ISSN: 2634 - 8845

Journal of Earth and Environmental Science Research

SCIENTIFIC Research and Community

Research Article

Open Access

Rebalancing Life Cycle Assessment (LCA): A Development-Just Framework for Palm Oil and the Global South

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ABSTRACT

Life cycle assessment (LCA) is indispensable for identifying environmental hotspots, improving production systems, and supporting credible climate action. Yet its results are never independent of choices about system boundaries, data, allocation, temporal horizons, land-use history, and responsibility. This article develops a qualitative literature review of how those choices can distribute burdens and benefits unevenly between the Global North and the Global South, using Indonesian palm oil as an analytically revealing case. The review synthesizes recent scholarship on LCA methodology, life cycle sustainability assessment, climate justice, carbon accounting, palm-oil production, certification, and smallholder livelihoods. It finds that current practice can become development-blind when global databases inadequately represent tropical systems, historical land-use emissions are applied without contextual differentiation, producer-country mitigation is absorbed into downstream claims, and social or developmental functions are treated as external to the assessment. The article does not argue for weaker environmental standards or preferential treatment for palm oil. Instead, it proposes a Development-Just LCA framework built on procedural co-governance, local data sovereignty, geographical and temporal representativeness, symmetric system boundaries, transparent uncertainty, coherent treatment of national and product claims, distributional incidence reporting, and safeguards for the right to development. Applied to Indonesian palm oil, the framework would distinguish expansion from replanting, recognize methane avoidance and productivity improvement, and reduce disproportionate compliance burdens on smallholders. A fairer LCA would improve scientific credibility, policy legitimacy, and environmental effectiveness by making global sustainability assessment more representative, contestable, and accountable.

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Received: August 03, 2026; **Accepted:** August 11, 2026; **Published:** August 20, 2026

Keywords: Life Cycle Assessment, Global South, Palm Oil, Indonesia, Climate Justice, Carbon Accounting, Land-Use Change, Right to Development, Smallholders, Sustainability Governance

Jel Classification Codes: F18, O13, Q18, Q54, Q56

Introduction

Life cycle assessment has moved from a specialist environmental-management technique to a central instrument of climate policy, corporate disclosure, sustainable finance, product regulation, and international trade. Its attraction is understandable: LCA can follow material and energy flows across a product system, identify environmental hotspots, compare alternative processes, and translate complex supply chains into indicators that appear decision-ready. In the palm-oil sector, this analytical capacity supports fertilizer optimization, methane capture, renewable-energy recovery, refinery improvement, biodiesel evaluation, and more transparent communication with buyers. The expanding role of LCA should therefore be seen as an opportunity for better environmental performance, provided that its methodological authority is matched by institutional accountability and contextual accuracy [1-4].

The difficulty is that an LCA result is not simply discovered in the same way that a thermometer records temperature. It is produced through a sequence of choices: the goal and scope, functional unit, reference flow, system boundary, data sources, allocation rule, counterfactual, time horizon, impact method, and treatment of uncertainty. Each choice may be scientifically defensible, but alternative defensible choices can lead to materially different results. The relevant question is consequently not whether LCA is objective or political in an absolute sense, but whether its assumptions are transparent, representative, reproducible, open to challenge, and governed by institutions in which affected producers have meaningful voice [5-7].

This issue has a pronounced North-South dimension. Many influential databases, product rules, certification systems, and regulatory templates are funded, hosted, or interpreted in advanced economies, while a substantial part of the biological production, land-use change, labor exposure, and compliance burden occurs in developing countries. Producers in the Global South may be assessed with generic data that do not adequately describe their agroecological conditions, yet they are expected to generate increasingly granular primary data to preserve access to high-value markets. A technically uniform rule can therefore have unequal effects when the capacity to collect data, influence standards, finance verification, and absorb transition costs is highly unequal [8-11].

Indonesian palm oil provides a particularly useful case because it combines global environmental significance with major economic and social functions. The crop has been associated with land-use change and biodiversity concerns, but it is also a high-yielding oil crop that supports processing industries, exports, public revenue, rural employment, and a large smallholder population. Recent scholarship increasingly rejects one-dimensional narratives and emphasizes that impacts vary by location, plantation history, management system, mill technology, governance arrangement, and livelihood context. A fair assessment must therefore distinguish among production pathways instead of treating all palm oil as a single environmental object [12-14].

The initial Indonesian concept note supplied for this article identifies a strategic tension between territorial greenhouse-gas inventories and product-based LCA. Emission reductions achieved in Indonesian plantations and mills may strengthen the national inventory and the country's nationally determined contribution, while the same lower product footprint can also support downstream corporate or importing-country decarbonization claims. That tension does not automatically amount to formal double counting under international law, because inventories, product footprints, and corporate claims have different accounting purposes. It does, however, create a risk of double claiming, asymmetric recognition, or reputational appropriation when the relationship among those systems is not made explicit [15-17].

Land-use-change accounting intensifies the controversy. Historical conversion can dominate the carbon footprint of a current agricultural product, especially when emissions are amortized over a fixed period. Such treatment can be environmentally justified because historical land transformation has long-lived consequences. Nevertheless, justice and accuracy problems arise when cut-off dates, baselines, and amortization periods fail to distinguish recent expansion from replanting, long-established plantations, development on previously degraded land, or current management improvements. A single historical penalty can then obscure the difference between practices that should be discouraged and practices that should be rewarded [18,19].

The urgency of addressing these issues is growing as deforestation-free supply-chain rules, carbon-border measures, sustainable-finance taxonomies, and net-zero procurement policies become more influential. Developing countries need environmental rules that are credible enough to drive real improvement but sufficiently representative to preserve legitimate policy space and the right to development. Fairness is not a request to discount environmental harm. It is a demand that responsibility, capability, historical context, and the distribution of transition benefits be examined alongside physical impacts, so that sustainability governance does not reproduce structural inequality under the appearance of technical neutrality [20-22].

This article therefore asks three questions. First, through which methodological and institutional mechanisms can contemporary LCA disadvantage Global South producers? Second, how are those mechanisms visible in the Indonesian palm-oil value chain? Third, what principles and policy arrangements could make LCA more objective, fair, and supportive of both environmental integrity and the right to development? The article answers these questions through a qualitative literature review and proposes a Development-Just LCA framework. The contribution is constructive: it seeks to make LCA more credible by improving representation, coherence, participation, and accountability rather than by weakening climate or biodiversity objectives [23-24].

The relationships among LCA methodology, palm-oil production, global sustainability governance, and development outcomes can be understood through the integrated conceptual framework presented in Figure 1. The framework provides a visual roadmap for the article by connecting methodological design choices with the stages of the palm-oil value chain, the interpretation and institutional use of LCA results, the structural asymmetries between producer and consumer countries, and the resulting distribution of environmental responsibilities, compliance costs, market benefits, and development opportunities.

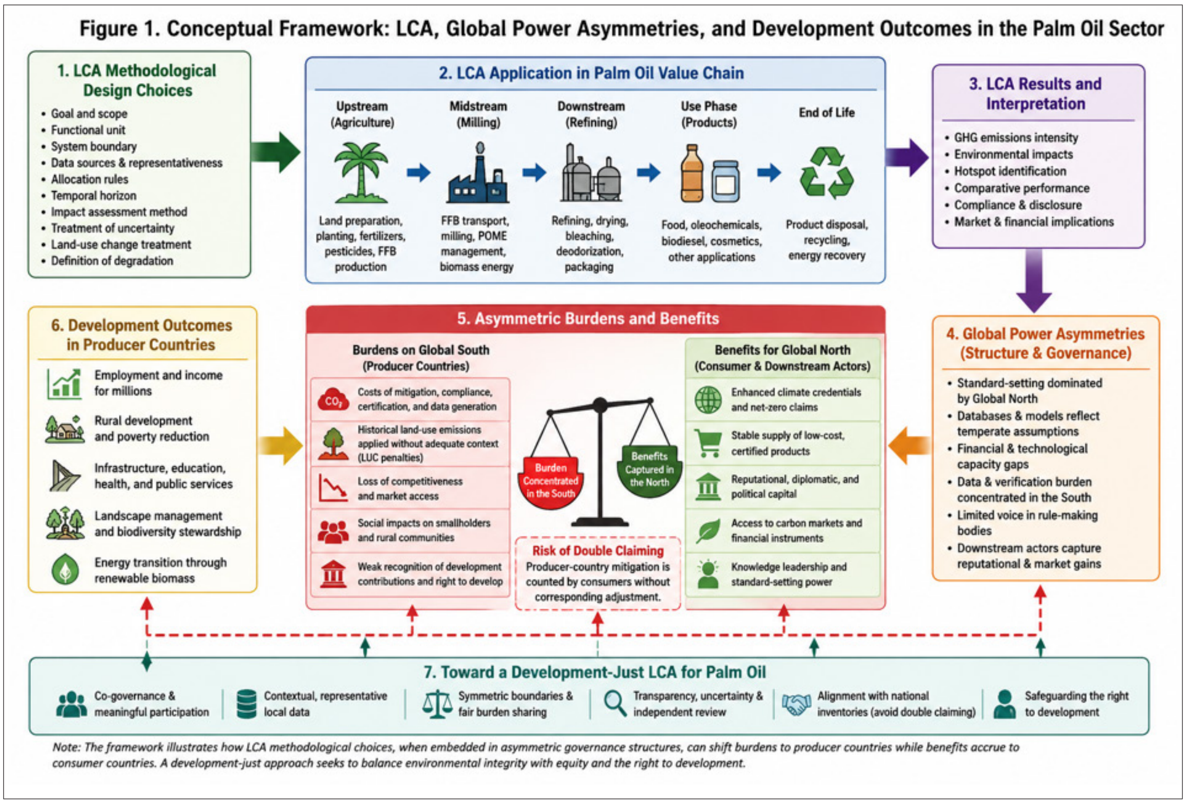


Figure 1. Conceptual Framework: LCA, Global Power Asymmetries, and Development Outcomes in the Palm Oil Sector

As illustrated in Figure 1, an LCA result is produced through interconnected methodological decisions concerning the functional unit, system boundary, data sources, allocation rules, temporal horizon, land-use-change treatment, impact-assessment method, and uncertainty. These choices are applied across upstream cultivation, milling, refining, product use, and end-of-life stages before the resulting indicators enter regulatory, financial, certification, procurement, and corporate reporting systems. When global databases, standards, and rule-making institutions insufficiently represent producer-country conditions, the resulting system may concentrate mitigation, verification, historical land-use, and data-generation burdens in the Global South while allowing downstream actors to capture market, reputational, diplomatic, and financial benefits. The lower part of the framework therefore presents Development-Just LCA as a corrective pathway based on co-governance, representative local data, symmetric burden sharing, transparency, coherent carbon claims, and safeguards for the right to development [25-27].

Figure 1: should not be interpreted as suggesting that every international LCA application intentionally disadvantages developing countries. Rather, it identifies the institutional pathways through which unequal effects may emerge even when individual methodological choices appear technically defensible. The analytical objective is therefore to examine whether the combined design and application of LCA provide adequate representation, contestability, and recognition for the countries and communities where production and mitigation activities physically occur.

Literature Review

LCA conventionally comprises four interrelated stages: goal and scope definition, life-cycle inventory, life-cycle impact assessment, and interpretation. The functional unit defines the service against which alternatives are compared, while the system boundary determines which processes are included. Inventory analysis compiles relevant inputs, outputs, emissions, resource uses, and co-products. Impact assessment then translates those flows into categories such as climate change, eutrophication, acidification, toxicity, water use, land occupation, and biodiversity pressure. Interpretation evaluates the robustness and decision relevance of the results. Because each stage influences the next, methodological transparency is essential to prevent apparently precise indicators from concealing weak assumptions [28-29].

Attributional LCA describes the environmentally relevant flows associated with a product system under a selected allocation logic, whereas consequential LCA estimates changes caused by a decision and therefore depends on market responses, marginal suppliers, substitution, and counterfactual scenarios. Neither approach is universally superior. Attributional methods may be more stable for reporting and benchmarking; consequential methods may be more suitable for policy decisions that change demand or production. Problems arise when an assessment presents one modeling perspective as the only scientifically valid representation or uses results beyond the purpose for which the model was designed [30-31].

Time further complicates interpretation. Conventional LCA often assumes a static production system, even though electricity mixes, yields, technologies, carbon stocks, and supply-chain structures change. Dynamic LCA and prospective scenarios can represent the timing of emissions and technological evolution more explicitly, but they require additional assumptions and data. For long-lived land-use effects, the selected reference year and amortization period can determine whether historical emissions dominate current performance. Temporal transparency is therefore not an optional technical refinement; it is a precondition for comparing legacy systems, current improvements, and future pathways fairly [32,33].

Geographical representativeness is equally consequential. Agricultural emissions depend on climate, soil, fertilizer practice, water regime, cultivar, yield, residue management, and local energy systems. Generic global datasets can be useful where primary data are absent, but they can systematically mischaracterize tropical production when regional processes are represented through European or global averages. Regionalized LCA attempts to connect inventory flows and impact characterization to location, thereby improving relevance for land, water, biodiversity, and pollution impacts. Its implementation, however, remains constrained by uneven data availability and modeling capacity [2,5,19].

Data quality is often discussed through technological, temporal, geographical, and completeness dimensions. Yet data quality also has an institutional dimension: who can afford measurement, who owns the data, whose databases are recognized, and who can contest a default value. A multinational plantation and refinery group can install sensors, commission verification, and negotiate technical interpretations. An independent smallholder may depend on group certification, public extension, or generic factors. If missing data automatically trigger conservative penalties, the assessment can transform capability differences into environmental scores and market exclusion [34,35].

Allocation is another source of disagreement. Palm-oil mills and refineries generate multiple products and residues, including crude palm oil, palm kernels, kernel oil, fiber, shells, empty fruit bunches, and potentially biogas or electricity. Environmental burdens may be allocated by mass, energy content, or economic value, or avoided burdens may be credited through substitution. Each method can alter the footprint of the principal product. A symmetric approach should avoid selectively assigning upstream burdens to the producer while allocating downstream substitution benefits elsewhere, and it should disclose sensitivity to alternative allocation rules [36,37].

Uncertainty analysis helps reveal how strongly conclusions depend on data variability and modeling choices. Parameter uncertainty concerns measured or estimated values; model uncertainty concerns the representation of processes; and scenario uncertainty concerns alternative futures or policy assumptions. Monte Carlo analysis, sensitivity analysis, and scenario comparison can quantify or expose these dimensions, but they do not resolve normative questions about which systems deserve comparison or which distributional effects matter. A fair LCA must therefore combine statistical uncertainty with transparent reporting of value-laden choices [1,30,32].

Life cycle sustainability assessment broadens the focus beyond environmental burdens by integrating economic and social dimensions. This expansion is especially relevant for commodities produced in regions where livelihoods, rural infrastructure, land tenure, and development opportunities are inseparable from environmental change. Social LCA has developed stakeholder categories and impact pathways for workers, communities, consumers, value-chain actors, and society. However, the literature still debates how to define well-being, aggregate heterogeneous indicators, and avoid reducing rights or social relations to a single score [38,39].

Justice scholarship offers a complementary vocabulary. Distributive justice concerns who bear costs andreceives benefits; procedural justice concerns participation and decision power; recognition justice concerns whether identities, knowledge, histories, and vulnerabilities are respected. These dimensions illuminate why two assessments with identical global environmental totals can have different ethical and political meanings. A product rule may reduce emissions while shifting compliance costs to smallholders, excluding producers from premium markets, or denying producer countries recognition for mitigation. Such outcomes are not external to sustainability; they are part of its legitimacy and durability [40].

The right to development adds a further principle: environmental governance should enable people and states to pursue economic, social, cultural, and political development while respecting ecological limits and human rights. This does not imply a right to unlimited emissions or deforestation. It requires that transition pathways consider capabilities, historical responsibility, access to technology, finance, and the distribution of policy space. Development-sensitive LCA should therefore report not only environmental intensity but also the feasibility and incidence of recommended changes [41].

Carbon-accounting systems allocate responsibility differently. Territorial inventories assign emissions to the jurisdiction where they occur; consumption-based accounts reassign embodied emissions to final demand; product footprints follow a product chain; and corporate inventories divide emissions across operational and value-chain scopes. Each framework answers a different question. Confusion arises when a result from one architecture is interpreted as an entitlement in another, or when downstream actors claim leadership without acknowledging the producer-country investments that generated the reduction [42-43].

Shared-responsibility approaches seek to avoid the extremes of assigning all responsibility to producers or all responsibility to consumers. They recognize that trade connects production decisions, final demand, value capture, and regulatory power. Such approaches are relevant to palm oil because upstream land management occurs in Indonesia, while refining, branding, consumption, finance, and standard-setting are distributed internationally. A fair product account should make these relationships visible instead of allowing a single carbon-intensity number to imply that the producer country alone is responsible for the entire life-cycle problem [44].

The palm-oil value chain begins with land preparation, nursery operations, planting, maintenance, fertilizer and pesticide use, harvesting, and fresh-fruit-bunch transport. Yields are central because higher output per hectare can lower many impacts per tonne, although productivity gains do not automatically prevent expansion without supportive land and market governance. Soil carbon, peat status, previous land cover, drainage, fire, and plantation age strongly influence the greenhouse-gas profile. Consequently, land history and management stratification are indispensable for a representative inventory [45].

At the mill, sterilization, threshing, pressing, clarification, kernel recovery, and effluent treatment create energy demands and emissions. Palm oil mill effluent can emit substantial methane under open anaerobic treatment, but covered lagoons or digesters can capture biogas for heat or electricity. Fiber and shells can replace fossil energy, while empty fruit bunches can be returned to fields or converted into materials and chemicals. LCA studies consistently show that technology and residue-management choices can materially improve the environmental profile, which supports a differentiated rather than categorical view of the sector [46,47].

Downstream stages include refining, fractionation, oleochemical conversion, food manufacture, biodiesel production, transport, distribution, and final use. The relevant functional unit depends on the question: a tone of refined oil, a unit of edible-oil service, a megajoule of fuel, or a specific chemical function. Comparisons that ignore functional differences can be misleading. Biodiesel assessments, for example, are particularly sensitive to land-use assumptions, co-product allocation, energy substitution, and the fossil reference system [48,49].

The environmental profile of palm oil cannot be attributed to one homogeneous production stage or represented by a single generic emission factor. Figure 2 maps the Indonesian palm-oil value chain from plantation establishment to distribution and final use, while identifying the major environmental hotspots and mitigation opportunities that should be represented within a comprehensive and context-sensitive LCA.

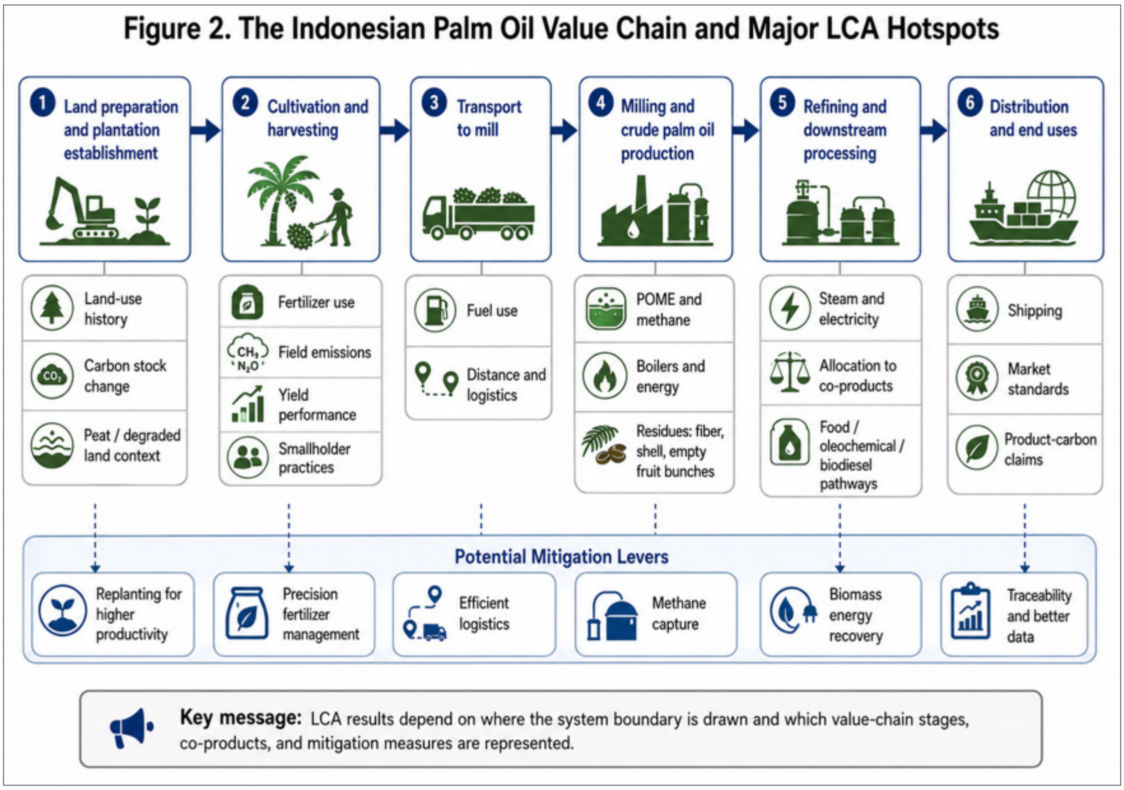


Figure 2 demonstrates that the life-cycle impacts of palm oil are distributed across interconnected stages. At the plantation-establishment stage, previous land cover, carbon-stock change, peat conditions, and the distinction between expansion and replanting can dominate the calculated greenhouse-gas profile. During cultivation, fertilizer production and application, nitrous-oxide emissions, yield performance, and differences between estate and smallholder management become important. Transportation introduces fuel-use and distance-related impacts, while milling creates potentially significant methane emissions from palm oil mill effluent as well as opportunities for biomass and biogas energy recovery. Refining and downstream processing introduce additional energy demands and methodological questions concerning the allocation of burdens among crude palm oil, palm-kernel products, oleochemicals, biodiesel, food products, residues, and exported energy. Distribution, market standards, and product-carbon claims subsequently determine how these physical impacts are communicated and governed internationally [3,36,46,48].

The figure also emphasizes that mitigation opportunities exist throughout the chain. Replanting accompanied by no-expansion safeguards can increase productivity without requiring new land conversion; precision fertilizer management can reduce input use and field emissions; improved logistics can lower fuel demand; methane capture can transform effluent from an emissions source into an energy resource; and biomass recovery can substitute for fossil energy. Traceability and improved local data can make these achievements visible within LCA results. Consequently, palm oil should not be assessed as a fixed environmental category. Its footprint depends substantially on land history, agricultural management, mill technology, allocation assumptions, logistics, and the degree to which verified improvement is recognized by the assessment system.

Palm oil also has heterogeneous social effects. Expansion has created income and infrastructure opportunities in some regions while generating conflict, inequality, or ecological loss in others. Smallholders differ by land tenure, market integration, farm size, access to credit, and relationship with mills. Certification can improve practices and market recognition, but costs, documentation requirements, audit processes, and unclear price benefits can limit participation. These findings reinforce the need to evaluate both averages and distributions [50-52].

Sustainability standards are therefore both environmental tools and institutions of market governance. Their legitimacy depends on credible criteria, independent verification, transparency, and demonstrable benefits, but also on proportionality and accessibility. Studies of Indonesian certification show that pre-certification conditions, training, organization, and financial support shape whether smallholders can comply. When product-footprint rules are layered onto certification without public data infrastructure, the marginal burden may fall on actors least able to respond [53-57].

Method

This study uses a qualitative literature review with an interpretive, critical-synthetic orientation. The purpose is not to estimate an average effect size or to claim exhaustive coverage of every LCA and palm-oil publication. It is to identify recurring concepts, methodological controversies, institutional asymmetries, and policy propositions across several bodies of scholarship that are rarely examined together. The review therefore integrates methodological LCA research, life cycle sustainability assessment, climate and environmental justice, carbon accounting, palm-oil environmental studies, and smallholder-governance research [10,23,24].

The literature on the conceptual note of LCA was used as an initial analytical input. It sensitized the review to four issues: the relationship between product footprints and national inventories; the distribution of recognition for mitigation; land-use-change cut-off dates; and the risk that externally framed assumptions weaken national policy interests. Those propositions were then examined against peer-reviewed literature, including studies that support, qualify, or complicate the initial argument. This procedure preserved the note's strategic questions while preventing the article from merely restating its claims [7,15,16].

Literature identification was iterative and thematic. Searches combined terms related to life cycle assessment, regionalization, temporal LCA, uncertainty, attributional and consequential modeling, social LCA, climate justice, consumption-based accounting, palm oil, land-use change, POME, biodiesel, certification, and smallholders. Priority was given to peer-reviewed journal articles published from 2020 onward, consistent with the requested contemporary focus. Sources were selected for conceptual relevance, methodological clarity, empirical usefulness, journal standing, and diversity of perspectives rather than through a fixed PRISMA protocol [1,5,12].

Analysis proceeded abductively. Initial codes were derived from the concept note and the research questions, including system boundaries, temporal baselines, data ownership, responsibility allocation, double claiming, national interest, and right to development. Additional codes emerged from the literature, including procedural justice, recognition, smallholder capability, prospective scenarios, co-product treatment, and distributional incidence. The codes were consolidated into themes and tested across methodological and sectoral sources. Contradictory findings were retained when they revealed variation by place, technology, or governance arrangement [9,34,38,57].

This approach has limitations. A qualitative review cannot determine the numerical magnitude of bias in a particular product rule, and the English-language literature may underrepresent locally published evidence and practitioner knowledge. The article also proposes a normative framework that requires empirical testing through comparative case studies and the development of participatory methods. Nevertheless, qualitative synthesis is appropriate for examining how technical assumptions interact with institutions, power, and development because those relationships cannot be reduced to a single pooled indicator [8,10,39].

Results

The first thematic finding is that LCA operates simultaneously as measurement and governance. A result may begin as an estimate of physical flows, but it becomes a rule when used to determine market access, procurement preference, finance, tax treatment, reputational ranking, or regulatory compliance. At that point, methodological choices distribute economic opportunities and political recognition. The authority of the model is therefore inseparable from the legitimacy of the process through which its assumptions are set [10,28,35].

This dual character explains why formal adherence to a standard does not guarantee substantive neutrality. A system boundary may be consistently applied and still omit producer-country benefits or consumer-side burdens. A land-use factor may be scientifically documented and still be temporally insensitive. A database may be transparent and still rely on unrepresentative processes. Objectivity is weakened not by acknowledging these choices but by presenting them as if no reasonable alternative exists [1,5,6].

The second finding concerns data and infrastructure asymmetry. Advanced economies and large firms possess greater capacity to fund life-cycle inventories, maintain databases, participate in technical committees, and commission third-party studies. Developing-country producers often face sparse local characterization factors and limited public measurement infrastructure. Where the default is based on foreign averages or conservative proxies, the producer must pay to disprove a potentially unfavorable assumption. This reverses the ordinary logic of evidence and embeds unequal capability in the footprint [58].

The asymmetry is sharper within producer countries. Integrated companies can generate estate-level and mill-level data, while independent smallholders may lack geolocation records, fertilizer logs, legal documentation, or access to accredited verification. Group certification and digital traceability can reduce costs, but only where institutions provide organization, training, finance, and trusted data governance. Without such support, more granular LCA requirements can improve average information while increasing exclusion at the margin [34,53,56].

The first findings of the review indicate that unequal LCA outcomes may emerge through several mutually reinforcing methodological and institutional mechanisms rather than through one isolated assumption. Figure 3 synthesizes these mechanisms by showing how data representativeness, system boundaries, allocation procedures, temporal assumptions, verification capacity, and governance arrangements can affect Global South producers.

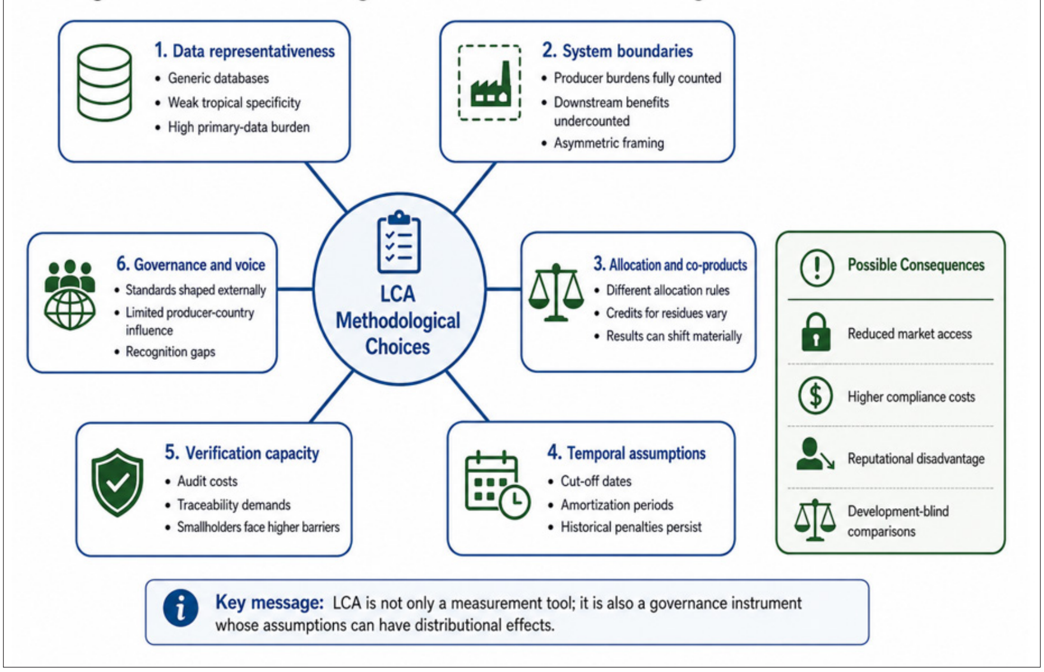


Figure 3. How Methodological Choices Can Disadvantage Global South Producers

As shown in Figure 3, six domains require particular scrutiny. First, generic databases may not adequately represent tropical soils, production technologies, electricity systems, yields, or smallholder practices, while the cost of producing better primary data is transferred to producers. Second, system boundaries may comprehensively include upstream producer burdens while giving less attention to downstream consumption, value capture, financing, or avoided impacts. Third, allocation and co-product rules determine how burdens and credits are divided among oil, kernels, biomass, biogas, electricity, and other outputs. Fourth, cut-off dates and amortization periods determine how long historical land-use emissions remain attached to current production. Fifth, demanding traceability, audit, and verification systems may impose proportionally greater costs on smallholders and smaller firms. Sixth, producer countries may have limited influence over the standards, datasets, and product rules through which their performance is evaluated [5,10,30,35,57].

These mechanisms may lead to reduced market access, higher compliance expenditures, reputational disadvantage, or comparisons that inadequately consider development conditions. However, an environmentally unfavorable LCA result should not automatically be regarded as evidence of methodological discrimination. The relevant test is whether the result is based on representative evidence, symmetric analytical treatment, transparent assumptions, meaningful sensitivity analysis, and procedures through which affected producers can challenge inaccurate defaults. Figure 3 therefore presents a diagnostic framework for distinguishing legitimate environmental accountability from context-blind or disproportionately burdensome assessment.

The third finding is temporal injustice in land-use-change accounting. LCA often amortizes land-use emissions over a selected period to connect past conversion with current output. This is necessary to prevent recently converted land from appearing artificially low-carbon. However, the same mechanism becomes problematic when it treats a replanting cycle as new expansion, continues to attach a legacy burden after substantial management change, or ignores the difference between forest conversion and planting on long-degraded open land. Temporal rules need environmental integrity and contextual discrimination at the same time [7,18,19].

A fair approach would retain strict treatment of recent high-carbon-stock conversion while separating at least four land histories: recent expansion into natural ecosystems, established plantations undergoing replanting, conversion of previously cultivated or degraded land, and rehabilitation or productivity improvement without area expansion. These categories should not receive identical carbon factors because they represent different causal pathways. Remote sensing, land registries, field verification, and transparent uncertainty ranges can support such stratification [59-60].

Temporal assumptions require separate attention because land-use-change emissions can dominate the calculated footprint of agricultural commodities long after the initial conversion has occurred. Figure 4 compares three materially different land-use pathways—recent expansion into high-carbon land, replanting on established plantation land, and cultivation on long-degraded land—to demonstrate why they should not automatically receive identical treatment.

Figure 4. Temporal Justice in Land-Use-Change Accounting

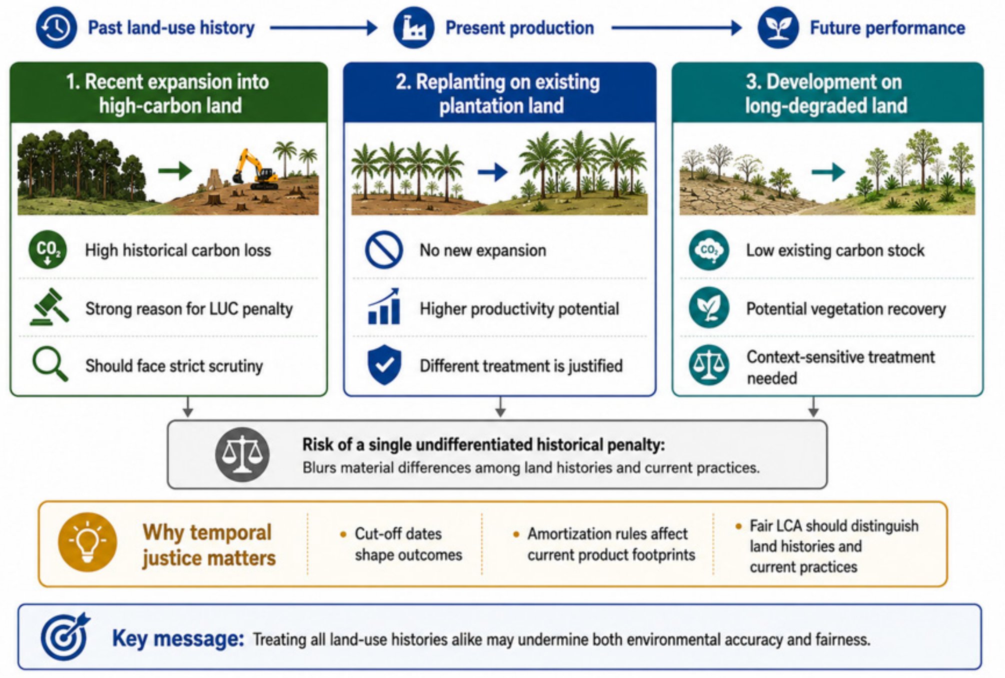


Figure 4 illustrates that recent expansion into forests, peatlands, or other high-carbon ecosystems creates substantial historical carbon loss and consequently provides a strong scientific basis for stringent land-use-change penalties. Replanting on existing plantation land represents a different causal pathway because it does not, by itself, involve new area expansion. Although continuing soil, peat, fertilizer, and management emissions must still be counted, replanting should not automatically be modeled as a new land conversion. Development on land that has remained degraded or sparsely vegetated for an extended period requires another form of analysis based on documented previous land cover, existing carbon stocks, a credible counterfactual, and an explicit uncertainty range [60].

The purpose of such differentiation is not to weaken deforestation safeguards or to create automatic carbon credits for plantation development. Rather, it is to prevent one historical factor from obscuring materially different relationships between past land use, current production, and future ecological performance. Cut-off dates, reference periods, and amortization rules should continue to deter recent conversion of natural ecosystems, but they should also distinguish current no-expansion replanting and verified rehabilitation pathways. Context-sensitive temporal accounting can therefore improve both environmental accuracy and distributive fairness by ensuring that current production is evaluated according to its actual land history and present management conditions.

The fourth finding concerns system-boundary asymmetry. Producer-country LCAs often emphasize plantation emissions, land use, fertilizer, processing energy, and mill effluent, all of which are legitimate. Yet downstream blending, refining, logistics, consumption, finance, and end-of-life decisions may receive less political attention, even when they influence total impacts or value capture. A full life-cycle perspective should prevent the environmental burden from being rhetorically localized at the production frontier while the economic and reputational benefits are distributed internationally [16,42,44].

Co-product allocation illustrates how this can occur technically. Palm kernels, fiber, shells, empty fruit bunches, biogas, and exported electricity can be treated as co-products, residues, or avoided products. Different choices shift burdens and credits among crude palm oil, kernel products, energy, and downstream users. The appropriate rule depends on the study purpose, but fairness requires symmetry: the actor assigned a burden should also receive transparent recognition for verified avoided emissions or useful co-products created by the same system [36,37,46].

The fifth finding is a mismatch between national and product accounts. Indonesia reports territorial emissions and removals through national inventory systems, while companies and importers use product footprints and corporate value-chain accounts. A methane-capture project at an Indonesian mill can lower national emissions, reduce the product footprint, and support a buyer's scope-three target. These claims can coexist if their purposes are clearly distinguished, but ambiguity allows multiple actors to imply exclusive ownership of the same underlying improvement [15,17,43].

The central problem is thus less mechanical double counting than unbalanced attribution. Indonesia may bear investment costs, regulatory enforcement, opportunity costs, and the responsibility for meeting its NDC, while downstream actors receive consumer recognition or sustainable-finance advantages. A Development-Just LCA should disclose where the physical reduction occurred, who financed it, which inventory records it, who purchases the product, and which claims each actor makes. Such a ledger would not prevent shared recognition; it would make shared responsibility explicit [8,21,40].

The sixth finding is the underrepresentation of development functions. Environmental LCA is not designed to measure employment, income distribution, rural infrastructure, food security, public revenue, or capability development. The methodological mistake is not that these variables are absent from an environmental indicator; it is that the indicator is sometimes used as if it were a complete sustainability verdict. Palm oil's ecological impacts must be addressed, but a transition policy based only on carbon intensity can overlook who loses income, whether alternatives use more land, and whether affected communities possess viable development pathways [61].

Life cycle sustainability assessment and social LCA can improve this picture, although they should not be used to trade fundamental rights against environmental damage. Their value lies in making distribution visible: which workers, smallholders, communities, firms, or consumers experience benefits and burdens; whether participation is meaningful; and whether a proposed improvement is feasible. For palm oil, such analysis can reveal that identical carbon targets have very different consequences for an integrated company and a two-hectare farmer [38,39,52].

The seventh finding is that certification and footprint requirements may create cumulative compliance burdens. Smallholders can face costs for mapping, documentation, organizational membership, audits, farm improvement, and delayed returns. Certification may generate benefits through better practices, market stability, or village welfare, but evidence on direct price premiums is mixed and context-dependent. Adding complex LCA reporting without pooled services can therefore exclude producers who are not necessarily the worst environmental performers but are the least documented [62].

Exclusion also creates environmental leakage. Buyers may simplify compliance by sourcing only from large, easily verified suppliers, while excluded smallholders continue to produce for less demanding markets with fewer incentives for improvement. A more effective strategy is inclusion with escalating support: conservative screening where data are absent, followed by affordable measurement, extension, finance, and recognition for verified progress. This converts LCA from a gatekeeping mechanism into a learning infrastructure [34,50,55].

The eighth finding is that fairness can be operationalized without sacrificing comparability. First, producer countries should participate in setting product-category rules and land-use baselines. Second, databases should prioritize local primary data and disclose where proxies remain. Third, assessments should report multiple credible scenarios for contested choices rather than hiding sensitivity behind a single score. Fourth, results should include distributional incidence and capability requirements alongside environmental indicators [10,23,30].

Fifth, product footprints should be linked to a transparent claims architecture that distinguishes physical emission reductions, national inventory effects, corporate reporting, and consumer communication. Sixth, appeal and review mechanisms should allow producer-country experts and affected communities to challenge unrepresentative assumptions. Seventh, improvement should be recognized dynamically: replanting, methane capture, fertilizer efficiency, renewable energy, and traceability should change the score when verified. These elements constitute the empirical foundation for the Development-Just LCA framework developed below [25,33,48].

Discussion And Analysis

The review suggests that objectivity should be understood as disciplined openness rather than context-free uniformity. An objective LCA makes its purpose explicit, uses the best available evidence, documents assumptions, evaluates uncertainty, and permits independent reproduction. A development-just LCA adds two requirements: affected producer countries must be able to contest the model, and the distributional consequences of methodological choices must be visible. These additions do not politicize an otherwise neutral method; they make existing value choices accountable [1,10,25].

Comparability remains important. International markets cannot function if every producer selects whichever assumptions yield the lowest footprint. Yet comparability does not require pretending that all land histories, electricity systems, yields, soils, and governance capacities are identical. The appropriate goal is comparability through common principles, transparent data-quality rules, and harmonized reporting formats, combined with context-sensitive parameters where physical conditions genuinely differ. This is comparability without context-blind uniformity [2,5,19].

Based on the synthesis, Development-Just LCA can be defined as a life-cycle assessment approach that preserves environmental integrity while incorporating procedural co-governance, recognition of local knowledge, geographical and temporal representativeness, symmetric responsibility, accounting coherence, distributional transparency, and capability safeguards. It is not a replacement for ISO-style LCA but a governance layer and methodological checklist for applications with significant North-South consequences [63].

Its first principle is procedural co-governance. Producer-country scientists, regulators, industry organizations, smallholder representatives, and civil-society actors should have meaningful representation in committees that determine product-category rules, default datasets, cut-off dates, and review procedures. Consultation after a rule is drafted is insufficient if agenda setting and model design remain concentrated elsewhere. Co-governance improves legitimacy and can also improve science by identifying locally relevant processes and data gaps [9,10,22].

The second principle is local data sovereignty with interoperability. Indonesia needs the capacity to collect, curate, quality-control, and update its own agricultural and industrial life-cycle data, while making appropriate datasets interoperable with international platforms. Data sovereignty does not mean withholding evidence or avoiding verification. It means that producers and public institutions participate in defining metadata, access conditions, confidentiality, uncertainty, and update cycles instead of remaining passive suppliers to external databases [5,35,45].

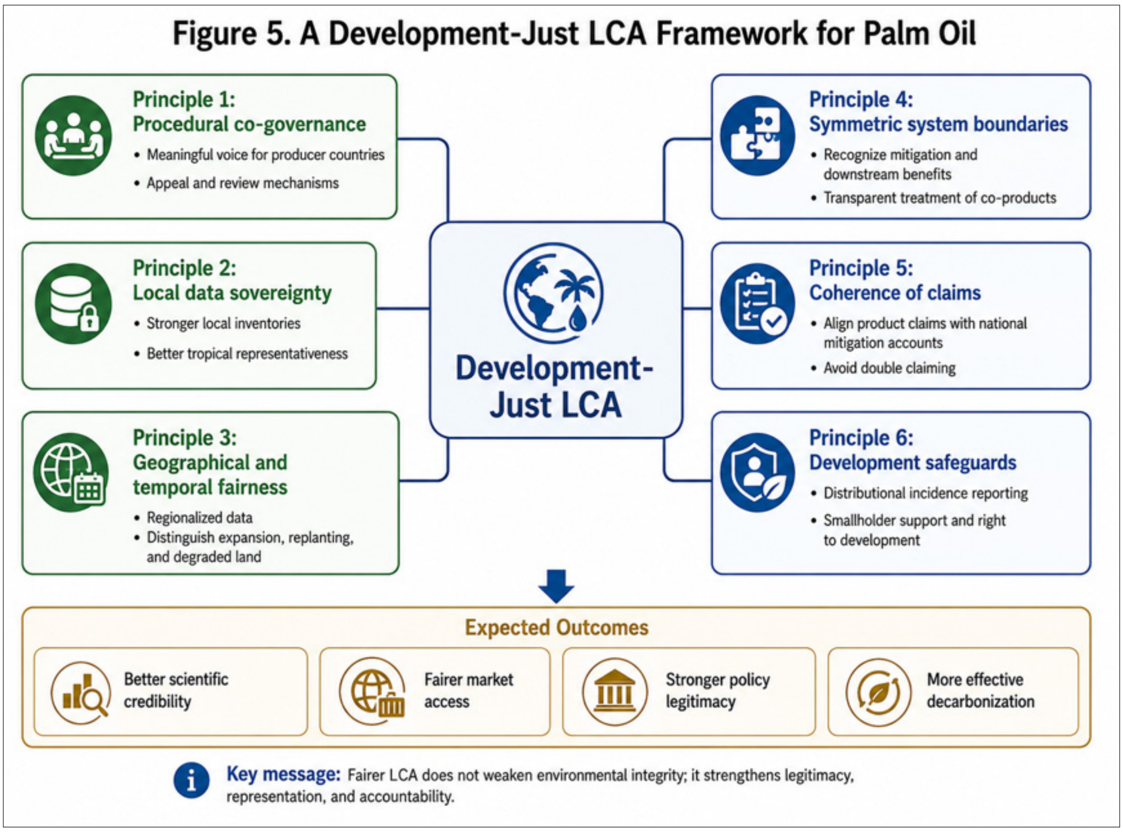
The third principle is geographical and temporal justice. Land-use-change factors should reflect verified prior land cover, carbon stocks, peat status, conversion date, plantation age, and current management. Recent conversion of natural ecosystems should remain strongly penalized. Replanting without expansion should be reported separately, and improvements should be reflected over time. Where land history is uncertain, assessments should disclose alternative scenarios rather than automatically choosing the assumption with the greatest trade consequence [7,18,60].

The fourth principle is boundary and allocation symmetry. If producer-side emissions are included comprehensively, downstream stages and the distribution of avoided burdens should receive equally transparent treatment. Allocation choices should be tested through sensitivity analysis, especially for palm kernels, biomass energy, biogas, and exported electricity. The objective is not to maximize credits but to prevent selective accounting in which burdens remain upstream while benefits migrate downstream [31,36,37].

The fifth principle is coherence between product claims and national mitigation accounts. Every material emission-reduction intervention should be traceable across four layers: the physical site, the product footprint, the national inventory, and downstream corporate or consumer claims. A claims statement should identify whether the actor financed, implemented, purchased, enabled, or merely benefited from the reduction. This allows shared recognition while reducing the risk that market communication obscures where the transition occurred and who carries continuing obligations [15,16,43].

The sixth principle is a right-to-development and capability safeguard. Before an LCA-based rule becomes a market condition, policymakers should assess the cost of data collection, technology adoption, verification, and organizational change for different producer groups. Where a requirement serves a global environmental objective but exceeds the capacity of smallholders, importing markets, lead firms, financial institutions, and producer-country governments should share the cost of compliance and transition. Otherwise, the rule externalizes governance costs onto the weakest participants [8,20,21].

The six principles developed from the literature synthesis are consolidated in Figure 5 as an integrated Development-Just LCA framework. The framework is intended neither to replace conventional LCA standards nor to provide preferential treatment for palm oil. It functions as a methodological and governance layer through which environmental assessments with significant North-South consequences can be evaluated for representation, coherence, distributional effects, and institutional legitimacy.



As summarized in Figure 5, Development-Just LCA rests on six connected principles. Procedural co-governance requires meaningful participation by producer-country scientists, regulators, industries, smallholder organizations, and affected communities in setting product rules and methodological defaults. Local data sovereignty requires producer countries to develop, control, validate, and update representative life-cycle inventories while maintaining interoperability with international databases. Geographical and temporal fairness requires regionalized information and explicit differentiation among recent expansion, replanting, established plantations, and genuinely degraded-land pathways. Symmetric system boundaries require transparent recognition of both upstream burdens and downstream impacts or benefits, including the treatment of co-products, residues, biogas, and exported energy. Coherence of claims requires product footprints, corporate reporting, consumer claims, and national mitigation inventories to be connected without implying exclusive ownership of the same physical reduction. Development safeguards require disclosure of compliance incidence and practical support for smallholders and other actors with limited transition capacity [8,10,23,24].

The expected outcomes shown in Figure 5 are mutually reinforcing. Greater representation and transparent uncertainty strengthen the scientific credibility of LCA results. More proportionate data and verification requirements improve the possibility of fair market access. Co-governance and review procedures increase the legitimacy of sustainability standards, while coherent recognition of mitigation creates stronger incentives for producer-country investment. Development-Just LCA should therefore not be understood as a compromise between environmental integrity and development. Its central proposition is that decarbonization and ecosystem protection are more effective and durable when rules are scientifically representative, institutionally accountable, and capable of rewarding verified improvement across the entire value chain.

Applied to Indonesian palm oil, the framework begins with a stratified inventory. Production should be separated by mineral or peat soil, prior land cover, plantation age, yield class, estate or smallholder status, fertilizer regime, mill technology, effluent treatment, energy recovery, and transport pattern. This does not require every farm to be modeled individually. Representative clusters can provide robust default factors, while verified primary data allow producers to demonstrate better performance [64].

Land reporting should explicitly distinguish expansion from replanting. Expansion after a defensible deforestation cut-off date should face stringent evidence and carbon treatment. Replanting on established plantations should not be modeled as a new land conversion, although existing peat or soil emissions must still be counted. Development on genuinely degraded land should use a documented counterfactual and uncertainty range, avoiding automatic assumptions that either idealize or condemn the pathway. Such differentiation rewards no-deforestation intensification while protecting credibility [18,50,59].

Mill performance offers a practical area for rapid improvement. Open effluent ponds, covered lagoons, digesters, biogas utilization, composting, and biomass energy systems have different emission profiles. A national LCA improvement program could prioritize measurement and finance for methane capture, reliable flare or energy-use monitoring, and standardized accounting for exported electricity. Verified reductions would lower product footprints and strengthen Indonesia's national mitigation performance simultaneously [36,46,47].

Productivity improvement should also be treated carefully. Higher yields can reduce land demand and many impacts per tone, but rebound or expansion risks remain if land governance is weak. Development-Just LCA should therefore pair yield metrics with no-expansion safeguards, traceability, and landscape monitoring. For smallholders, replanting finance, quality planting material, extension, and secure market access are essential because a low-yield transition period can otherwise create pressure to clear additional land or sell assets [12,34,50].

Institutionally, Indonesia would benefit from a national LCA data and methods platform governed by a multi-stakeholder board. The platform could publish versioned datasets, uncertainty ranges, methodological guidance, and sector-specific product rules; provide secure channels for confidential primary data; and maintain interfaces with national inventory and traceability systems. Universities and public research institutes should lead independent validation, while smallholder organizations should participate in deciding what data are feasible and how benefits are returned [65].

Internationally, Indonesia and other producer countries should pursue mutual-recognition arrangements for verified datasets and accredited methods. Importing jurisdictions should accept scientifically robust local data rather than privileging a single database by default. Technical cooperation should finance regional characterization factors for tropical land, water, and biodiversity impacts. Appeals should be reviewed by panels with balanced geographical representation and published reasoning [2,25,58].

Smallholder inclusion requires pooled services. Cooperatives, mills, local governments, and digital platforms can aggregate farm records, remote-sensing evidence, fertilizer information, and training. Public or blended finance should cover initial mapping and verification where global buyers demand the information. Data minimization and privacy protections are important because traceability systems can otherwise shift power toward lead firms without strengthening farmers' bargaining position [53,55-57].

For trade policy, the main implication is that environmental due diligence should be development-sensitive and performance-oriented. Rules should target demonstrable environmental harm, recognize verified improvement, provide transition periods and technical assistance, and avoid discriminatory assumptions that are weakly connected to current practice. A fair rule may be demanding, but it must be proportionate, evidence-based, and open to equivalent methods from producer countries.

The research agenda should move from debate about whether LCA is biased to empirical testing of where, how much, and for whom methodological choices matter. Comparative studies could recalculate the same palm-oil system using alternative land histories, allocation rules, regional datasets, and responsibility frameworks. Distributional analysis could estimate compliance costs for estates, scheme smallholders, and independent smallholders. Participatory studies could test whether proposed indicators are understandable, verifiable, and useful to affected communities

Conclusion

Life cycle assessment remains one of the most valuable tools available for improving environmental performance across complex supply chains. The problem is not the existence of LCA, nor the legitimate expectation that palm oil and other commodities reduce greenhouse-gas emissions, protect biodiversity, and become more transparent. The problem arises when methodological choices with substantial distributional consequences are treated as neutral facts, producer-country data are structurally underrepresented, and affected communities have little influence over the rules that shape their market access.

The Indonesian palm-oil case shows why a more careful architecture is necessary. Land-use history, plantation age, soil type, yields, effluent treatment, co-product use, and smallholder capacity vary widely. A single default narrative cannot represent this diversity. Strong treatment of recent deforestation should coexist with clear differentiation of replanting, degraded-land pathways, methane capture, renewable-energy recovery, and verified productivity improvement. This is not preferential treatment; it is better classification.

The article's central proposal is Development-Just LCA. Its core principles are procedural co-governance, local data sovereignty, geographical and temporal representativeness, symmetric system boundaries, transparent uncertainty, coherent treatment of national and product claims, distributional incidence reporting, and safeguards for the right to development. These principles would make LCA more contestable and representative while preserving common rules and environmental rigor.

For Indonesia, priority actions include establishing a national LCA data and methods platform, integrating product-footprint information with national inventory and traceability systems, creating stratified palm-oil datasets, financing methane capture and smallholder measurement, and strengthening representation in international standard-setting bodies. Producer-country institutions should be able to generate authoritative evidence rather than merely respond to external defaults.

For importing jurisdictions, lead firms, standard setters, and financial institutions, fairness requires accepting robust local data, sharing transition and verification costs, disclosing the basis of downstream claims, and providing accessible review mechanisms. Environmental ambition will be more durable when producers see that improvement changes their score, that verified mitigation receives balanced recognition, and that compliance does not become a mechanism of exclusion.

A fairer LCA is ultimately not a concession to the Global South. It is a condition for scientific credibility and effective global sustainability governance. When the people and countries that produce traded commodities can participate in defining evidence, contest assumptions, and share the benefits of improvement, life-cycle assessment becomes better able to guide genuine decarbonization, protect ecosystems, and support development within ecological limits.

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