations Sustainable Development Goals (SDGs), specifically SDG Indicator 6.4.1, which monitors "Change in water use efficiency over time." While the indicator aims to promote sustainable water management, its underlying mathematical formulation has severe structural limitations when applied to paddy farming. The formula relies on the Gross Value Added (GVA) of the agricultural sector divided by the volume of water extracted. Because paddy rice cultivation naturally demands large volumes of water compared to upland crops and generates a relatively lower market GVA, the conventional indicator computes paddy farming as an inefficient, unsustainable use of water resources. This single-dimensional valuation entirely obscures the vast network of positive externalities—or multifunctionality—that paddy fields provide to the environment and human society.

To overcome these conceptual limitations, a paradigm shift is required: an agro-ecological transition of irrigated and drained systems. This transition reframes paddy fields not as isolated manufacturing units of food calories, but as functional ecosystem units that can provide Nature-based Solutions (NbS) to modern climate crises. The International Network on Water and Ecosystem in Paddy Fields (INWEPF)

was established in 2004, following the Tokyo Declaration, to address the nexus of water, food, and environmental sustainability (INWEPF, website). Composed of 19 member countries, INWEPF has spent two decades accumulating field evidence, organizing policy dialogues, and tracking the evolving paradigm of agricultural water management.

This paper reviews the findings, conceptual evolutions, and multi-country case studies from 20 years of INWEPF activities (2004–2024). The core objective is to demonstrate that an agro-ecological transition does not necessarily require the complete replacement of existing irrigation infrastructure with entirely new technologies. Instead, it can be achieved through systematic reevaluation, operational optimization, and institutional scaling of the ecological and hydrological functions inherent to paddy irrigation systems. By evaluating these practices against the modern SDG framework, this paper provides irrigation professionals, water institutions, and policymakers with a comprehensive blueprint for climate-resilient water governance.

2. METHODOLOGY AND THE CONCEPTUAL EVOLUTION OF INWEPF (2004–2024)

This comprehensive review utilizes qualitative and quantitative data extracted from two decades of INWEPF administrative records, symposium proceedings, working group reports, and individual country case studies compiled between 2004 and 2024. The chronological analysis reveals a profound conceptual trajectory, moving through four major evolutionary phases that parallel global shifts in environmental governance and climate science.

2.1 Phase 1 (2004–2010): The Multifunctionality of Paddy Fields

The founding period of INWEPF focused primarily on establishing the scientific framework for the "multifunctionality" of paddy fields. During this phase, member nations cooperated to counter the international pressure that viewed paddy fields as wasteful water users. Research focused on the physical quantification of positive externalities. Key keywords included flood mitigation, groundwater recharge, soil erosion prevention, biodiversity conservation, and cultural landscape preservation. The core finding of this phase was that the unique flooding irrigation of rice paddies functions as a massive decentralized network of temporary retention basins, stabilizing river-basin hydrology and capturing rainwater during monsoon storm events.

2.2. Phase 2 (2010–2016): Sustainable Irrigation and Participatory Management

As water scarcity intensified globally, INWEPF's focus shifted from purely recognizing environmental functions to actively managing water volumes through technological and social interventions. This phase saw the widespread introduction of Integrated Water Resources Management (IWRM) concepts to the irrigation sector. Technically, water-saving technologies like Alternate Wetting and Drying (AWD) gained prominence. Socially, the network heavily documented and advocated for Participatory Irrigation Management (PIM). By transferring water-allocation responsibilities directly to Farmer Organizations, member countries achieved both a substantial reduction in water extraction and an increase in the equitable distribution of water at the local level.

2.3 Phase 3 (2016–2020): Climate Adaptation and Resilience via Nature-based Solutions

With climate change accelerating the frequency and severity of catastrophic droughts and flash floods across Monsoon Asia, INWEPF integrated modern climate resilience frameworks into its core agenda. The concept of multifunctionality was explicitly updated to align with the global framework of Nature-based Solutions (NbS). Rather than building massive, carbon-intensive concrete infrastructure to manage floods and droughts, this phase emphasized the engineering rehabilitation of traditional irrigation systems and the landscape-scale deployment of agricultural ecosystems to buffer extreme climate events. Paddy fields were increasingly evaluated for their capacity to absorb sudden high-intensity precipitation, protecting downstream urban centers from inundation.

2.4 Phase 4 (2020–2024): SDG Alignment and Ecosystem Services Frameworks

In its most recent phase, INWEPF has modernized its conceptual framework by translating the traditional notion of multifunctionality into the standardized vocabulary of Ecosystem Services under the United Nations SDGs. This shift represents more than a linguistic modification; it provides a structured methodology to integrate the environmental benefits of paddy fields into national policy and economic accounting. Recent work has increasingly focused on carbon neutrality (mitigating methane emissions through water management), payment for ecosystem services (PES), and the development of comprehensive sustainability assessment metrics that can supersede single-dimensional efficiency indicators.

3. CONCERNS REGARDING THE CONVENTIONAL SDG INDICATOR OF WATER USE EFFICIENCY

To justify and scale up the agro-ecological transition, the structural flaws in current global assessment metrics must be dissected mathematically and conceptually. As noted, the United Nations Food and Agriculture Organization (FAO) monitors water sustainability through SDG Indicator 6.4.1 (Water Use Efficiency - WUE), calculated as follows:

$$WUE = Awe * PA + Mwe * PM + Swe * PS$$

Where *WUE* represents total Water Use Efficiency [USD/m³], *Awe* is irrigated agriculture water-use efficiency, *Mwe* is the efficiency of the industrial sector, and *Swe* is the efficiency of the services sector. The variables *PA*, *PM*, and *PS* represent the respective proportions of water allocated to each sector over total water withdrawal. The specific sub-equation for *Awe* is formulated as:

$$Awe = (GVA_{al} + GVA_{aa} + GVA_{ai} * (1 - Cr)) / Va$$

Where *GVA_{al}*, *GVA_{aa}*, and *GVA_{ai}* represent the Gross Value Added [USD] of the livestock, freshwater aquaculture, and irrigated cultivations subsectors, respectively. *Cr* represents the proportion of agricultural GVA derived from rainfed agriculture, and *Va* represents the total volume of water used by the agricultural sector [m³].

The INWEPF Japan Committee and international water experts have raised major scientific concerns regarding the application of this formula to paddy-dominated regions due to three critical systemic errors:

- **The Mathematical Penalty on Multi-functional Systems:** Because paddy fields rely on continuous or semi-continuous ponding depth during the vegetative phase, the volume of water used (*Va*) is inherently large. Simultaneously, commodity market prices for staple rice are often politically controlled or kept low to ensure urban food security, resulting in a modest Gross Value Added (*GVA_{ai}*). Consequently, the calculated *Awe* value is exceptionally low. The formula misinterprets the massive water throughput—which remains within the local ecosystem—as a sign of systemic economic waste.
- **Vulnerability to Climate Disasters:** When a region is struck by an extreme natural disaster, such as a major typhoon or drought, agricultural production collapses, causing GVA to drop precipitously. Because the irrigation infrastructure must still draw water to maintain basic landscape stability or salvage remaining crops, *Va* does not drop proportionally. This results in a severely degraded *WUE* calculation. Thus, a country that suffers from severe climate shocks is erroneously penalized by the indicator as having become "less efficient," masking its urgent need for adaptation support.
- **Neglect of Local Hydrological Cycles:** Water is fundamentally a local, basin-specific resource. In many monsoon river basins, water diverted into an upstream paddy field is neither consumed nor lost; a substantial percentage drains back into the river system or infiltrates into the underlying aquifer, becoming available for downstream municipal or agricultural reuse. The

conventional formula treats V_a as an absolute, permanent depletion of a resource, ignoring the cyclic nature of water in paddy landscapes.

To correct this systemic error, INWEPF advocates integrating the positive externalities of paddy farming into the core mathematical evaluation framework. If the multifunctionality of paddy fields is properly quantified and added to the numerator, the formula is modified to accurately reflect true socio-ecological efficiency:

$$Awe = (GVA_{ai} + GVA_{aa} + GVA_{ai} * (1 - Cr) + \text{Other Functions of Paddy Fields}) / V_a$$

The economic justification for this modification is immense. For example, the Science Council of Japan scientifically estimated that the aggregate economic value of the multifunctionality provided by paddy fields in Japan (including flood mitigation, groundwater recharge, and ecological stabilization) is worth approximately 48.6 billion USD per year (Science Council of Japan, 2001). Omitting a value of this magnitude from global indicators leads to severely distorted policy decisions, potentially encouraging the premature abandonment or conversion of vital agricultural ecosystems.

4. COMPREHENSIVE MAPPING OF INWEPF INITIATIVES TO THE SUSTAINABLE DEVELOPMENT GOALS

Over its 20-year history, INWEPF has generated a vast repository of field-tested methodologies and technological interventions across its 19 member countries. When systematically audited against the SDG framework, these initiatives demonstrate that the agro-ecological transition of paddy systems directly drives a broad spectrum of sustainable development targets well beyond water management alone (**Figure 1**).

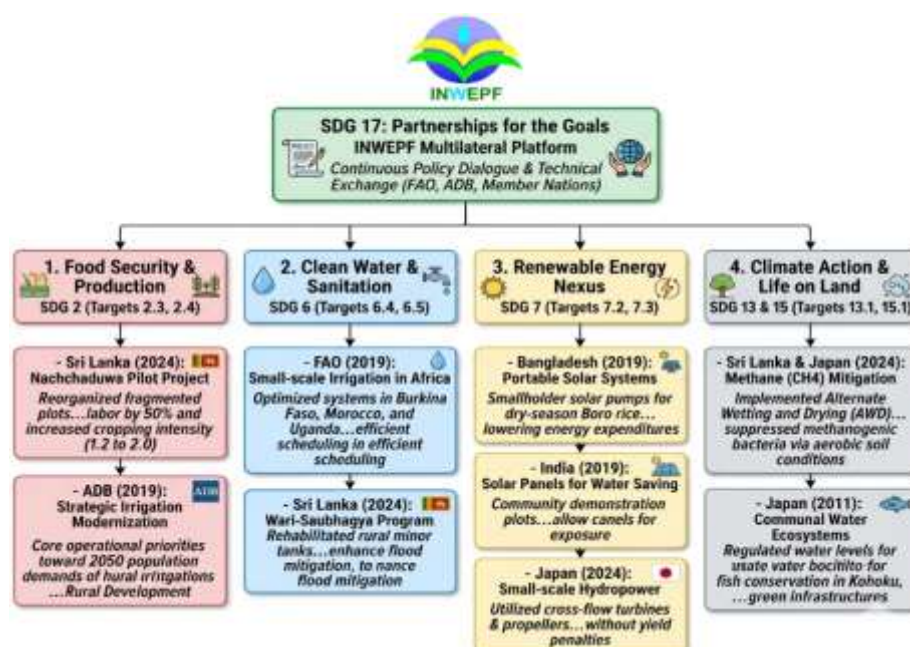


Figure 1. Comprehensive mapping of INWEPF initiatives and case studies to the SDGs

4.1 SDG 2: Zero Hunger

Paddy irrigation systems directly drive SDG Target 2.3 (improving agricultural productivity and incomes) and Target 2.4 (ensuring sustainable and resilient food production systems) through land optimization and strategic investments:

- **Farmland Consolidation and Crop Diversification (Sri Lanka, 2024):** In the Nachchaduwa Irrigation Scheme, Sri Lanka, a pilot project on farmland consolidation successfully addressed longstanding challenges of agricultural inefficiency and water mismanagement, directly contributing to SDG 2. By reorganizing highly fragmented, irregularly shaped farm plots into larger rectangular parcels, the project significantly facilitated the adoption of modern agricultural mechanization. This transformation proved crucial in mitigating the impacts of severe labor shortages, ultimately reducing harvesting labor requirements by half and machinery costs by up to 30%. Beyond operational efficiency, the project substantially enhanced land and water productivity. Through optimized irrigation and drainage layouts, the initiative increased cropping intensity from 1.2 to 2.0 in the selected land area, resulting in a remarkable surge in overall crop yields. Furthermore, the improved infrastructure enabled farmers to transition from water-intensive single-crop reliance toward diverse agricultural practices. This crop diversification not only reinforced regional food security by ensuring a stable and varied food supply but also strengthened the economic resilience of rural households by boosting their agricultural income, creating a sustainable model for future development.
- **Strategic Irrigation Investment for Food Security (ADB, 2019):** Addressing the escalating challenge of food insecurity driven by rapid population growth and shifting dietary demands, the Asian Development Bank (ADB) has strategically positioned irrigation modernization at the core of its operational priorities in Asia. With the region's population projected to continue growing through 2050, ensuring a stable food supply requires a fundamental transformation of existing agricultural infrastructure. The ADB's comprehensive approach emphasizes that modernizing irrigation systems is not merely an engineering upgrade but a vital intervention for sustainable rural development and poverty reduction. By upgrading aging facilities and introducing efficient water distribution mechanisms, these modernization efforts aim to maximize crop yields, thereby directly supporting the zero hunger objective. Furthermore, this strategic focus is intricately linked with building climate and disaster resilience, enabling agricultural communities to sustain productivity despite the increasing unpredictability of water availability and extreme weather events induced by climate change. Through sustained financial and technical assistance, the ADB empowers member countries to build robust, inclusive agricultural sectors that can reliably meet the nutritional needs of growing populations while uplifting rural economies.

4.2 SDG 6: Clean Water and Sanitation

Sustainable water management in paddy ecosystems requires balancing field-level productivity with basin-scale water monitoring, directly aligning with SDG Target 6.4 (water-use efficiency) and Target 6.5 (Integrated Water Resources Management):

- **Monitoring Water-Use Efficiency (SDG 6.4.1) & Small-scale Irrigation (FAO, 2019):** In alignment with SDG target 6.4 to substantially increase water-use efficiency and ensure sustainable freshwater withdrawals, the Food and Agriculture Organization (FAO) has championed initiatives to optimize small-scale irrigation systems across Africa, including Burkina Faso, Morocco, and Uganda. Faced with increasing food demand and water scarcity, these projects focused on delineating optimal farming practices to enhance both crop water productivity and overall system efficiency. The FAO implemented comprehensive strategies to improve the efficiency of conveyance, distribution, and application within existing irrigation networks. Furthermore, the initiatives addressed critical on-farm challenges by introducing efficient irrigation scheduling consistent with actual crop water requirements, demonstrating proper land leveling techniques, and recommending tailored fertilizing plans. By transitioning poorly resourced smallholders toward these optimized agricultural practices, the projects successfully minimized unnecessary water losses and improved the balance between water demand and supply. This integrated approach not only safeguarded scarce water resources but also improved farmers' livelihoods, demonstrating that enhanced water productivity is a pivotal strategy to simultaneously address regional water scarcity and food security concerns.

- **Climate Resilience in Paddy Ecosystems via Tank Cascade Restoration (Sri Lanka, 2024):** To counteract the adverse impacts of climate change, such as severe droughts and flash floods, Sri Lanka initiated the "Wari-Saubhagya" (Prosperity of Irrigation) program, a massive undertaking aimed at rehabilitating rural minor tanks and anicuts across the island. This initiative directly supports SDG 6 by enhancing the agricultural and water productivity of minor irrigation schemes while fundamentally improving the living standards of rural communities. The comprehensive rehabilitation process focuses on restoring the structural integrity and storage capacity of these vital water bodies, many of which are part of traditional interconnected tank cascade systems. By increasing the water-holding capacity and minimizing water losses through improved delivery facilities, the program ensures a reliable water supply for paddy cultivation even during prolonged dry spells. Concurrently, the strengthened infrastructure significantly improves flood mitigation capabilities during extreme rainfall events. Furthermore, the initiative emphasizes developing these tanks as local economic entities to generate diverse income streams for farmers. Ultimately, this holistic restoration not only ensures clean, sufficient water for agriculture but also fortifies the socio-ecological resilience of the entire rural landscape.

4.3 SDG 7: Affordable and Clean Energy

Modern paddy water management increasingly intersects with renewable energy deployment, expanding technical avenues for clean energy transition and energy efficiency (Targets 7.2 and 7.3):

- **Solar Irrigation Systems (Bangladesh, 2019):** As part of the pursuit of affordable and clean energy solutions in agriculture, Bangladesh has actively evaluated and introduced smallholder solar irrigation systems for crop production. Traditionally heavily reliant on fossil fuels or grid electricity to power groundwater pumps for dry-season Boro rice cultivation, the agricultural sector faced significant challenges, including high operational costs and environmental impacts. The deployment of portable solar panel systems and solar-powered irrigation pumps presents a transformative alternative. By harnessing abundant solar energy, these systems provide a reliable, continuous power supply for water extraction, ensuring essential irrigation needs are met without the economic burdens of diesel consumption. This transition not only significantly reduces the carbon footprint of agricultural operations but also empowers rural farmers by drastically lowering their long-term energy expenditures. Consequently, the integration of solar irrigation technology serves as a critical step toward establishing sustainable, energy-efficient farming models that protect local ecosystems while simultaneously enhancing the economic viability and energy independence of smallholder agricultural communities.
- **Solar Panels for Water Saving (India, 2019):** Facilitated water-saving irrigation practices by providing land for irrigation demonstrations powered by solar panels. The institutional scaling of renewable-energy-driven water conservation was highlighted by the ICID Water Saving in Agriculture Farmers Award recipients from India (2019). Their initiative facilitated widespread water-saving irrigation practices by using dedicated farmland for community demonstration plots powered entirely by solar panels, thereby coupling water-use restrictions with exposure to clean energy.
- **Small-scale Hydropower Generation (Japan, 2024):** In Japan, the integration of small-scale hydropower generation into existing agricultural water infrastructure exemplifies an innovative approach to achieving SDG 7. Capitalizing on the nation's extensive network of irrigation canals, dams, and headworks, this initiative harnesses the potential energy of water flowing from upstream watersheds to generate clean, renewable electricity. A key advantage of this system is that it utilizes pre-existing irrigation facilities, which means it requires minimal new capital investment and results in a remarkably low environmental impact during construction, effectively avoiding the high greenhouse gas emissions typically associated with building large-scale power plants. Various technologies, such as improved cross-flow water turbines and vertically coupled propellers, have been adapted for use in reservoirs, gentle canal slopes, and drop structures. From a water-energy-

food nexus perspective, small hydropower not only provides a sustainable energy source but also enhances the multifaceted value of agricultural water systems. This approach demonstrates how rural infrastructure can be leveraged synergistically to supply clean, domestically produced renewable energy while supporting traditional agricultural production and contributing to global climate change mitigation efforts.

4.4 SDG 13: Climate Action

Paddy fields represent critical ecological infrastructure where climate adaptation and greenhouse gas mitigation can be operationalized simultaneously (Targets 13.1 and 13.2):

- **Methane (CH₄) Emission Reduction via AWD (Sri Lanka & Japan, 2024):** Addressing the significant contribution of agriculture to global greenhouse gas emissions, specific water management interventions in paddy fields have emerged as powerful tools for climate action. Traditional continuously flooded rice paddies are major sources of methane (CH₄) due to the anaerobic decomposition of organic matter in the soil. To combat this, practices such as Alternate Wetting and Drying (AWD) have been actively promoted and implemented, as demonstrated in projects in Sri Lanka and highlighted in Japanese technical frameworks. AWD involves periodically draining the paddy fields to introduce oxygen into the soil, deliberately shifting the environment from anaerobic to aerobic conditions. This critical change in soil chemistry fundamentally suppresses the activity of methanogenic bacteria, thereby drastically reducing the generation and release of methane into the atmosphere. In pilot studies, such as the farmland consolidation project in Nachchaduwa, Sri Lanka, improved drainage infrastructure was pivotal in enabling the precise water control required for these practices. By successfully reducing methane emissions without compromising rice yields, these strategies align perfectly with global carbon-neutrality targets and sustainable agro-ecological transitions.

4.5 SDG 15: Life on Land

Constructed irrigation networks can function as vital engineered wetlands that sustain freshwater biodiversity, satisfying SDG Targets 15.1 and 15.5:

- **Ecosystem Conservation through Paddy Water Management (Japan, 2011):** In Japan, the management of irrigation water extends far beyond mere agricultural productivity, playing a critical role in preserving local biodiversity and terrestrial ecosystems, thereby contributing to SDG 15. Research highlights the multifaceted functions of paddy irrigation systems, portraying them as vital "communal water" networks that sustain rich ecological habitats. A prime example is the implementation of new paddy management efforts specifically designed for fish conservation in regions like Kohoku. By carefully regulating water levels and maintaining the connectivity of drainage and irrigation canals, these systems provide essential breeding and feeding grounds for various aquatic and terrestrial species that depend on the rural wetland environment. Furthermore, recognizing the historical and environmental value of these irrigation networks fosters a sense of attachment and cooperative management among both farmers and non-farmer residents. This community-driven approach ensures the continuous maintenance of water channels, preventing ecosystem degradation. Consequently, these traditional, well-managed irrigation landscapes act as extensive green infrastructures, protecting local flora and fauna and ensuring the sustainable coexistence of human agricultural activities with vibrant natural ecosystems.

4.6 SDG 17: Partnerships for the Goals

The implementation and cross-border scaling of these agro-ecological interventions depend entirely on stable institutional linkages and polycentric governance architectures:

- **International Collaboration for Water Management (INWEPF, ADB, FAO):** The International Network for Water and Ecosystem in Paddy Fields (INWEPF) stands as a prime embodiment of SDG 17, demonstrating the profound impact of robust international partnerships. Over the

past two decades, INWEPF has cultivated a dynamic platform for continuous policy dialogue and technical exchange among its member nations across Asia and Africa. This collaboration extends beyond national governments to encompass critical partnerships with prominent international organizations, including the Food and Agriculture Organization (FAO) and the Asian Development Bank (ADB). Together, these entities facilitate the extensive sharing of knowledge, innovative research, and best practices related to sustainable agricultural water management, climate resilience, and food security. Whether it involves disseminating guidelines for water-use efficiency, supporting capacity-building workshops for local farmers, or jointly funding infrastructure modernization projects, this multiscale governance approach ensures that developing nations receive the necessary technical and financial support. By aligning diverse stakeholders—from global policymakers to local water user associations—these partnerships synergistically drive the global transition toward sustainable agro-ecological systems (Various Representatives, Continuous efforts 2018–2024).

5. DISCUSSION: INSTITUTIONAL CONDITIONS, PARTNERSHIPS, AND GOVERNANCE FOR TRANSITION

The technical and environmental successes documented across the 19 member countries reveal a fundamental truth: the agro-ecological transition of water systems cannot be achieved through engineering interventions alone. The ultimate determining factor in the successful scaling of these practices is the presence of robust institutional conditions and multi-stakeholder partnerships, which directly align with SDG 17 (Partnerships for the Goals).

INWEPF has operated continuously for 20 years, not as a standard commercial project or a rigid regulatory enforcement body, but as a flexible, long-term international platform for policy dialogue, knowledge exchange, and institutional learning. This long-term continuity has established an invaluable foundation of trust among ministries of agriculture, irrigation departments, research institutions, and international development agencies (such as the FAO, ADB, JICA, and IWMI). This partnership architecture has successfully bridged three distinct levels of governance:

- **Bridging Research and Policy:** Scientific innovations developed in academic institutions—such as methane mitigation metrics for AWD or economic evaluation models for multifunctionality—are directly introduced into high-level steering meetings and symposiums. This allows policymakers to immediately witness the macro-benefits of agro-ecological water management, translating scientific data into national budget allocations and national agricultural strategies.
- **Bridging Policy and On-the-Ground Implementation:** Through international institutional exchanges (such as JICA-supported knowledge transfers between Japan, the Philippines, and Cambodia), successful governance models like PIM are translated and adapted to match local socio-political contexts. This prevents the common failure of copying a technology without adapting its social governance structure.
- **Fostering Inclusivity and Co-Design:** Modern governance requires moving beyond treating farmers as passive beneficiaries of water infrastructure. The evolution of INWEPF's working groups highlights a steady trajectory toward inclusive co-design, in which traditional local knowledge—such as the community management of tank cascades—is integrated with modern digital water accounting and engineering tools.
- **Despite these extensive achievements, the discussion must also candidly address current unresolved challenges.** The network identifies four primary bottlenecks that must be resolved to completely institutionalize the agro-ecological transition:
- **The Need for Standardized Ecosystem Service Evaluation:** While the economic value of multifunctionality is clearly understood conceptually, there is still an urgent need for an internationally standardized, easily applicable methodology to measure and verify these ecosystem services at the individual field or catchment scale. Without standardized metrics, it remains difficult to fully integrate these values into formal global monitoring frameworks like the

SDGs.

- Limitations in Socio-Economic Data: Existing irrigation databases are heavily weighted toward physical engineering parameters (e.g., canal lengths, water flow rates, concrete volumes). Comprehensive, long-term socio-economic data tracking how agro-ecological water transitions directly alter farmer household wealth, gender equity in water access, and local job creation remain comparatively scarce.
- The Acceleration of Digital Governance and Carbon Accounting: As global carbon markets expand, the rice sector must urgently transition toward verifiable digital tracking of greenhouse gas reductions. Developing low-cost, remote-sensing-based tools to verify AWD compliance and translate water management directly into carbon credits represents a crucial next step for agricultural water governance.

6. CONCLUSIONS

Two decades of collective work by the International Network on Water and Ecosystem in Paddy Fields (INWEPF) provide conclusive evidence that paddy irrigation and drainage systems are not static engineering conduits for food production. They are dynamic, multi-functional socio-ecological assets that form the indispensable foundation for an agro-ecological transition under a changing climate. When evaluated holistically, sustainable water management in paddy landscapes simultaneously addresses critical global imperatives anchored within the global sustainability agenda: eradicating hunger through structural consolidation and strategic investments (SDG 2), conserving trans-regional water resources and restoring cascade networks (SDG 6), generating clean, decentralized renewable energy through solar innovations and open-canal hydro-turbines (SDG 7), driving aggressive climate mitigation via AWD methane suppression (SDG 13), and preserving fragile freshwater wetland ecosystems and terrestrial biodiversity (SDG 15).

The core policy recommendation of this study is that international institutions and global water metrics must immediately move beyond single-dimensional, efficiency-oriented assessment frameworks such as the conventional SDG Indicator 6.4.1. Evaluating water systems solely by dividing market-based Gross Value Added by raw water extraction creates a severe mathematical distortion that penalizes multifunctional agricultural ecosystems, potentially leading to irreversible environmental degradation and heightened vulnerability to climate change. Global indicators must be structurally updated to systematically incorporate the positive externalities and ecosystem services inherent to paddy landscapes.

Ultimately, long-term international institutional platforms such as INWEPF offer profound lessons for the broader International Commission on Irrigation and Drainage (ICID) community and stakeholders in the global water sector. They demonstrate that the path toward a climate-resilient, water-secure future does not necessarily depend on constructing entirely new, capital-intensive infrastructure. Rather, it depends on our capacity to reframe, revalue, and manage cooperatively the ecological and hydrological functions that have always been embedded in our traditional irrigation landscapes. By leveraging international partnerships to integrate science, community governance, and enlightened policy, the global irrigation community can successfully transform global paddy systems into resilient, nature-based engines of sustainable development.

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