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Environmental Damage and Environmental Ethics in Oil Palm Plantation Expansion: Ecological Degradation, Justice, and Circular Transition Pathways in Indonesia and the Global Palm Oil Economy

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ABSTRACT

Oil palm is frequently defended on the grounds of exceptional land productivity, foreign-exchange earnings, and its growing role in food, oleochemical, and biofuel markets. Yet the same production system has become one of the most contested agro-industrial frontiers of the twenty-first century because plantation expansion, mill waste generation, peat conversion, and socio-spatial asymmetries can transfer large environmental costs to forests, soils, waterways, workers, and rural communities. Building on the attached review of oil palm biomass and integrating the recent literature extracted in file containing plain-text abstracts of newer publications, this article develops a critical review that centers environmental damage and environmental ethics rather than viewing palm oil only through the lens of technical efficiency or biomass valorization. The review argues that oil palm sustainability cannot be judged solely by yield per hectare, certification uptake, or downstream circular-economy initiatives. A more adequate assessment must combine ecological evidence on deforestation, biodiversity simplification, hydrological disruption, climate forcing, air pollution, and palm oil mill effluent with ethical questions of land rights, recognition, procedural justice, labor conditions, intergenerational responsibility, and the risk of burden shifting. The recent literature shows real progress in waste conversion, biochar, effluent treatment, industrial symbiosis, and low-carbon material substitution, but it also shows that technical mitigation is ethically incomplete when expansion reproduces unequal control over land, inadequate compensation, weak worker protection, or insufficient Free, Prior and Informed Consent. The article proposes an integrated framework in which no-deforestation production, peat protection, rights-based governance, transparent value distribution, and carefully bounded circular bioeconomy strategies are treated as mutually reinforcing rather than optional. Such a synthesis is necessary if oil palm landscapes are to move from extractive efficiency toward ecologically restorative and ethically legitimate sustainability.

Keywords: oil palm plantations; environmental damage; environmental ethics; deforestation; biodiversity loss; palm oil waste; climate justice

INTRODUCTION

Oil palm occupies a paradoxical position in contemporary sustainability debates. On the one hand, it is one of the most productive oil crops, supplies a large share of the world's vegetable oil, and plays a strategic economic role in Indonesia and other producing countries (Harahap et al., 2020; Hambali & Rivai, 2017; Mukherjee & Sovacool, 2014). It is also tightly bound to state ambitions in energy security and biodiesel blending, especially in Indonesia, where biodiesel policy has been framed as a development instrument as well as a climate policy tool (Halimatussadiah et al., 2021; Wirawan et al., 2024). On the other hand, the oil palm economy has become emblematic of the limits of productivist reasoning. Yield superiority does not eliminate the moral weight of deforestation, carbon loss, biodiversity decline, hydrological disturbance, toxic effluents, open burning, or unequal relations between firms, workers, smallholders, and indigenous communities (Wicke et al., 2011; Lam et al., 2019; Meijide et al., 2018; Kubitza et al., 2018; Simatupang et al., 2026).

The environmental critique of palm oil has often been narrated in sectoral fragments. Land-use studies focus on forest conversion and carbon stocks; life-cycle studies focus on greenhouse gas balances; engineering studies emphasize biomass utilization, pyrolysis, gasification, pellets, or effluent treatment; and policy studies examine certification, biofuel mandates, or renewable-energy targets (Schmidt, 2010; Wahyono et al., 2020; Nabila et al., 2023; Kurniawan et al., 2025; Goh et al., 2025). This fragmentation produces an important blind spot. It allows technical improvements to be interpreted as evidence of sustainability even when the underlying system remains ethically compromised. A mill that converts empty fruit bunches into pellets or biochar may reduce waste burdens, yet those gains do not by themselves resolve questions of whose land was transformed, who bears occupational risk, whose river absorbs residual discharge, or whose futures are constrained by ecological simplification. Environmental damage in palm oil landscapes is therefore not only biophysical; it is relational, distributive, and procedural.

This review proceeds from the premise that environmental ethics is not an optional philosophical appendix to environmental assessment. It is the framework that allows scholars to determine whether apparently efficient production systems are morally defensible. In oil palm landscapes, an ethical perspective is needed for at least five reasons. First, the transition from forest or complex agroforestry systems to monoculture plantations changes not only carbon balances but also the moral status of non-human life, habitat integrity, and ecosystem resilience (Meijide et al., 2018; Guillaume et al., 2018; Dicky et al., 2025). Second, plantation development can reshape access to land, water, labor, and compensation, raising questions of justice and recognition that cannot be captured by energy balances or gross value added alone (Kubitza et al., 2018; Rosaprana et al., 2025; Simatupang et al., 2026). Third, the temporal horizon of plantation profitability is often shorter than the temporal persistence of peat oxidation, biodiversity loss, and degraded soils, which makes intergenerational ethics central (Afriyanti et al., 2016; Bossio et al., 2020). Fourth, the recent enthusiasm for circular bioeconomy solutions risks normalizing expansion by promising that waste valorization can neutralize the sector's deeper externalities (Kahar et al., 2025; Goh et al., 2025; Rendón-Camargo et al., 2026). Fifth, climate mitigation claims become ethically fragile when emissions reductions depend on counterfactuals that ignore land conflict, methane leakage, or burden shifting across space and time (Schmidt & De Rosa, 2020; Sato et al., 2025; Purnama et al., 2025).

The present article builds upon the attached review article on oil palm biomass in Indonesia and extends it with the recent literature extracted in file containing plain-text abstracts of newer publications. The earlier review is indispensable because it maps the scale of residues, thermochemical pathways, market routes for torrefied biomass and biochar, and the life-cycle implications of biomass valorization (Nabila et al., 2023). However, its main emphasis is on technological upgrading and utilization. The current article shifts the center of gravity toward the damages generated by oil palm plantations and mills, and then asks what kinds of ethical reasoning are required to judge both the harms and the proposed solutions. Recent literature from 2024–2026 is especially useful here because it expands the discussion toward indigenous rights and FPIC, local well-being, worker stress and burnout, carbon stock comparisons, agroclimatic suitability under climate change, industrial symbiosis, decarbonization strategies, rural-scale biochar deployment, and new material uses for ash and biomass residues (Majesty et al., 2024; Rosaprana et al., 2025; Dicky et al., 2025; Jamidi et al., 2025; Purnama et al., 2025; Simatupang et al., 2026).

The objective of this review is therefore fourfold. First, it synthesizes the major pathways through which oil palm plantation systems generate environmental damage, including land-use change, carbon loss, biodiversity simplification, water and air pollution, peat-related emissions, and waste externalities. Second, it develops an environmental ethics framework suited to the palm oil question by integrating ecological integrity, procedural justice, recognition, labor ethics, and intergenerational responsibility. Third, it evaluates whether emerging circular and decarbonization strategies genuinely reduce harm or merely rearrange it. Fourth, it identifies research and policy priorities for a transition from extractive palm oil landscapes toward ecologically restorative and ethically legitimate systems. The central claim advanced throughout the review is that sustainable palm oil must be judged not by technical efficiency alone, but by whether it simultaneously reduces ecological harm, prevents injustice, and avoids converting circularity into a license for continued expansion.

LITERATURE REVIEW

Review basis and analytical lens

This article is a critical integrative review rather than a narrow engineering review or a formal meta-analysis. Its evidence base combines the attached review article on oil palm biomass and the recent extraction file containing plain-text abstracts of newer publications. The original review supplies the foundational literature on biomass generation, waste streams, biochar, torrefaction, pyrolysis, gasification, market deployment, and life-cycle assessment in Indonesia (Nabila et al., 2023). The newer extraction extends the discussion into 2024–2026 with studies on resilient and equitable value chains, circular bioeconomy, waste management by independent smallholders, labor well-being, carbon storage under alternative land uses, agroclimatic suitability, low-cost biochar systems, industrial symbiosis, ash reuse, and POME remediation (Majesty et al., 2024; Rosaprana et al., 2025; Dicky et al., 2025; Goh et al., 2025; Simatupang et al., 2026). Because the user explicitly requested that no additional web references be introduced, the review deliberately remains bounded by the uploaded materials.

The analytical lens used here distinguishes between three levels of sustainability argument. The first level is efficiency, where plantation systems are evaluated in terms of yields, energy balances, calorific value, waste conversion, or cost effectiveness. The second level is impact, where attention shifts to greenhouse gas emissions, land-use change, effluent loads, air pollutants, soil degradation, and ecological function. The third level is ethics, where the question becomes whether the distribution of costs and benefits, the recognition of affected groups, the treatment of labor, and the long-term fate of ecosystems are morally acceptable. In oil palm scholarship, the first level is highly developed, the second is unevenly developed, and the third is often implied but not directly theorized. Yet it is precisely the third level that determines whether technical mitigation counts as just sustainability or only as more efficient extraction.

In practical terms, environmental ethics in this review is organized around five principles. Ecological integrity asks whether land conversion and residue management preserve climate regulation, habitat quality, water function, and soil health. Distributional justice asks who receives profits and who absorbs pollution, risk, or ecological loss. Procedural justice asks whose consent matters and whether decision processes are transparent, participatory, and fair. Recognition asks whether indigenous communities, smallholders, workers, and non-human life are treated as morally visible rather than as peripheral obstacles. Intergenerational responsibility asks whether present gains are secured by imposing long-lived carbon, peat, biodiversity, or hydrological costs on future generations. These principles are used not as abstract moral slogans but as evaluative tools for the environmental evidence reviewed below.

Table 1. Major pathways of environmental damage associated with oil palm plantations and mills

Damage domain	Primary mechanism	Representative environmental consequence	Core ethical concern	Ref.
Forest conversion and land-use change	Expansion into forest, peat, or more diverse agroecosystems	Carbon stock loss, habitat simplification, long-lived climate burdens	Ecological integrity and intergenerational justice are compromised when high-carbon landscapes are converted for near-term returns	Wicke et al., 2011; Lam et al., 2019; Afriyanti et al., 2016; Kubitza et al., 2018
Biodiversity and microclimate simplification	Replacement of structurally complex vegetation with monoculture stands	Lower habitat heterogeneity, altered temperature and moisture regimes, reduced resilience under extremes	Non-human life and landscape resilience are treated as expendable externalities	Meijide et al., 2018; Guillaume et al., 2018; Dicky et al., 2025
Soil and peat degradation	Drainage, compaction, nutrient disruption, residue mismanagement	Peat emissions, acidity problems, declining soil function and long-horizon restoration burdens	Future generations inherit slower, costlier repair than the speed of present extraction	Susilawati et al., 2016; Bossio et al., 2020; Bakar et al., 2018
Water pollution and POME	High-organic-effluent discharge and insufficient treatment	COD/BOD/turbidity burdens, methane release, downstream water-quality damage	Downstream communities bear preventable harm if treatment is treated as optional	Iskandar et al., 2018; Saputera et al., 2021; Bandara et al., 2025; Rahman et al., 2025
Air pollution and combustion externalities	Open burning, poorly controlled combustion, ash and chlorine-rich fuel	Particulate emissions, local air burdens, slagging/fouling, corrosion and ash disposal	Climate gains cannot justify avoidable local pollution and occupational exposure	Nacua & Lacang, 2024; Pawlak-Kruczek et al.,

	streams	issues		2020; Ren et al., 2017
Value-chain climate burden	Boundary-dependent LCA outcomes and wastewater methane leakage	Mitigation claims vary with system assumptions and upstream controls	Selective carbon accounting can hide morally relevant harms	Wahyono et al., 2020; Chew et al., 2023; Sato et al., 2025; Anyaoha & Zhang, 2022

Pathways of environmental damage in oil palm plantation systems

Deforestation, land-use change, and carbon stock loss

The most widely recognized environmental critique of oil palm is that plantation expansion often entails a large ecological simplification of land previously covered by rainforest, secondary forest, peat forest, or more structurally diverse agroecosystems. Even where palm oil is defended on the basis of its superior oil yield per hectare, expansion into carbon-rich or biodiverse landscapes can erase much of that advantage in climate and ecological terms (Wicke et al., 2011; Schmidt, 2010; Mukherjee & Sovacool, 2014). Spatial analyses show that the greenhouse-gas footprints of Indonesian palm oil vary substantially across regions and land-use histories, underscoring that "palm oil" is not a single environmental object but a land-use outcome whose impacts depend on what was there before conversion and how the plantation is subsequently managed (Lam et al., 2019; Wahyono et al., 2020). From an ethical standpoint, this matters because a high-yield crop is not morally exculpatory when its expansion pathway destroys irreplaceable ecological stocks.

The conversion question is particularly serious because plantation expansion reorganizes carbon across multiple pools at once. Aboveground biomass falls sharply when complex forest canopies are replaced by monoculture stands; belowground carbon is destabilized; and, in peat areas, oxidation can continue for years after drainage and conversion (Afriyanti et al., 2016; Smith et al., 2014). Studies on Indonesian rainforest conversion show that plantation transitions alter the balance of ecological costs and benefits in ways not captured by yield statistics alone, while comparative land-use analysis from South Sulawesi demonstrates that oil palm stores substantially less carbon and supports less atmospheric CO_2 uptake than secondary natural forest or cocoa agroforestry (Guillaume et al., 2018; Dicky et al., 2025). The ethical implication is straightforward: where plantation development lowers carbon storage and eliminates more complex habitat, the burden is transferred from private balance sheets to the global climate system and to future communities who inherit a less resilient landscape.

Land-use change is also not only an ecological matter but a property-rights matter. Kubitza et al. (2018) show that land property rights, intensification, and deforestation in Indonesia are deeply entangled. This is important ethically because many policy discussions treat deforestation as a technical problem of mapping and monitoring when it is also a problem of power over land allocation, land titles, and the ability to define what counts as "available" land. Simatupang et al. (2026) extend this concern in South Papua by documenting sustainability challenges linked to inequality and indigenous community rights, while arguing that a resilient value chain requires mandatory FPIC, fairer institutional relations, and inclusive governance forums. Where land rights remain uncertain or procedural recognition is weak, plantation expansion can become an ethically defective form of enclosure even before the first tree is felled.

The deforestation question therefore cannot be isolated from the moral economy of certification and zero-deforestation commitments. Certified palm oil can reduce greenhouse gas emissions compared with non-certified production, and strategic scenarios show that Indonesian production could be maintained without further deforestation or peat conversion if the sector reorients around different land-use choices and productivity assumptions (Schmidt & De Rosa, 2020; Afriyanti et al., 2016). But certification is not an ethical endpoint. It is at best a mechanism for partial constraint. If certification improves emissions intensity while leaving weak consent processes, unequal compensation, or biodiversity fragmentation intact, then certification may be environmentally useful yet ethically incomplete. That duality recurs across much of the oil palm literature.

Biodiversity simplification, microclimatic alteration, and ecological resilience

Biodiversity loss in oil palm landscapes is often described in coarse terms, but the real problem is not simply lower species richness. The deeper issue is ecological simplification: fewer structural niches, fewer trophic interactions, lower habitat heterogeneity, altered edge conditions, and a narrower set of species able to persist under plantation management. Meijide et al. (2018) show that forest conversion to oil palm and rubber plantations changes microclimate in ways that matter for ecosystem functioning, including under extreme climate anomalies such as ENSO years. That finding is significant because it indicates that plantation conversion does not merely substitute one vegetative cover for another; it reorganizes temperature, moisture, and exposure regimes in ways that can intensify stress on remaining biota and reduce landscape resilience.

The carbon-stock comparison reported by Dicky et al. (2025) reinforces this ecological interpretation. Secondary natural forest stores more carbon and releases more oxygen than oil palm plantation, while agroforestry occupies an intermediate position. These differences are not only metrics of climate mitigation; they are proxies for vegetation complexity, understory diversity, and system multifunctionality. In ethical terms, a transition from forest or agroforestry to monoculture should therefore be understood as a contraction of ecological possibilities. A purely anthropocentric calculus may judge that contraction acceptable if commodity output rises. A stronger environmental ethic, however, insists that the integrity of non-human habitats has value that cannot be reduced to short-term export revenues.

This ethical tension is amplified by the temporal rigidity of plantation systems. Agroclimatic suitability analysis for North Aceh indicates a shift from highly suitable to moderately suitable classes under projected climate scenarios, implying possible future productivity decline and adaptation stress (Jamidi et al., 2025). The significance of this result extends beyond agronomy. It means that expansion today may lock communities into landscape forms that are ecologically less adaptive tomorrow. Converting a diverse landscape into a simplified monoculture under conditions of climate uncertainty raises a strong intergenerational challenge: future farmers and rural communities may inherit a system that is both less ecologically resilient and more expensive to maintain.

Recent value-chain research also shows that sustainability debates cannot stop at biodiversity accounting alone. Simatupang et al. (2026) argue that ecological integrity in South Papua remains an urgent necessity even where economic potential is high, while Rosaprana et al. (2025) note that public debates have often foregrounded deforestation and biodiversity loss over local benefits. The ethical task is not to deny the reality of socioeconomic gains, but to reject the false trade-off in which biodiversity loss is treated as a regrettable but negotiable cost of modernization. Where palm oil development reduces ecological complexity, moral legitimacy depends on whether those losses are minimized, transparently governed, and socially consented to—conditions that are far from automatic.

Soil degradation, peat disturbance, and hydrological externalities

Soil is often the forgotten medium in palm oil sustainability discourse. Yet plantations can alter soil organic carbon, bulk density, moisture dynamics, nutrient cycling, and erosion patterns through vegetation change, drainage, compaction, and residue handling. The attached review shows that oil palm biomass streams are massive, frequently underutilized, and capable of creating leachate, methane, odor, and open-burning problems when mismanaged (Nabila et al., 2023). That matters for soils because residue disposal practices influence nutrient return, mulch effects, erosion control, and local hydrology. Where residues are abandoned, burned, or poorly composted, soils can shift from being slow regenerative media to being mere physical supports for input-intensive production.

The peat question is especially consequential. Studies on peat amendment and greenhouse gas emissions indicate that water depth, amelioration, and soil condition are central to emissions behavior, while reviews of biochar in Indonesian peat and acid soils show both the promise and the limits of post hoc remediation (Susilawati et al., 2016; Berek, 2019). Ethically, peat conversion is a vivid example of temporal injustice. It produces present-day income streams by mobilizing carbon and hydrological functions accumulated over centuries or millennia. Even where peat management is improved after conversion, the moral problem of transforming a long-lived ecological asset into a short-lived commodity frontier remains. In this sense, peat conversion is not just environmentally risky; it is ethically asymmetric because irreversible or slowly reversible ecological losses are exchanged for comparatively immediate returns.

At the same time, the literature on biochar and soil amendment shows that degraded soils can be partially restored through organic-carbon strategies. Oil palm empty fruit bunch biochar can improve acid sulfate soils and rice performance, while longer-term field evidence from Indonesian Ultisols suggests that biochar can initially improve acidity and crop response even though some benefits fade over time (Bakar et al., 2018; Cornelissen et al., 2018). Reviews further indicate that biochar can improve soil quality, nutrient availability, water retention, and in some cases reduce greenhouse gas emissions, particularly when integrated with compost or organic fertilizers (Kong et al., 2014; Lee et al., 2017; Robb et al., 2020; Maulana et al., 2025). But this restorative potential should not be romanticized. Ethical evaluation requires a distinction between repair and justification. Soil amendment may repair part of the damage caused by plantation systems or related waste streams, but it cannot retroactively justify unjust conversion or normalize recurrent degradation.

This distinction is crucial because circular-economy narratives often treat residues as evidence that the system can close its own loops. In reality, loops are never fully closed. Some nutrients are lost, some emissions escape, and some residues compete with existing uses such as mulching, combustion, or local amendment. Sato et al. (2025) show that greenhouse gas reductions from empty fruit bunch pellets depend strongly on methane control in wastewater treatment and the conditions of final energy use. Purnama et al. (2025) similarly show promising carbon-offset potential for rural biochar systems, but as a techno-economic and policy-oriented model rather than a universal outcome. The ethical lesson is that soil and carbon repair strategies are valuable, but only when accompanied by honest accounting of leakage, trade-offs, and the opportunity costs of diverting residues away from agronomic functions.

Waste, air pollution, and combustion-related burdens

One of the strongest empirical contributions of the attached review is its clear demonstration that the oil palm industry generates enormous quantities of solid residues—empty fruit bunches, palm kernel shells, mesocarp fiber, fronds, and trunks—and that poor handling of these streams can create substantial environmental burdens (Nabila et al., 2023). When residues are openly burned, piled, dumped, or incompletely managed, the result may include particulate emissions, methane formation, odor, landfilling pressure, and leachate. The broader regional literature on agricultural waste valorization confirms that open burning and weak logistics remain persistent barriers across Southeast Asia, even where waste streams have obvious energy or material value (Nacua & Lacang, 2024; Erdiwansyah, 2024).

Combustion and co-firing do not eliminate environmental concerns either. Transitioning from coal to biomass can reduce fossil emissions, yet emissions characteristics depend on fuel preparation, chlorine content, ash chemistry, slagging risk, and operating conditions (Pawlak-Kruczek et al., 2020; Ren et al., 2017; Sonjaya et al., 2025). Biochar or torrefied biomass may improve calorific value and reduce certain pollutants relative to raw residues, but these gains coexist with ash management challenges and uneven efficiencies across facilities (Yek et al., 2021; Kurniawan et al., 2025). The environmental ethics issue here is one of burden shifting. A climate-positive substitution at the boiler or grid level is not ethically sufficient if it intensifies local ash burdens, incentivizes additional residue extraction from soils, or depends on poorly controlled upstream methane releases.

Recent materials literature widens the field of possible waste management options. Palm oil boiler ash can substitute part of ordinary Portland cement, while calcium carbonate waste from clay-bath separation can be regenerated and reused effectively in mills (Jonbi et al., 2025; Syarifuddin et al., 2024). Such approaches are environmentally promising because they reduce waste disposal and displace more carbon-intensive materials. Yet they also reveal how much the ethical quality of the sector depends on what happens after the fruit leaves the field. A plantation system that appears efficient at the estate level may still externalize serious harms through milling residues, boiler ash, effluents, and occupational exposure. Therefore, downstream material recovery is not peripheral to plantation ethics; it is central to whether the sector can credibly claim stewardship rather than extraction.

Water pollution, POME, and the ethics of effluent discharge

Palm oil mill effluent is one of the clearest examples of how environmental damage in the palm oil sector becomes visible at the water interface. POME is highly loaded with organic matter and, when inadequately treated, can generate severe biochemical oxygen demand, chemical oxygen demand, turbidity, methane release, and downstream ecological stress (Iskandar et al., 2018; Saputera et al., 2021; Bandara et al., 2025). The ethical significance of POME is unusually direct. Unlike carbon loss, which may be globally dispersed and temporally diffuse, effluent discharge affects rivers, drainage systems, and local aquatic conditions encountered by nearby communities in real time. In such cases the ethics of harm is not abstract: it concerns who lives downstream, whose water quality deteriorates, and whether pollution is treated as a cost of doing business.

The recent literature shows meaningful progress in POME treatment and reuse. Electrocoagulation can markedly reduce COD and turbidity under optimized conditions, while microalgal cultivation in POME can simultaneously reduce waste loads and produce value-added biomass such as phycocyanin (Bandara et al., 2025; Rahman et al., 2025). Other studies propose integrated biogas systems, bioethanol–biogas linkages, or combined wet torrefaction and gasification using POME as part of a valorization stream (Hermawan et al., 2025; Aziz et al., 2025). These advances support the practical argument that untreated or poorly treated POME is not an unavoidable feature of the sector. It is a governance failure, an investment failure, or an enforcement failure.

Still, it would be ethically naïve to interpret treatment potential as proof of resolved pollution. The mere availability of remediation technology does not ensure adoption, maintenance, or access. Smallholders and independent producers may lack capital, mills may underinvest where regulation is weak, and some valorization routes may privilege export-oriented carbon claims over local water justice. Environmental ethics therefore demands that POME management be evaluated against a threshold of non-harm, not only against profitability. If downstream communities remain exposed to degraded water quality because treatment is seen as optional or contingent on favorable market conditions, then the sector fails a basic justice test even if some flagship facilities achieve impressive circularity metrics.

Climate impacts across the plantation–mill–energy continuum

Climate assessment in the palm oil sector requires more than counting combustion emissions. It requires tracing impacts across land conversion, fertilizer use, residue decomposition, methane from wastewater, transport, processing, and final energy substitution (Lam et al., 2019; Schmidt, 2010; Wahyono et al., 2020). Life-cycle studies show that outcomes differ significantly depending on baseline scenarios and system boundaries. For example, certified palm oil can perform better than non-certified systems in greenhouse-gas terms, while EFB pellet export can reduce emissions relative to certain reference scenarios but may still underperform LNG unless methane abatement and energy-efficiency thresholds are met (Schmidt & De Rosa, 2020; Sato et al., 2025). These findings underscore that climate claims in palm oil are conditional rather than automatic.

This conditionality has ethical consequences. Climate-positive narratives can become misleading when they foreground downstream substitution benefits while backgrounding the carbon costs of land conversion or the methane losses associated with milling and wastewater handling. Comparative LCA studies on biodiesel and biomass conversion remind us that technology choice matters, but so do the assumptions embedded in allocation, avoided-burden logic, and counterfactual baselines (Wahyono et al., 2020; Chew et al., 2023; Anyaoha & Zhang, 2022; Matuštík et al., 2020; Zhu et al., 2022). An ethically serious climate assessment must therefore ask whether mitigation claims remain robust when indirect land-use effects, residue competition, and local ecological damage are included. Otherwise, carbon accounting may become a language of selective visibility.

The climate challenge also reframes the role of circularity. Biogas, biochar, torrefied biomass, and industrial symbiosis can all contribute to lower-carbon futures when they reduce methane releases, displace fossil inputs, or enhance soil carbon (Harsono et al., 2015; Purnama et al., 2025; Rendón-Camargo et al., 2026). Yet circularity becomes ethically weak when it is mobilized as a reputational shield for continued expansion into ecologically sensitive areas. In other words, circularity is morally strongest as a constraint on waste and pollution within already existing production systems, and morally weakest when used to legitimate new frontiers of extraction. That distinction runs through the discussion that follows.

Table 2. Environmental ethics questions raised by contemporary oil palm development

Ethical question	How it appears in oil palm landscapes	Who is affected	Why technical sustainability is insufficient	Ref.
Recognition and consent	FPIC is incomplete or weakly institutionalized in some frontier regions	Indigenous communities, customary land users, local governments	Residue innovation or certification cannot compensate for decisions made without legitimate consent	Simatupang et al., 2026; Kubitza et al., 2018
Distributional justice	Mills and capital-intensive nodes capture higher value than farmers and local communities	Smallholders, rural households, local governments	Climate or circular gains remain ethically thin if new value streams deepen asymmetry	Simatupang et al., 2026; Rosaprana et al., 2025
Smallholder capability	Waste management and sustainability participation remain uneven	Independent smallholders and village-scale actors	Uniform compliance models can exclude actors with weaker capital and technical access	Majesty et al., 2024; Apriyanto, 2020
Labor ethics	Stress, burnout, weak protection, insecure contracts, accident responsibility gaps	Plantation workers and their households	A commodity system is not sustainable if environmental transition depends on precarious labor	Lesmana et al., 2025
Compliance versus legitimacy	RSPO/ISPO can improve measurable performance but may not resolve rights or recognition deficits	Producers, certifiers, communities, importing markets	Audit-based compliance is a floor, not an endpoint of moral legitimacy	RSPO, 2021; Schmidt & De Rosa, 2020; Simatupang et al., 2026
Intergenerational justice	Present gains rely on long-lived carbon, peat, and resilience losses	Future farmers, rural communities, climate-vulnerable populations	Discounted future harms are still morally real and politically consequential	Afriyanti et al., 2016; Bossio et al., 2020; Jamidi et al., 2025

Environmental ethics, justice, and the social legitimacy of palm oil landscapes

From ecological externalities to moral accountability

Environmental ethics enters the palm oil debate at the moment we stop asking only whether the sector is efficient and start asking whether it is legitimate. Ecological externalities such as carbon loss, effluent discharge, and biodiversity simplification are not morally neutral. They redistribute capabilities and vulnerabilities: rivers become less usable, forests less habitable, soils less fertile, and future adaptation options narrower. A plantation may remain profitable while the broader landscape becomes less resilient. The ethical question is therefore not simply how much environmental damage occurs, but who is entitled to authorize that damage, who benefits, and who carries the residual risk.

This is why a narrow utilitarian defense of oil palm—high yield, high export value, lower labor requirements—cannot settle the issue. Utilitarian reasoning aggregates gains and losses, but it often obscures unequal power and irreversibility. The destruction of a peatland or the exclusion of an indigenous community cannot be adequately compensated by a favorable national biodiesel balance or by lower unit costs of vegetable oil. Scholars examining palm oil-based biofuels and sustainability have long emphasized that social welfare effects, profitability, and climate outcomes interact in complex ways rather than lining up neatly (Saikkonen et al., 2014; Mukherjee & Sovacool, 2014). An ethical review must therefore resist any framework in which export revenues or carbon intensity are allowed to dominate all other values.

Recognition, indigenous rights, and FPIC

Recent literature makes especially clear that environmental ethics in palm oil-producing regions must be grounded in recognition. Simatupang et al. (2026) show that in South Papua, sustainability is inseparable from indigenous community rights and from the still-insufficient implementation of FPIC. Their proposed strategy includes mandatory FPIC, more inclusive forums for governance and conflict resolution, and greater parity among stakeholders. This is a fundamentally ethical intervention because it shifts sustainability from a technical compliance model to a rights-based model. A landscape cannot be called sustainable if the people with historical, cultural, or territorial attachment to it are treated merely as one stakeholder among many after the central land decision has already been made.

The importance of recognition is also visible in studies of smallholders and local waste management. Majesty et al. (2024) report that less than 16% of independent smallholders in the study area actively manage palm oil waste using local-wisdom approaches that also create livelihoods. Their argument is not only that local knowledge should be preserved, but that it can widen the meaning of sustainable development beyond standardized industrial disposal routes. From an ethical standpoint, this suggests that sustainability schemes that ignore locally grounded practices may reproduce a hierarchy in which valid knowledge is only what comes from certification manuals, engineering standards, or corporate sustainability reports.

Recognition also affects how environmental harms are perceived and debated. Rosaprana et al. (2025) observe that public debate has emphasized deforestation and biodiversity loss more than socioeconomic benefits, while their case study finds generally positive community perceptions on income, jobs, transport access, and infrastructure, alongside dissatisfaction with land compensation. This mixed picture is ethically important. It shows that communities are not passive victims of an abstract global commodity chain, nor are they uniform supporters of plantation expansion. They experience gains and harms simultaneously. Recognition requires taking both seriously: neither romanticizing resistance nor instrumentalizing local welfare gains to excuse inadequate consent or compensation.

Distributional justice and asymmetry in the value chain

The newer value-chain literature highlights a structural asymmetry that should become central to environmental ethics in palm oil studies. Simatupang et al. (2026) report that palm oil mills captured 56.2% of total value added in their case, while farmers received 21.7%. Even if absolute figures vary across regions, the pattern is instructive: environmental risks and land transformation are often territorialized in rural spaces, whereas value capture is concentrated in more capital-intensive nodes. Distributional justice asks whether such asymmetries are acceptable when coupled with land conversion, ecosystem degradation, or volatile farm-level incomes.

This question becomes sharper once waste and circularity are considered. Residues such as EFB, shells, fronds, and mill ash can become feedstocks for energy, adsorbents, cement substitution, fertilizer, graphene-like materials, or industrial symbiosis (Nabila et al., 2023; Jonbi et al., 2025; Soleh et al., 2025; Rendón-Camargo et al., 2026). But who captures the value from these secondary streams? If circular-economy rents accrue mostly to mills, industrial processors, or export markets while local communities remain exposed to effluent, odor, ash, or transport burdens, then circularity may reduce some emissions yet reproduce distributive injustice. Ethical sustainability requires that value generated by environmental mitigation not be monopolized by the same actors who control the primary commodity chain.

Recent techno-economic studies are therefore ethically useful only when interpreted alongside governance questions. Purnama et al. (2025) show that rural-scale biochar production from oil palm fronds and waste cooking oil can achieve attractive internal rates of return and measurable carbon sequestration potential. This is an important finding because it implies that mitigation can be organized in more decentralized and locally embedded ways. Yet even successful rural biochar systems will require enabling policy, secure access to feedstock, and fair carbon-accounting arrangements. Without those, community-scale circularity may remain demonstrative rather than transformative.

Labor ethics and the human cost of sustainability narratives

Environmental ethics in palm oil cannot remain confined to land and non-human nature. Labor conditions matter because environmental improvement strategies are implemented by workers whose safety, security, and mental well-being shape the real social cost of production. The recent plantation labor literature is striking in this regard. Lesmana et al. (2025) report that job stress and burnout are significant problems among oil palm plantation employees, with dissatisfaction over employment status, inadequate participation in social security and health schemes, and avoidance of responsibility for work accidents by some companies. Even when the study is not framed as environmental ethics, its implications are obvious. A sector cannot plausibly present itself as sustainable if environmental management coexists with precarious labor relations and moral indifference to worker well-being.

Labor ethics also alters how we interpret efficiency. A production system that minimizes labor requirements may appear economically attractive, but reduced labor intensity is not an unconditional social good if it is coupled with insecure contracts, weak protections, or heightened stress among the remaining workforce. This is especially relevant in plantation frontiers where workers may also face heat stress, chemical exposure, and psychosocial pressure tied to productivity targets. An ethical review of palm oil must therefore reject the idea that occupational well-being is external to environmental sustainability. The human body is one of the first environments in which ecological and industrial intensities meet.

Certification, policy, and the limits of compliance ethics

Certification regimes and public standards have become major instruments for disciplining palm oil production. RSPO defines sustainability criteria in global markets, while ISPO represents Indonesia’s state-centered effort to structure sustainable palm oil governance (RSPO, 2021; Apriyanto, 2020). These mechanisms matter. Evidence suggests that certified palm oil can reduce emissions relative to non-certified production, and recent value-chain research shows that expanding RSPO and ISPO uptake remains an important part of sectoral reform (Schmidt & De Rosa, 2020; Simatupang et al., 2026). Yet certification embodies what might be called a compliance ethic: moral responsibility is translated into auditable indicators and checklists.

Compliance ethics has strengths. It creates thresholds, documentation routines, and transnational comparability. But it also has limits. First, certification may privilege what is measurable over what is morally central. A producer may meet documented waste-management requirements while local communities still judge compensation or participation to be inadequate. Second, certification can improve average performance without resolving frontier effects: land pressure may shift spatially, and improvements at certified mills may coexist with weak practices elsewhere. Third, certification often depends on institutional capacity that smallholders may struggle to access, thereby risking a governance gap between corporate estates and more fragmented production systems (Apriyanto, 2020; Majesty et al., 2024). In ethical terms, certification should therefore be treated as necessary but insufficient.

Recent biodiesel policy analysis sharpens this point. Indonesia's biodiesel implementation has advanced rapidly, but its long-term sustainability depends on regulatory design, economic formulas, and the internalization of environmental external costs (Wirawan et al., 2024). Earlier analyses similarly question whether government economic propositions fully capture the complexity of renewable-energy transitions (Halimatussadiah et al., 2021; Maulidia et al., 2019). If biodiesel policy expands palm demand without strong safeguards for no-deforestation production, peat exclusion, methane capture, labor protection, and land rights, then climate policy may unintentionally deepen environmental injustice. Ethics requires that energy transition policies be evaluated not only by blending ratios and import substitution, but by the full moral geography of the commodity systems they intensify.

Table 3. Representative recent literature (2024-2026) extending the environmental-damage and ethics agenda

Recent study	Primary focus	Environmental contribution	Ethical or governance relevance	Ref.
Resilient value-chain analysis in South Papua	Value-chain structure, profit distribution, sustainability and indigenous rights	Shows ecological integrity must remain a central criterion despite economic potential	Explicitly foregrounds FPIC, asymmetry, and inclusive governance	Simatupang et al., 2026
Local-wisdom waste management among independent smallholders	Village-scale waste utilization and livelihood generation	Shows waste valorization can support environmental improvement and rural development	Demonstrates the importance of recognition and capability-sensitive sustainability support	Majesty et al., 2024
Carbon storage comparison across land uses	Secondary forest, cocoa agroforestry, and oil palm plantation	Shows oil palm stores less carbon and absorbs less CO2 than more complex land uses	Supports the ethical claim that monoculture efficiency does not erase landscape losses	Dicky et al., 2025
Agroclimatic suitability under future climate	Projected climate suitability for oil palm in Aceh	Shows future suitability shifts and adaptation pressures	Raises intergenerational and resilience-based questions about lock-in	Jamidi et al., 2025
Circular bioeconomy and decarbonization review	Palm oil waste management and low-carbon pathways	Synthesizes routes for biogas, biochar, fuels, and material recovery	Useful only if circularity is tied to rights and no-deforestation constraints	Goh et al., 2025

Rural-scale biochar deployment	Low-cost biochar production from fronds and waste cooking oil	Links carbon sequestration and decentralized waste valorization	Shows mitigation can be designed for more distributed benefit rather than only mill-scale capture	Purnama et al., 2025
Electrocoagulation for POME treatment	Improved post-treatment of mill effluent	Large reductions in COD and turbidity under optimized conditions	Supports a non-harm threshold for downstream water protection	Bandara et al., 2025
Boiler ash substitution and mineral reuse	POBA in cement and CaCO3 regeneration in mills	Reduces disposal pressure and displaces more carbon-intensive material inputs	Illustrates when circularity has direct local environmental benefits	Jonbi et al., 2025; Syarifuddin, 2024

Circular bioeconomy, waste valorization, and the risk of ethical burden shifting

Why circularity matters

There is no doubt that oil palm waste management is a central environmental issue. The original review demonstrates the scale of residues and the technical rationale for converting them into solid fuels, biochar, adsorbents, fertilizers, and other products (Nabila et al., 2023). The newer literature reinforces this point with studies on decarbonization, industrial symbiosis, ash substitution in cement, regeneration of calcium carbonate waste, effluent-based biorefineries, and rural-scale biochar systems (Jonbi et al., 2025; Syarifuddin, 2024; Goh et al., 2025; Rendón-Camargo et al., 2026). At its best, circularity reduces dumping and open burning, displaces carbon-intensive materials, cuts methane losses, and creates additional value from already existing biomass streams.

In environmental ethics, such strategies are attractive because they operationalize a principle of responsibility: once a production system exists, its operators ought to minimize the harms of its residual outputs. Waste valorization can therefore be read as a moral improvement over linear disposal. Recent reviews of palm oil waste management and decarbonization make precisely this case, arguing that the sector's waste burden can be transformed into a platform for lower-carbon energy, bio-based chemicals, material substitution, and cleaner production (Kahar et al., 2025; Kurniawan et al., 2025; Goh et al., 2025). The ethical force of these studies lies in their refusal to treat residues as inevitable nuisances.

Why circularity is not enough

Yet circularity can also become a language of absolution. A plantation system may adopt sophisticated residue pathways and still remain embedded in an unjust land regime or ecologically destructive expansion frontier. This is the core risk of ethical burden shifting. The sector highlights secondary gains—biochar, pellets, renewable electricity, carbon offsets—while the primary harms of land conversion, community exclusion, or worker precarity remain structurally intact. In such cases, circularity improves the moral appearance of the system more than its underlying legitimacy.

The recent literature itself contains evidence for this caution. Simatupang et al. (2026) report that some actors have adopted zero-waste initiatives through biochar and biogas, but the central challenges in South Papua still include inequality, indigenous rights, and the need for FPIC. Majesty et al. (2024) emphasize that sustainable waste management among independent smallholders remains limited despite obvious environmental benefits. Sato et al. (2025) show that even an apparently climate-positive residue pathway—EFB pellets for electricity in Japan—depends on methane control and supply-chain conditions that may not be universally met.

These studies imply that technical valorization is real progress, but only conditional progress.

The same caution applies to life-cycle accounting. Biochar, torrefaction, and thermochemical conversion often look favorable in system boundaries that emphasize avoided disposal or fossil substitution (Robb & Dargusch, 2018; Matuštík et al., 2020; Zhu et al., 2022). However, if the carbon accounting framework is detached from land rights or local ecological degradation, then a morally ambiguous system may still produce attractive carbon numbers. Ethics requires a nested evaluation: first prevent unjust and ecologically destructive expansion, then optimize the handling of the residues generated within a constrained and legitimate production system.

Ethical criteria for judging circular palm oil strategies

A genuinely ethical circular strategy in palm oil should satisfy at least five criteria. First, it should operate under a no-deforestation and no-peat-conversion premise. Circularity should clean up existing systems, not justify further expansion (Afriyanti et al., 2016; Schmidt & De Rosa, 2020). Second, it should improve local environmental quality in measurable ways—less methane, better effluent treatment, lower open burning, reduced ash disposal, or improved soil health (Bandara et al., 2025; Rahman et al., 2025; Jonbi et al., 2025; Maulana et al., 2025). Third, it should distribute benefits more fairly, including among smallholders and local communities rather than only mills and external processors (Majesty et al., 2024; Purnama et al., 2025; Simatupang et al., 2026). Fourth, it should avoid depleting residues that play agronomic roles such as mulching, soil cover, or on-site nutrient cycling unless equivalent benefits are restored. Fifth, it should be transparent about trade-offs, especially methane leakage, transport emissions, energy requirements, and competing uses.

Under these criteria, several recent developments are promising. Purnama et al. (2025) present a rural deployment model for premium biochar from oil palm fronds that links process optimization with policy relevance and carbon benefits. Rendón-Camargo et al. (2026) show that industrial symbiosis can widen the set of sectors involved in residue valorization, potentially increasing systemic efficiency. Jonbi et al. (2025) and Syarifuddin (2024) demonstrate that ash and calcium carbonate wastes can substitute or regenerate materials otherwise associated with additional environmental costs. Bandara et al. (2025) and Rahman et al. (2025) expand the repertoire of POME treatment toward electrocoagulation and microalgal pathways. Taken together, these studies indicate that the downstream environmental burden of palm oil need not be treated as fixed.

The deeper ethical challenge, however, is cultural and political rather than merely technical. Circularity must be subordinated to justice. If community consent is weak, land compensation contested, worker protections inadequate, or ecological frontiers still expanding, then even highly innovative residue pathways remain part of a morally compromised system. Environmental ethics therefore demands a hierarchy of action: rights and ecological limits first; circular optimization second.

Table 4. Integrated transition framework for ecologically restorative and ethically legitimate palm oil systems

Transition priority	Operational intervention	Expected ecological gain	Expected ethical gain	Ref.
No-deforestation supply base	Verified exclusion of forest and peat conversion	Protects carbon, biodiversity, and hydrological	Honors ecological limits and intergenerational	Afriyanti et al., 2016; Schmidt & De Rosa, 2020;

		functions before damage occurs	responsibility	Guillaume et al., 2018
Rights-based land governance	Mandatory FPIC, stronger grievance systems, tenure clarity, inclusive forums	Reduces opportunistic frontier expansion and conflict-driven degradation	Improves recognition and procedural justice	Simatupang et al., 2026; Kubitza et al., 2018
Clean milling and effluent control	Methane capture, robust POME treatment, strict discharge compliance	Lower CH4 emissions and better local water quality	Protects downstream communities from preventable harm	Hermawan et al., 2025; Bandara et al., 2025; Rahman et al., 2025
Just circularity	Biochar, ash reuse, CaCO3 regeneration, industrial symbiosis, residue-sharing rules	Less dumping, open burning, and fossil substitution pressure	Ensures circular value is not monopolized by already dominant actors	Jonbi et al., 2025; Syarifuddin, 2024; Rendón-Camargo et al., 2026
Soil and landscape restoration	Biochar/compost use on degraded sites and acid or peat-affected soils	Improves soil function, carbon retention, and local resilience	Transforms restoration from branding into obligation to repair	Bakar et al., 2018; Cornelissen et al., 2018; Maulana et al., 2025
Worker-centered sustainability	Contracts, social protection, and OHS safeguards	More reliable pollution-control and waste-system operation	Adds labor dignity to sustainability metrics	Lesmana et al., 2025

Integrative discussion: from extractive efficiency to restorative legitimacy

The evidence reviewed here suggests that the central weakness of many palm oil sustainability debates is not the absence of technical solutions. It is the absence of an explicit moral ordering among competing goals. Yield, export revenue, biodiesel substitution, residue valorization, and carbon reduction are all important, but they do not occupy the same ethical rank. Ecological integrity and justice should function as boundary conditions within which efficiency is pursued, not as variables that can be traded away when market returns are favorable. This is the core shift required if palm oil is to be judged by restorative legitimacy rather than extractive efficiency.

Such a shift changes how key problems are interpreted. Deforestation is no longer only a carbon and biodiversity issue; it becomes a failure to respect the ecological and social conditions that make landscapes livable across generations. POME is no longer only a wastewater engineering problem; it becomes a question of whether downstream communities are exposed to preventable harm. Residue burning is no longer only a lost energy opportunity; it becomes evidence of a governance order willing to offload pollution costs onto local air, soils, and bodies. Labor burnout is no longer only a human-resources problem; it becomes evidence that sustainability claims are hollow if they do not include the people whose work underpins the commodity chain (Lesmana et al., 2025).

This perspective also helps clarify the proper place of circular bioeconomy in the palm oil sector. Circularity is ethically valuable when it reduces residual harm within already constrained systems and when it shares benefits fairly. It is ethically dubious when it functions as a compensatory narrative suggesting that waste valorization can offset unjust land acquisition, unresolved FPIC, or continuing ecological simplification. In other words, circularity should be read as a second-order virtue: desirable and necessary, but incapable of redeeming first-order injustice.

The recent literature on decarbonization and waste management is most persuasive when it implicitly acknowledges this hierarchy, as in studies that connect residue innovation to governance, smallholder participation, and policy design rather than to technical novelty alone (Goh et al., 2025; Purnama et al., 2025; Rendón-Camargo et al., 2026).

A rights-based and ecologically bounded sustainability framework for oil palm would contain at least six commitments. The first is strict no-deforestation and peat exclusion, backed by independent verification and public transparency. The second is rights-based land governance, including mandatory FPIC in indigenous territories, stronger dispute-resolution mechanisms, and clearer land-tenure safeguards. The third is non-harmful mill operation, which means methane capture or strong control in wastewater systems, rigorous effluent treatment, and the elimination of routine open burning. The fourth is fair value distribution, especially where new residue-based revenue streams emerge. The fifth is worker-centered sustainability, in which labor contracts, occupational health, and psychosocial well-being are treated as sustainability indicators rather than peripheral social issues. The sixth is landscape restoration, using biochar, organic amendments, and diversified land management not as green branding, but as tools for long-horizon repair in already degraded sites (Bakar et al., 2018; Cornelissen et al., 2018; Maulana et al., 2025).

From a research perspective, the literature still has several limitations. First, there is a persistent imbalance between engineering evidence and justice evidence. Residue conversion pathways are described in great technical detail, while procedural and recognition-based outcomes are still documented comparatively sparsely. Second, many climate claims remain highly boundary-dependent, making them difficult to compare across studies. Third, longitudinal evidence on whether certification, circularity, or biochar deployment actually transforms rural power relations remains limited. Fourth, there is still inadequate integration between land-use science, labor studies, and mill-level pollution studies. Future research should therefore move toward multi-scalar designs that connect plantations, mills, communities, and landscapes in the same analytical frame. Without that integration, the literature risks mistaking environmental management at one node for sustainability of the system as a whole.

A more mature palm oil ethics must also reject both simplistic demonization and simplistic redemption. It is analytically inadequate to portray all oil palm production as uniformly destructive, just as it is ethically inadequate to infer legitimacy from isolated technical successes. The recent case literature shows that local communities may experience real benefits, that waste valorization can produce measurable improvements, and that some governance reforms are feasible (Rosaprana et al., 2025; Simatupang et al., 2026; Jonbi et al., 2025). The challenge is to hold these truths together without allowing them to cancel one another. Ethically legitimate sustainability is not the absence of all trade-offs; it is the establishment of non-negotiable protections for ecosystems and affected people, followed by transparent management of the remaining trade-offs.

Reframing productivity: why “more oil on less land” is not a complete ethical defense

A recurring defense of oil palm is that because it produces more oil per hectare than many alternatives, it should be treated as environmentally preferable by default. There is an important empirical truth in this claim: oil palm’s yield advantage means that replacing it one-for-one with lower-yield oil crops could, under some circumstances, require more land globally (Harahap et al., 2020; Mukherjee & Sovacool, 2014). However, this argument becomes ethically incomplete when it is detached from actual land governance. The relevant comparison is not only "oil palm versus soybean" in abstract agronomic terms, but "oil palm as actually expanded and regulated" versus realistic alternatives in specific landscapes. If high-yield production is achieved through conversion of high-carbon forest, inadequate land consent, or weak pollution control, then the yield defense describes only one dimension of efficiency while omitting the moral quality of the pathway.

Moreover, the productivity argument can obscure threshold effects. Some environmental damages are not linearly substitutable. The loss of a culturally significant forest area, the drainage of peat, or the fragmentation of a high-conservation-value corridor may be ethically unacceptable even if aggregate land demand for vegetable oil falls elsewhere. This is why environmental ethics often requires side constraints rather than simple optimization. Certain places, rights, and ecological functions should not be entered into trade-offs as if they were fully fungible. The palm oil debate has often struggled precisely because public justification moves too quickly from per-hectare yields to generalized claims of sustainability. A more careful argument would say that oil palm's yield advantage can only count as a sustainability asset after no-go areas, rights protections, and pollution safeguards are secured.

The productivity defense also does little to address mill-level and post-harvest burdens. Even if oil palm were land-efficient in the field, the industry would still need to manage extraordinary quantities of biomass residues and POME in ways that do not create new environmental harms (Nabila et al., 2023; Iskandar et al., 2018; Goh et al., 2025). The recent circularity literature shows that these burdens can be transformed into energy, materials, and carbon-storage pathways, but the necessity of those interventions itself demonstrates the incompleteness of yield-based arguments. A sector that generates large external waste loads cannot be judged by hectare-level oil output alone. Ethical legitimacy depends on full-system stewardship.

Another limitation of the productivity frame is that it often assumes national-scale welfare aggregation while understating local heterogeneity. Rosaprana et al. (2025) show that local communities may indeed perceive improved transport, jobs, or income, but also dissatisfaction over compensation. Simatupang et al. (2026) show that strong value-chain asymmetry can coexist with environmental and institutional challenges. Lesmana et al. (2025) point to worker stress and burnout within plantation companies. These findings indicate that a nationally beneficial sector can still generate ethically troubling micro-level outcomes. Environmental ethics therefore resists the move from macro-benefit to micro-legitimacy. It asks whether the people living and working in plantation regions experience sustainable development as fair, not only whether the national economy records gains.

Finally, the productivity narrative can weaken imagination. Once a sector is treated as "necessary" because of global oil demand, policy becomes preoccupied with optimizing the existing model rather than exploring diversification, restoration, agroforestry integration, demand-side reform, or differentiated regional pathways. Yet the evidence on carbon storage, microclimate, and agroclimatic suitability suggests that landscape pluralism may be ethically superior to relentless monocultural expansion in many contexts (Meijide et al., 2018; Dicky et al., 2025; Jamidi et al., 2025). Reframing productivity means asking not simply how to grow more palm oil, but what mix of land uses can best sustain livelihoods, rights, biodiversity, carbon, and adaptation over time.

A normative framework for evaluating future palm oil transitions

Drawing together the literature reviewed above, future palm oil transitions can be evaluated through a four-part normative framework. The first dimension is ecological restraint. Expansion must be bounded by explicit no-go rules for forests, peatlands, and high-conservation-value landscapes, with measurable targets for emissions, effluent quality, and residue handling. The second is democratic legitimacy. Land development and processing infrastructure should be contingent on meaningful consent, grievance mechanisms, and recognition of customary and indigenous rights. The third is shared value creation. New benefits from waste valorization, carbon markets, renewable electricity, or material substitution must be distributed in ways that reduce rather than deepen value-chain asymmetry. The fourth is restorative obligation. Existing degraded landscapes and mill waste burdens create duties of repair, not only opportunities for investment.

This framework implies a different interpretation of innovation. Under extractive efficiency, innovation is good if it raises yields, lowers unit costs, or creates new revenue from residues. Under restorative legitimacy, innovation is good if it lowers absolute ecological harm, strengthens justice, and increases long-term resilience. A biochar project that improves soil quality on degraded land while sharing benefits locally ranks highly under both logics. A pellet export chain that produces favorable carbon accounting but relies on weak methane control or deprives estates of mulch needed for soil management ranks much lower. The normative point is that not all circular innovations are equal; they must be ordered according to ecological and ethical quality rather than technological sophistication alone.

Importantly, the framework also clarifies the role of the state. Governments are not only facilitators of investment or arbiters of certification. They are moral institutions responsible for setting ecological floors and justice guarantees. In the Indonesian context, this means that palm oil policy should not be split between production ministries, energy mandates, and environmental compliance as disconnected domains. Instead, plantation development, biofuel strategy, waste valorization, labor protection, and rights recognition must be governed as a single socio-ecological system. The recent literature on value chains, biodiesel, and circular bioeconomy all points to the same conclusion: fragmented governance is one of the reasons why local harms and sector-wide efficiencies can coexist (Wirawan et al., 2024; Goh et al., 2025; Simatupang et al., 2026).

The framework further implies that sustainability indicators should be redesigned. Current indicator systems often overemphasize output, productivity, and auditable compliance while underrepresenting procedural justice, land restitution, local environmental quality, and worker well-being. A next-generation indicator system would include, at minimum, verified no-deforestation status, peat exclusion, methane capture rate, effluent performance, local compensation outcomes, worker protection coverage, value-sharing from circular products, and ecological restoration effort per unit of production. Such indicators would make it harder for actors to present isolated technical achievements as comprehensive sustainability.

In this sense, the future of palm oil sustainability research and governance lies not in choosing between environmental science and ethics, but in integrating them more rigorously. Environmental science tells us what changes in carbon, water, soils, and ecosystems. Ethics tells us how those changes should count in public judgment and policy. When combined, they offer a more honest basis for decision making than either can provide alone. The transition question for palm oil is therefore not only how to reduce emissions or use residues efficiently. It is how to reorganize production so that environmental gains are inseparable from justice, recognition, and long-term ecological responsibility.

Research agenda for the next generation of palm oil sustainability studies

Three research priorities stand out. The first is the need for integrated landscape ethics metrics that combine carbon, biodiversity, water quality, land rights, labor conditions, and benefit distribution in a single evaluative framework. Existing studies typically isolate only one or two of these domains. The second is the need for smallholder-centered circularity research. Many promising technologies assume mill-scale capital and logistics, yet much of the ethical credibility of sustainable palm oil will depend on whether independent smallholders can participate in and benefit from improved waste management, carbon programs, and low-emission value addition (Majesty et al., 2024; Purnama et al., 2025). The third is the need for long-term evidence. Researchers should test whether biochar, residue recovery, certification, and methane capture produce durable ecological gains over five to ten years rather than only short-term improvements under project conditions.

A fourth priority is procedural evidence. FPIC is increasingly invoked, but there is still insufficient comparative evidence on how consent processes are designed, who is recognized as a legitimate representative, how information asymmetries are handled, and what forms of redress are available when consent is absent or contested. A fifth priority is climate-resilience research that links agroclimatic suitability, microclimate change, and diversified production systems. The emerging literature on climate suitability and microclimatic effects suggests that the future of oil palm cannot be discussed apart from adaptation and landscape heterogeneity (Meijide et al., 2018; Jamidi et al., 2025). Finally, a sixth priority is ethical LCA, meaning life-cycle assessment that explicitly states its normative assumptions and reports how conclusions change when land rights, biodiversity integrity, and local pollution burdens are treated as non-substitutable values rather than as background context.

Intergenerational justice and the ethics of temporal discounting

A great deal of palm oil decision-making is implicitly governed by temporal discounting. Immediate export earnings, rapid estate development, and short to medium-term energy targets receive priority, while slower ecological processes—peat oxidation, soil carbon decline, biodiversity attrition, or hydrological instability—are treated as future management issues rather than current ethical constraints. Intergenerational justice challenges that logic. If present-day profitability depends on exhausting ecological functions that took centuries to accumulate, then the moral ledger cannot be settled by contemporary market gains alone. The literature on AFOLU mitigation, soil carbon, peat emissions, and natural climate solutions reinforces the point that land systems are long-horizon infrastructures of climate stability and biological productivity, not merely surfaces for annual accounting (Smith et al., 2014; Bossio et al., 2020; Susilawati et al., 2016; Afriyanti et al., 2016).

This temporal issue is particularly acute in landscapes where plantation establishment narrows future adaptation choices. Jamidi et al. (2025) show that projected climate change may reduce agroclimatic suitability in major oil palm-producing areas, implying that systems optimized for present conditions may become less stable under future rainfall and temperature regimes. Meijide et al. (2018) further demonstrate that conversion changes microclimate in ways that matter under extreme events. These findings imply that present development decisions can reduce the ecological option value of landscapes. Intergenerational ethics therefore requires that palm oil governance treat resilience, restoration potential, and reversible land-use choice as moral goods. Where development locks in simplified systems that are harder to adapt, rehabilitate, or diversify, future communities may inherit greater vulnerability even if current actors record growth.

A related problem is the temporal asymmetry between damage and repair. Some circular interventions can be implemented relatively quickly—effluent treatment upgrades, ash reuse, biochar deployment, or methane capture—whereas the reconstitution of forest structure, peat functions, or landscape biodiversity may take far longer or may be only partially achievable. Ethical evaluation should therefore distinguish between damages that are rapidly reversible and those that involve long-term or quasi-irreversible loss. This matters because policy language often assumes that all impacts can be "managed," when in practice management may only dampen a fraction of the original loss. Environmental ethics becomes more demanding under such conditions: the stronger the irreversibility, the stronger the burden of justification for permitting the activity in the first place.

The recent waste-management and decarbonization literature contributes usefully here by showing that some future-oriented alternatives are already feasible. Purnama et al. (2025) emphasize rural-scale, policy-linked biochar systems; Goh et al. (2025) and Kurniawan et al. (2025) frame waste management as part of broader decarbonization and circular bioeconomy agendas; and Rendón-Camargo et al. (2026) show that industrial symbiosis can extend value and reduce waste burdens across sectors. Intergenerational justice does not require the abandonment of all palm oil activity, but it does require that current systems move away from frontier expansion and toward restoration, residue accountability, and carbon-conscious land stewardship. In ethical terms, the sector's legitimacy increasingly depends on whether it can prove that tomorrow's environmental inheritance will be better, not worse, because of what is done today.

Governance conditions for a just circular transition

A just circular transition in palm oil landscapes requires institutional architecture, not only technical innovation. First, waste and residue policies should be explicitly tied to land-use safeguards. Producers should not be able to claim circular-economy credit for residue valorization if the same supply base involves recent deforestation, peat conversion, or unresolved land disputes. Linking downstream incentives to upstream safeguards would reduce the risk that circularity becomes a compensatory narrative rather than a genuine sustainability pathway (Afriyanti et al., 2016; Schmidt & De Rosa, 2020; Goh et al., 2025). Second, community benefit-sharing needs to be built into new residue economies. Where ash reuse, biochar, pellets, or industrial symbiosis create new revenue streams, those benefits should not accrue exclusively to mills or external investors. Distributional justice suggests that local communities and smallholders should participate materially in the returns from cleaner production.

Third, governance should prioritize transparency on methane, effluent, and residue flows. Several recent studies show that greenhouse-gas outcomes depend on biogas treatment rates, wastewater performance, and site-specific assumptions (Sato et al., 2025; Hermawan et al., 2025; Bandara et al., 2025). Without routine disclosure of these parameters, climate claims are difficult to verify and local stakeholders cannot judge whether promised environmental gains are real. Fourth, policy frameworks should differentiate between large estates, company-owned mills, and independent smallholders. Majesty et al. (2024) demonstrate that smallholder waste management constraints remain significant, meaning that compliance expectations and support mechanisms cannot simply be copied from corporate systems. Ethical governance requires capability-sensitive regulation: strong standards paired with realistic technical and financial support.

Fifth, labor and occupational health should be integrated into circular transition policy. New processing routes—pyrolysis, gasification, effluent treatment, ash handling, activated carbon production—create their own safety regimes. If the sector's environmental transition increases technical complexity without strengthening labor protection, then sustainability gains may be partly financed by worker risk. Lesmana et al. (2025) remind us that job stress, burnout, and weak social protection are already serious issues in plantation settings. Finally, circular transition governance should include monitoring of agronomic trade-offs. Residues removed for off-site energy or industrial use should be assessed against soil-cover, nutrient-return, and moisture-retention functions that would otherwise support field sustainability. The circular question is not whether a residue can be valorized, but whether it can be valorized without undermining ecological repair at source.

Policy implications for Indonesia and exporting regions

For Indonesia, the review points toward a layered policy agenda. At the national level, biodiesel strategy, renewable-energy targets, and industrial downstreaming policies need to be aligned with strict ecological safeguards. The experience summarized by Wirawan et al. (2024) shows that biodiesel policy can be implemented at significant scale, but policy success in blending terms does not automatically translate into broader sustainability. A stronger policy package would connect biodiesel incentives to verified no-deforestation supply, methane-controlled milling, and rights-based grievance systems. Earlier analyses of renewable-energy reform in Indonesia suggest that private-sector and institutional perspectives remain critical to whether such reforms become credible and durable (Maulidia et al., 2019; Halimatussadiah et al., 2021).

At the provincial and district levels, the literature suggests that policy should become more place-specific. South Papua, North Aceh, South Sulawesi, peat regions, and acid sulfate areas present different ecological and social conditions, and therefore different ethical priorities (Simatupang et al., 2026; Dicky et al., 2025; Jamidi et al., 2025). In some regions the primary issue may be indigenous consent and asymmetrical profit capture; in others it may be climate suitability decline, peat emissions, or effluent treatment capacity. The policy implication is that "one-size-fits-all sustainable palm oil" is a weak concept. Minimum safeguards should be national, but implementation should be landscape-specific, with local knowledge and local rights institutions built into the governance structure.

Export markets also matter. Certification and sustainability requirements from importing jurisdictions have already shaped industry practices, but their legitimacy depends on whether they reward genuine improvements rather than document-heavy compliance. Importing regions that consume palm-based biofuels, pellets, or bio-based materials should avoid outsourcing moral responsibility to producer countries alone. Where downstream decarbonization benefits depend on upstream methane control, land protection, or labor safeguards, importing markets have an ethical obligation to structure demand in ways that reinforce those conditions rather than merely seek low-cost low-carbon claims. This is particularly relevant for transnational residue trade, as shown by the conditional emissions benefits found in the EFB pellet literature (Sato et al., 2025).

CONCLUSION

Oil palm's environmental problem is not only that it produces waste, emissions, and ecological simplification. It is that these damages are often organized through systems of unequal power that render some harms visible and monetizable while obscuring others. The literature reviewed here shows that plantation expansion can reduce carbon stocks, simplify habitats, disrupt microclimates, degrade soils, intensify effluent burdens, and create pollution from residues and combustion. It also shows that recent innovation in biochar, industrial symbiosis, POME treatment, ash reuse, and low-carbon materials offers genuine opportunities to reduce downstream impacts. But these technical gains do not by themselves answer the ethical questions of land rights, FPIC, compensation, labor well-being, and intergenerational responsibility.

The most defensible path forward is therefore not a choice between productivity and prohibition, but a reordering of priorities. No-deforestation production, peat protection, and rights-based governance must form the floor below which the sector is not permitted to operate. Within that floor, circular bioeconomy strategies, methane capture, residue valorization, soil restoration, and material substitution can play a powerful supporting role. Sustainable palm oil, in this stronger sense, is not merely efficient palm oil or circular palm oil. It is palm oil produced within ecological limits, under just institutions, with transparent responsibility for harms that cannot be wished away by technical ingenuity alone.

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