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Tropical Peatland Restoration in Indonesia as an Integrated Pathway to Sustainable Development Goals: Policy, Rewetting, Revegetation, and Livelihood Revitalization

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ABSTRACT

Indonesia's tropical peatlands are globally significant carbon stores and locally important socio-ecological landscapes, yet decades of drainage, fire, and conversion have transformed many peat hydrological units into persistent sources of greenhouse gas emissions, disaster risk, biodiversity loss, and livelihood vulnerability. This manuscript revises and strengthens the original policy-action analysis of Indonesian peatland restoration by positioning restoration as an integrated pathway for achieving selected Sustainable Development Goals (SDGs), particularly SDGs 1, 2, 3, 4, 5, 8, 10, 13, and 15. Using a qualitative synthesis of policy instruments, restoration program experience, and recent scientific literature, the paper examines how three restoration measures - rewetting, revegetation, and revitalization of local livelihoods - interact with national peat governance and sustainable development targets. The novelty of this paper lies in reframing the "3R" restoration framework not merely as technical rehabilitation, but as a governance-to-ecosystem-services pathway that links hydrological recovery,

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fire-risk reduction, carbon mitigation, biodiversity rehabilitation, community-based livelihoods, and adaptive monitoring. Recent evidence shows that rewetting can reduce peat CO2 emissions and subsidence, but its effectiveness depends on time, water-table stability, canal-network configuration, vegetation recovery, land tenure, and community adoption. Revegetation and paludiculture can improve ecosystem function when species selection is hydrologically compatible and market pathways are secured. Livelihood revitalization remains the most socially sensitive component because economic transitions require trust, extension, gender-sensitive participation, and viable value chains. The manuscript concludes that peat restoration in Indonesia will contribute meaningfully to SDGs only when implemented as long-term, landscape-scale, data-driven, and locally legitimate governance, rather than as a short-term infrastructure project.

1. Introduction

Tropical peatlands occupy a relatively small proportion of the global land surface but store exceptionally large amounts of organic carbon and provide hydrological regulation, biodiversity habitat, disaster-buffering functions, and livelihood resources. In Indonesia, peatland degradation has become a critical development issue because the same landscapes that store carbon and regulate water have also been opened through drainage canals, plantation expansion, fire-prone land preparation, and infrastructure development. Once drained, peat soils oxidize, subside, and become highly flammable, creating a reinforcing cycle of ecological degradation, haze disasters, greenhouse gas emissions, livelihood insecurity, and public-health impacts [1-5]. Therefore, peatland restoration is no longer only an environmental rehabilitation agenda; it is a strategic development intervention that connects climate mitigation, disaster-risk reduction, rural poverty reduction, biodiversity recovery, and governance reform.

The Sustainable Development Goals (SDGs) provide a useful integrative framework for understanding this connection. Unlike sectoral development targets, the SDGs require simultaneous attention to poverty, food security, health, education, gender inclusion, economic opportunity, climate action, terrestrial ecosystem protection, and institutional capacity [6,7]. Degraded peatlands directly intersect with these goals. Recurrent peat fires undermine public health and education through haze exposure and school disruption; drainage-based production systems increase carbon emissions and long-term land subsidence; and poorly governed land-use transitions increase vulnerability among peatland communities. Conversely, restoration can generate bundled benefits when hydrological recovery, vegetation rehabilitation, and livelihood transformation are treated as mutually reinforcing components.

Indonesia responded to the severe 2015 peat and forest fires by strengthening national peat governance through the establishment of the Peat Restoration Agency (BRG) in 2016, later expanded into the Peatland and Mangrove Restoration Agency (BRGM). Restoration policy has been organized around peat hydrological units, protection and cultivation functions, water-level management, and the "3R" strategy: rewetting, revegetation, and revitalization of local livelihoods. Early restoration policy was heavily shaped by the urgency of fire prevention, but the scientific and policy literature has increasingly emphasized that restoration success depends on institutional coordination, long-term monitoring, social legitimacy, economic viability, and the capacity to handle landscape heterogeneity [8-15].

This paper strengthens the original manuscript by making three academic contributions. First, it clarifies peat restoration as a policy-action pathway connecting national governance instruments to SDG outcomes. Second, it updates the evidence base with recent literature on emissions mitigation, rewetting effectiveness, InSAR-based monitoring, livelihood transitions, restoration economics, and socio-ecological complexity. Third, it sharpens the novelty of the analysis by arguing that Indonesian peat restoration should be evaluated not simply by hectares rewetted or canals blocked, but by the degree to which hydrological recovery, ecological function, livelihood resilience, and governance accountability are achieved across peat hydrological units.

2. Research Significance

This manuscript is significant for IJoPRI because it directly addresses the journal scope on peatland restoration, hydrology, fire mitigation, socio-economic approaches, policy innovation, disaster adaptation, biodiversity, and sustainable utilization of peatland products. It also speaks to the Indonesian policy context in which restoration must simultaneously meet ecological, climate, and livelihood objectives. The analysis is particularly relevant to Riau and other peat-dominated provinces because peat degradation is not merely a biophysical problem; it is a multi-level governance problem involving land tenure, commodity markets, hydrological engineering, fire-risk institutions, community participation, and data systems.

The central argument is that peat restoration contributes to sustainable development only when restoration outputs are translated into measurable socio-ecological outcomes. Canal blocks, wells, nurseries, community training, and livelihood pilots are important outputs, but they do not automatically produce restoration success. The more decisive outcomes are stable water tables, reduced fire probability, lower peat oxidation, recovery of peat-adapted vegetation, protection of biodiversity habitat, viable wet-livelihood systems, and strengthened community-governance relationships.

3. Methods

This paper applies a qualitative policy and evidence synthesis. The analysis builds on the original manuscript's review of action research and restoration activities conducted by partners of the national peat restoration program during 2016-2019, with attention to Sumatra and Kalimantan. The revision expands the evidence base by incorporating recent peer-reviewed literature and current journal-style requirements. The synthesis follows three analytical steps.

First, national peatland policies and SDG targets were interpreted to identify how restoration mandates are connected to development outcomes. Key policy instruments include the establishment of the Peat Restoration Agency, peat ecosystem protection and management regulations, and national SDG implementation frameworks. Second, restoration measures were grouped into the 3R framework: rewetting, revegetation, and revitalization of local livelihoods. For each measure, the analysis assessed expected mechanisms, potential SDG contributions, and implementation risks. Third, the policy and technical components were integrated into a governance-to-ecosystem-services framework that links restoration actions to ecological functions, carbon mitigation, disaster-risk reduction, and livelihood resilience.

The analysis is interpretive rather than experimental. It does not claim to provide a direct causal measurement of restoration impact across all Indonesian peatlands. Instead, it offers a strengthened conceptual and evidence-based synthesis to improve the manuscript's academic clarity, novelty, and relevance for a peatland-focused journal.

Table 1. Linkage between peat restoration measures and SDG pathways

SDG cluster	Restoration pathway	Critical interpretation
SDG 1: No Poverty; SDG 8: Decent Work; SDG 10: Reduced Inequalities	Revitalization of peat-adaptive livelihoods, social forestry, community enterprise, and value-chain development.	Restoration becomes pro-poor only when wet-livelihood options are marketable, locally accepted, gender-sensitive, and not dependent on continued peat drainage.
SDG 2: Zero Hunger	Peat-adaptive food and agroforestry systems, fishery, sago-based systems, and paludiculture commodities.	Food security must be aligned with hydrological limits; drainage-dependent crops may increase short-term income while weakening long-term ecosystem resilience.
SDG 3: Good Health and Well-being	Reduced haze exposure through fire-risk reduction, improved water management, and landscape-level prevention.	Health benefits are indirect but substantial; they depend on preventing recurrent fires rather than reacting to smoke disasters.
SDG 4: Quality Education; SDG 5: Gender Equality	Community extension, farmer schools, participatory monitoring, and inclusive restoration planning.	Education and gender inclusion are enabling conditions for adoption, maintenance, and legitimacy of restoration measures.
SDG 13: Climate Action	Rewetting, avoided peat oxidation, reduced fire emissions, and improved monitoring of greenhouse gas implications.	Climate contributions depend on water-table stability, vegetation recovery, fire prevention, and transparent monitoring, reporting, and verification.
SDG 15: Life on Land	Revegetation, biodiversity habitat recovery, peat swamp forest protection, and landscape connectivity.	Biodiversity recovery requires native or peat-adapted species, protection from recurrent fire, and long-term ecological monitoring.

4. Results and Discussion

4.1. Peat restoration as a governance-to-ecosystem-services pathway

The original manuscript correctly identified peat restoration as a potential contributor to SDGs. The strengthened argument is that this contribution operates through a governance-to-ecosystem-services pathway. Policies define the restoration mandate, institutions coordinate action, technical measures alter hydrological and ecological conditions, and these changes generate ecosystem services such as carbon storage, fire-risk reduction, biodiversity habitat, water regulation, and livelihood resources. The pathway is not linear. It is mediated by land tenure, canal-network design, community acceptance, commodity markets, monitoring capacity, and climatic variability.

This framing helps avoid a common weakness in restoration narratives: equating restoration area or infrastructure count with restoration success. Recent evidence confirms the mitigation importance of peat swamp forests in Southeast Asia. Land-use change affecting peat swamp forests and mangroves generated a large share of regional land-use emissions during 2001-2022, while conservation and restoration of these ecosystems offer major mitigation potential [1]. However, mitigation potential becomes real only when restoration produces sustained hydrological and ecological change. Thus, policy success should be evaluated through outcomes such as water-table recovery, subsidence reduction, fire incidence, vegetation structure, carbon balance, livelihood adoption, and governance performance.

4.2. Rewetting: necessary but insufficient without adaptive hydrological governance

Rewetting is the foundational restoration measure because drained peat becomes vulnerable to oxidation, subsidence, and fire. Canal blocking, canal backfilling, and water-level management are intended to raise and stabilize the groundwater table, reduce peat flammability, and slow carbon loss. In cultivation zones, maintaining a maximum water table of approximately 40 cm below the peat surface has been widely used as a regulatory benchmark to reduce fire susceptibility and peat oxidation, although site-specific hydrological conditions remain critical.

Recent empirical evidence strengthens the case for rewetting but also clarifies its limits. Measurements from rewetted oil palm plantations on tropical peatlands indicate that rewetting significantly reduces peat CO2 emissions; one study reported reductions in heterotrophic respiration and total soil respiration, while also noting that rewetting alone may not restore emissions to levels observed in secondary forest [10]. Remote-sensing evidence using L-band InSAR further suggests that canal blocks can reduce subsidence over time, but that restoration effects are time-dependent and spatially variable [11]. These findings support a more careful academic claim: rewetting is a necessary condition for peatland recovery, not a complete guarantee of restoration success.

For SDG 13, rewetting contributes to climate action by reducing oxidation and fire emissions. For SDG 3, it contributes to public health by lowering haze risk. For SDG 2 and SDG 8, however, rewetting can create short-term tensions because farmers accustomed to drained systems may face reduced suitability for certain crops. Therefore, rewetting must be paired with livelihood transition, market support, extension, and compensation or incentive mechanisms where necessary. Without these social and economic supports, communities may view hydrological restoration as a constraint rather than a pathway to resilience.

4.3. Revegetation: from planting activity to ecosystem-function recovery

Revegetation is often understood as planting trees, but in peatland restoration it should be defined more precisely as the recovery of peat-adapted vegetation structure, ecological function, and biodiversity-supporting habitat under wet conditions. Degraded peatlands often experience seed-source limitation, repeated fire, altered microtopography, and invasive vegetation pressure. Under these conditions, natural regeneration may be slow and uncertain. Assisted revegetation is therefore needed in many sites, especially where fire has repeatedly removed vegetation and seed banks.

The academic revision of the manuscript emphasizes that revegetation contributes to SDG 15 only when the selected species are ecologically appropriate, hydrologically compatible, and socially useful. Native peat swamp species, sago, jelutung, gelam, purun, and other paludiculture-compatible species can support both ecological recovery and livelihood development if there is a viable value chain. Conversely, planting species that require drainage or lack market pathways can undermine restoration objectives. Revegetation must therefore be evaluated through survival rate, canopy development, biodiversity indicators, peat moisture effects, fire-buffering function, and local economic relevance, not only through the number of seedlings planted.

Landscape context is also decisive. Revegetation in isolated plots may have limited ecological effect if surrounding canals continue to drain the peat or if fire prevention is weak. A more robust approach is to combine revegetation with hydrological zoning, protection of peat domes, community patrols, biodiversity corridors, and long-term monitoring. This aligns restoration with ecosystem-service recovery rather than short-term planting campaigns.

4.4. Revitalization of local livelihoods: the most decisive social test of restoration

Revitalization of local livelihoods is the most socially sensitive component of the 3R framework. It recognizes that peatland degradation is partly driven by economic necessity, commodity demand, and limited alternatives. Communities living in and around peatlands often depend on land-based activities, yet many conventional crops are tied to drainage. Restoration therefore requires an economic transition from drainage-dependent livelihoods toward wet or low-drainage livelihood systems.

Recent livelihood studies show that such transitions are difficult. Demonstration plots and capacity-building programs may not be widely adopted if they are not aligned with local preferences, market access, labour availability, capital constraints, cultural meanings of land, and trust in external programs [12,13]. One study in Central Kalimantan found that only a minority of demonstration initiatives were adopted beyond direct participants, illustrating that livelihood revitalization cannot be reduced to training or pilot projects alone [12]. Economic reviews also show that peat restoration involves substantial costs and that existing valuation studies still insufficiently capture trade-offs and forgone opportunities [14].

This evidence strengthens the manuscript’s novelty by positioning livelihood revitalization as the bridge between ecological restoration and social legitimacy. If livelihoods fail, rewetting infrastructure may be neglected, canals may be reopened, and fire risk may return. If livelihoods succeed, communities become co-producers of restoration outcomes. Thus, revitalization should include participatory commodity selection, market feasibility analysis, gender-inclusive training, access to finance, farmer-to-farmer learning, social forestry arrangements, and long-term buyer relationships. Peat-adaptive commodities such as sago, purun handicrafts, fishery, honeybee systems, and selected paludiculture products should be assessed not only by ecological suitability but also by profitability, labour demands, cultural fit, and market continuity.

Table 2. Restoration measures, expected outcomes, and implementation risks

Measure	Main actions	Expected outcomes	Key risks
Rewetting	Canal blocking, canal backfilling, water-table monitoring, fire-prevention coordination	Water-table stability; reduced peat oxidation; lower subsidence; reduced fire probability	Insufficient maintenance; hydrological leakage; community resistance; extreme drought
Revegetation	Native peat species, assisted natural regeneration,	Vegetation survival; biomass recovery; habitat recovery;	Wrong species selection; poor survival; recurrent

	enrichment planting, paludiculture species	canopy development; fire-buffering vegetation	fire; disconnected planting sites
Revitalization	Wet-livelihood pilots, value-chain development, social forestry, community enterprise	Adoption rate; income stability; reduced drainage dependence; inclusive participation	Weak markets; short project cycle; limited trust; gender exclusion; capital barriers
Adaptive monitoring	TMA sensors, field surveys, remote sensing, community-based reporting	Evidence-based adjustment; transparent MRV; accountability	Fragmented data; underfunded maintenance; weak institutional coordination

4.5. Policy integration and institutional continuity

The establishment of BRG in 2016 was a turning point because it created a dedicated institution for restoring degraded peatlands after the 2015 fire crisis. However, the long-term sustainability of restoration depends on institutional continuity beyond a single agency mandate or project cycle. Peat hydrological units cut across administrative boundaries, concession areas, village territories, and sectoral responsibilities. This requires coordination among national ministries, provincial and district governments, concession holders, communities, researchers, and civil-society organizations.

The policy challenge is therefore not only to issue regulations, but to ensure that restoration targets are embedded in spatial planning, licensing, disaster management, agricultural extension, social forestry, village development, carbon governance, and monitoring systems. Recent policy and socio-ecological reviews emphasize that tropical peatland restoration is complex because it requires simultaneously managing carbon, livelihoods, biodiversity, governance, and local knowledge [8,15]. For IJoPRI, this point is central: peatland innovation should include institutional and governance innovation, not only technological innovation.

Table 3. Integrated framework for peat restoration as sustainable development

Dimension	Main components	Contribution to restoration success
Policy mandate	Peat ecosystem protection, restoration targets, SDG alignment	Clear legal basis for restoration and cross-sector coordination
Technical implementation	Rewetting, revegetation, livelihood revitalization	Operational transformation of degraded peat hydrological units
Community legitimacy	Participation, local knowledge, gender inclusion, social forestry	Higher adoption, maintenance, and conflict prevention
Economic viability	Market access, peat-adaptive commodities, value-chain development	Reduced dependence on drainage-based production systems
Monitoring and learning	Water table, subsidence, GHG flux, fire, biodiversity, livelihood indicators	Adaptive management and credible reporting for SDGs and climate commitments

4.6. Implications for Riau and other peat-dominated provinces

Riau is a strategic province for applying the integrated restoration framework because it contains extensive peat hydrological units, recurrent fire-risk landscapes, plantation pressures, sago-based livelihoods, and growing institutional capacity through universities, CPDS, local government agencies, and community initiatives. The strongest policy implication is that Riau's restoration agenda should move from output reporting toward outcome-based restoration governance. This means that canal blocks, revegetation sites, and livelihood programs should be connected to measurable indicators of water-level recovery, reduced fire hotspots, reduced subsidence, peat-adapted commodity adoption, biodiversity recovery, and community income resilience.

For other peat-dominated provinces, the lesson is similar. Restoration should be designed according to peat hydrological units rather than administrative convenience alone. Protection zones should prioritize rewetting and conservation, while cultivation zones should adopt water-compatible production systems. Data platforms should integrate field measurements, remote sensing, community observations, and policy reporting. Most importantly, restoration should be treated as a long-term social contract between government, communities, concession holders, and scientific institutions.

5. Conclusions

Peat restoration in Indonesia is a long-term pathway for achieving sustainable development, not merely a technical response to degraded land. The revised analysis shows that restoration contributes most directly to SDGs 1, 2, 3, 4, 5, 8, 10, 13, and 15 through the integration of rewetting, revegetation, and livelihood revitalization. Rewetting is fundamental for reducing peat oxidation, subsidence, and fire risk; revegetation is essential for recovering ecological function and biodiversity habitat; and livelihood revitalization is the social foundation that determines whether restoration is maintained, accepted, and scaled.

The manuscript's central novelty is the reframing of Indonesia's 3R restoration framework as a governance-to-ecosystem-services pathway. This pathway links policy mandates, institutional coordination, hydrological recovery, vegetation rehabilitation, livelihood transition, monitoring, and SDG outcomes. Recent literature supports the climate and disaster-risk value of rewetting, but also demonstrates that restoration success is time-dependent, site-specific, economically challenging, and socially negotiated.

For peat restoration to produce durable SDG outcomes, Indonesia should strengthen outcome-based monitoring, long-term maintenance financing, cross-sector coordination, community co-design, peat-adaptive value chains, and transparent reporting. In this sense, peat restoration is a practical test of sustainable development: it succeeds only when ecological recovery, climate mitigation, disaster prevention, and community welfare are achieved together.

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