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Original Article

Integrated Palm Oil Production Systems: Navigating Complexity from Upstream Cultivation to Downstream Value Creation in the Sustainability Era

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ABSTRACT: *This review of qualitative literature addresses the complexity of oil palm (Elaeis guineensis) as an integrated upstream to downstream production system. The analysis synthesizes recent scholarly evidence (2020-2025) on how vertical and horizontal integration mechanisms, silvopastoral livestock-crop co-management strategies, and supply chain governance arrangements interact with ecological carrying capacity and economic profitability imperatives. It also identifies three foundational dimensions of complexity: structural multidimensionality relating to economic, ecological and institutional domains; actor heterogeneity giving rise to asymmetric power relations and issues of value distribution; and emergent system properties that cannot be predicted from its individual components. Critical insights show that integrated systems, especially livestock–crop co-management and Special Economic Zone clustering, provide pathways in this direction by reducing chemical dependence. There are diversification of farmer livelihoods and capture value downstream, but significant barriers remain. These issues include issues of fragmented governance across RSPO, ISPO and MSPO certification schemes, mechanisms for smallholder inclusion being inadequate as well as unresolved trade-offs between profitability driven by expansion while at the same time fulfilling ecological conservation mandates. The synthesis feasibility itself illustrates how the downstream industrialisation strategy of Indonesia, which aims for 200 derivative products by 2030 generates opportunities to add value but also risks further marginalising seven million small holders who account for 40% supply (Aquila et al., 2023). The review closes with evidence-based policy recommendations that highlight consolidated governance frameworks, differentiated smallholder support mechanisms and landscape-level integration 'sustainable intensification' approaches that reconcile productivity goals with sustainability imperatives.*

KEYWORDS: *Oil palm integration, Silvopastoral systems, Supply chain governance, Ecological carrying capacity, Downstream industrialization, Smallholder inclusion, Sustainability certification, RSPO, ISPO, Circular economy.*

JEL CLASSIFICATION: **Q01, Q13, Q56, Q57, O13, O14, L73**

1. INTRODUCTION

1.1. BACKGROUND: THE STRATEGIC IMPERATIVE OF PALM OIL INTEGRATION

The oil palm (Elaeis guineensis) has transitioned from a mere plantation commodity to the largest single source of vegetable oils in the world, meeting 35.5% of total global demand for vegetable oil with only 19 million hectares less than 10% of the area planted globally to all oilseeds. This astonishing efficiency in land use, producing 7.5 times as much oil per hectare than soybeans and 4.7 times more than sunflowers, fuels the commodity's position in global food, feed and industrial markets. The giants of production Indonesia and Malaysia together account for 84.4% of global output, while Indonesia is responsible for 54.7% of world supply and $26.66 billion worth of crude palm oil (CPO) export revenues in 2021 (Utzinger et al., 2023). The sector's economic importance, however, is not limited to trade figures; it directly employs six million workers and supports eleven million livelihoods across the value chain, making it Indonesia's principal employer in agricultural industries [1].

This transition from monoculture plantation systems to integrated production architectures is a virtues paradigm change for the industry. Historically, oil palm expansion has also been characterized by intensive monoculture models that externalize ecological costs and seek to maximize short-term yields. But growing pressures including climate change impacts, disease outbreaks, and regulatory frameworks such as the European Union Deforestation Regulation (EUDR) and sustainability certification requirements have catalyzed innovation toward integrated systems. The Indonesian government has actively pursued this transition in conjunction with downstream industrialization policies focused on 200 palm oil derivative products by 2030 and Special Economic Zones (SEZs) as integrated complexes that cluster both upstream productions alongside midstream processing as well as downstream manufacturing. Some examples of SEZs include Sei Mangkei in North Sumatra and MTBK Kalimantan, where the hub-and-spoke model is illustrated with large mills as pillars for industrial ecosystems consisting of input suppliers, oleochemical manufacturers, and bioenergy creators [2].

At the same time, silvopastoral integration that integrates grazing livestock into plantation management has arisen as a climate-smart agricultural practice solving multiple sustainability dimensions at once.[4] Targeted grazing systems, in which naked cattle herds are mobbed through plantation blocks as an organic means of regulating weeds, have been shown to decrease herbicide use by 80% or more, while also sequestering carbon and diversifying farmer incomes. This integration positively impacts nine of seventeen UN Sustainable Development Goals (SDGs), including poverty reduction, food security and climate action. Downstream industrialization, supply chain integration, and ecological intensification via livestock co-management converge into a complex adaptive system in which decisions made at one node produce cascading effects throughout the value chain [3].

1.2. RESEARCH URGENCY: GOVERNANCE FRAGMENTATION AND EQUITY CHALLENGES

Although it has made some strides toward integration, the palm oil industry faces serious governance challenges that detract from sustainability goals. Regulatory fragmentation among various jurisdictions national standards (Indonesian Sustainable Palm Oil/ISPO, Malaysian Sustainable Palm Oil/MSPO), international certification (Roundtable on Sustainable Palm Oil/RSPO) and import market regulations (EUDR) results in compliance confusion and disproportionately burdens smallholders. Hundreds of millions of smallholders (7 million farms covering 40% of global oil palm area) have almost no support in navigating these overlapping requirements and only capture a tiny fraction of the value they generate. Estimates from meta-analyses indicate that certification produces around 10% income benefits for smallholders, yet these findings are unreliable without existing institutional support as well as secure land tenure and collective action mechanisms [4].

Equity concerns are further magnified by the asymmetric power relations that exist within supply chains. Downstream value is absorbed by large plantation companies and integrated downstream processors in oleochemical production, where added value can achieve 1,000% over raw CPO prices (Goh in Arocha et al., 2011), while smallholders are price-takers at the farm-gate. Such profit displacement can lead to an environmental compliance gap, since financial incentives are relatively weak compared with the pressures (from traders and increasing demands for land) faced by small holders to expand onto marginal lands or abandon sustainable practices. While potentially beneficial for forest protection, the EUDR's strict traceability requirements have the potential to alienate smallholders altogether from European markets unless significant investments in capacity are made [5].

Ecologically, the sector is on the edge of planetary boundaries. Oil palm expansion accounts for 6-17% of global anthropogenic emissions from land-use change, with Indonesia and Malaysia emitting approximately 340 and 105 teragrams carbon (C) yr−1, respectively, due primarily to activities related to deforestation. Conversion of tropical forests to plantations leads to declines in eleven out of fourteen ecosystem functions, including carbon storage, water regulation and maintenance of biodiversity. Integrated systems provide avenues to minimize such effects, but the underlying conflict between profit from expansion versus ecological carrying capacity has yet to be reconciled. On top of this, climate change is exacerbating it, with projections on yield penalties due to changed rainfall patterns and increased susceptibility to disease jeopardizing long-term sustainability [6].

1.3. RESEARCH OBJECTIVES

This qualitative literature review addresses three primary objectives. First, it analyzes the structural complexity of palm oil as an integrated production system, examining how vertical integration, horizontal coordination, and silvopastoral practices interact within multi-level governance frameworks. Second, it explores the dynamic relationship between ecological carrying capacity and economic profitability, identifying trade-offs and synergies across different integration models. Third, it evaluates the role and challenges of smallholders within integrated supply chains, assessing inclusion mechanisms and distributional outcomes.

Specifically, the review aims to: (1) identify critical factors enabling or constraining system integration; (2) analyze the contribution of palm oil-livestock integration to environmental and socio-economic sustainability; (3) assess impacts of integrated production on regional and national economies; (4) evaluate the effectiveness of certification and governance frameworks in promoting upstream-downstream integration; and (5) formulate evidence-based policy recommendations for enhancing sustainability across the integrated value chain.

2. LITERATURE REVIEW

2.1. PALM OIL AS AN INTEGRATED PRODUCTION SYSTEM

2.1.1. CONCEPTUALIZING INTEGRATED PRODUCTION ARCHITECTURES

Integrated production systems of oil palm involve vertical coordination at the cultivation, processing and manufacturing stages, horizontal cooperation among similar actors, and ecological integration through diversified management themes that are intertwined. Vertical integration can take many forms, from upstream-only operations that specialize in fresh fruit bunch (FFB) production to fully integrated models where companies exercise control over breeding; plantation management; milling and refining; and downstream derivative manufacturing. At the opposite end of the spectrum, there are intermediate cases such as nucleus-plasma arrangements, which usually involve large plantations (intis) offering technical assistance and guaranteed

purchasing to surrounding smallholder farmers (plasmas), thereby enabling integration through contract rather than ownership consolidation [7].

The transition from monocultural paradigms to integrated systems recognizes that externalized social and environmental costs weaken the sustainability of an entire sector in the long run. However, newer approaches integrate cycle economy practices valorizing waste streams (empty fruit bunches (EFB), palm oil mill effluent (POME) and fronds) into renewable energy, organic fertilizers and biomaterials. Industry 4.0 technologies, such as Internet of Things (IoT) sensors in precision agriculture or blockchain for supply chain traceability enable increasing integration by minimizing information asymmetries and allowing real time coordination [8].

2.1.2. VALUE CHAIN ARCHITECTURE AND GOVERNANCE STRUCTURE

The oil palm value chain has three main stages which have different technical and economic characteristics. Upstream activities include the breeding of seeds, managing nurseries, establishing plantations and harvesting fresh fruit bunches (FFB). It is labor-intensive, geographically fragmented, and dominated by smallholders managing 40% of cultivated area globally. Midstream processing refers to the transformation of FFB into crude palm oil (CPO) and palm kernel oil (PKO) via milling operations which are capital-intensive and technologically demanding, thus possessing inherent economies of scale that favours large integrated processors [9].

Once produced, CPO is then converted in four pathways (down-stream manufacturing). The major product pathways are oleofood [cooking oil, margarine and specialty fats], oleochemicals [biosurfactants, cosmetics and bioplastics], bioenergy [biodiesel and aviation fuel] and biomass valorization [animal feed and biochar]. Value added through oleochemical processing can be as much 1,000% higher than that of raw CPO and powerful incentives for vertical integration exist. However, this value capture is concentrated among large processors while excluding smallholders from downstream participation [4].

Governance along this fractured chain requires multiple layers of institutions. In Indonesia, for example, there are mandatory laws (ISPO) alongside an international certification (RSPO), and in Malaysia a new one MSPO was introduced to fill the gap between a regulatory system and voluntary CSR compliance. The version 4.0 (which would be enforced from the year 2024) of RSPO's Principles and Criteria encompasses no deforestation; peatland protection, and Free, Prior, Informed Consent (FPIC) principles whereas ISPO lays emphasis on greenhouse gas mitigation as well as identification of areas with High Conservation Value (HCV). This multiplicity exacerbates compliance burdens, especially on smallholders that lack the means to accommodate diverging audit requirements [10].

2.2. PALM OIL-LIVESTOCK INTEGRATION: SILVOPASTORAL SYSTEMS

2.2.1. PRINCIPLES AND MECHANISMS OF SILVOPASTORAL INTEGRATION

Silvopastoral integration targets some grazing—using livestock to achieve particular goals in vegetation management—of oil palm plantations. Cattle herds, which average 30-35 animal units per 125 hectares, are rotated about every three days through plantation blocks on top of manure disposal, as weed and understory vegetation that would be removed by herbicide application is consumed. Through this biological control mechanism, glyphosate-based herbicide application is reduced from approximately 75 spray cycles in a 25-year plantation cycle to only around 15 cycles, yielding cost savings of MYR 300,000-600,000 per year for every single plantation at the scale of 2,200 hectares [11, 12].

Weed control is maximized in mixed-species grazing systems that include cattle (grass grazers) with goats or sheep (browsers), to target both herbaceous and woody understory plants. These synergetic ecological advantages are derived from the fact that livestock waste contributes nitrogen and organic matters to the soil, improving nutrient cycling and carbon sequestration; decreased input of chemicals facilitates biodiversity through protection of beneficial insects and soil organisms; moreover, trampling incorporates organic debris into topsoil, which speeds up decomposition and restoration [3].

2.2.2. CONTRIBUTION TO SUSTAINABLE DEVELOPMENT GOALS AND RURAL LIVELIHOODS

Integration of palm oil and livestock directly supports nine Sustainable Development Goals (SDGs). Diversified incomes and local protein production support SDG 1 (No Poverty) and SDG 2 (Zero Hunger). SDG 3 (Good Health) is realized with reduced exposure to pesticides and better nutrition. Employment generation in grazing management and fairer value spreads contribute to SDG 8 (Decent Work) and SDG 10 (Reduced Inequalities) advancement. SDG 12 (Responsible Consumption), SDG 13 (Climate Action), and SDG 15 (Life on Land) derive from chemical application reduction, carbon sequestration, and biodiversity protection [13].

From an economy perspective, integration leads to new business models. The income from targeted grazing is separated from the traditional livestock revenue stream as contractors provide services in vegetation management to plantations for fees. This service-oriented approach creates demand for skilled labor that is not just limited to plantation activities based on the understanding of plant physiology, grazing management and animal handling; it also offers professional development paths

beyond manual plantation work [4]. Livestock act as a financial buffer for smallholders during periods when CPO prices tend to fluctuate significantly [14, 15, 16].

2.2.3. IMPLEMENTATION BARRIERS AND RISK FACTORS

They confirm silvopastoral integration benefits, but … Some of the technical challenges include balancing nutrient competition between oil palms and forage, and managing risks of soil compaction as a result of livestock trampling, in addition to disease transmission most notably Ganoderma boninense (basal stem rot) that could be facilitated via soil disturbance. Proximity to optimal management through precise control of stocking density, scheduling of rotations and selection of species according to local soil type and topography, is possible [17, 18].

Adoption is further constrained by social and institutional factors. Managing livestock requires skills and time investments that most smallholders, who are already resource-constrained, cannot afford. Such risks lead to psychological and economic costs, largely concentrating in geographies where property rights enforcement is weak because of the threats in its enforcement environment including theft or trespassing. Traditional farmers have limited awareness of the benefits of targeted grazing in addition to insufficient support from policy such as financial incentives, training subsidies, and livestock access credit. Such issues of scale and speed explain why, even given clear benefits, silvopastoral integration is so under-utilised across the 19 million hectares of oil palm cultivated in Southeast Asia [19, 20].

2.3. REGIONAL ECONOMIC CONTRIBUTION: MACRO AND MICRO IMPACTS

2.3.1. MACROECONOMIC SIGNIFICANCE AND DOWNSTREAM INDUSTRIALIZATION

The palm oil industry operates as the leading engine of economic expansion in Indonesia and Malaysia, providing a large share of GDP, export revenues, and jobs. In 2021, Indonesia's CPO exports alone contributed to $26.66 billion, while when combined with CPO derivatives reached $36.2 billion—this is equivalent to 19% of the national state budget. The industry directly employs 6 million workers, with an additional 11 million livelihoods dependent indirectly through input supply, logistics, processing and distribution activities [2].

Downstream industrialization is Indonesia's strategic answer to raw commodity dependency. Aiming for 200 derivative products of palm oil by 2030, the government is focused on adding value via oleochemicals, specialty fats and bioenergy. Long-standing, targeted Special Economic Zones (SEZs) are used as experimental implementation kraks, where upstream production is concentrated near midstream downstream facilities in a manner that reduces transaction costs and can enable knowledge spillovers. As of 2024, Indonesia’s palm oil-based special economic zones (SEZs) attracted a cumulative investment of IDR 21.9 trillion and created 6,247 jobs directly, with KEK Sei Mangkei upending IDR 5.4 trillion in downstream export value in 2023 alone. AHP studies reveal six significant policy variables of downstreaming: tax incentives, SEZ developments, plantation productivity enhancement, FFB pricing unequalization (favorable) for the smallholders, agro industrial financing and integration between upstream and downstream [7].

2.3.2. SMALLHOLDER MICROECONOMICS AND VALUE DISTRIBUTION

Smallholders manage 40% of global oil palm area (13 million ha) on around seven million farms, but appropriate small value shares. Most farm on 1–2-hectare plots and make $100-150 per hectare a month, so they are extremely vulnerable to CPO price fluctuations. Difficulties obtaining the marketplace means many sell through collectors and traders, lessening bargaining power and price transparency. Downstream value is extracted through oleochemical manufacture of products by vertically-integrated processors and larger plantations [21], while smallholders continue to be locked out of highly lucrative segments.

Certification has the potential to improve income but achieves mixed results. Meta-analyses of 30 studies show that certified smallholders earn about 10% higher incomes (7–13% confidence intervals). But these gains need institutional support, secure land tenure and collective action conditions that are often lacking. One of the best examples to highlight here is Thailand's cooperative-NGO partnership model, which successfully achieved a 66% scaling outcome for RSPO certified area from 2022-2024 when supporting 9,000 smallholders. In contrast, Indonesia's fragmented policy landscape, land tenure uncertainty and limited extension services make for less progress. While innovative corporate initiatives like Cargill's engagement with 26,400 smallholders in virtually all (95%) third-party supply chains are encouraging [22], they fall short of filling systemic inclusion gaps.

2.4. ECOLOGICAL CARRYING CAPACITY AND PROFITABILITY RELATIONS

2.4.1. CONCEPTUALIZING ECOLOGICAL CARRYING CAPACITY IN OIL PALM SYSTEMS

The term ecological carrying capacity describes the ability of any ecosystem to regenerate and absorb waste without causing functional change. In oil palm settings, this includes carbon sequestration, water regulation, nutrient cycling and maintenance of biodiversity. Converting tropical forests to plantations impairs eleven out of fourteen ecosystem functions, most strikingly carbon storage, habitat connectivity and hydrological regulation. Carbon payback times the time needed for oil palm carbon sequestration to counteract emissions arising from land clearing typically range from 15–30 years depending on baseline land use, with peatland conversion emissions persisting over centuries due to slow decomposition of deep stores of carbon [23].

This helped quantify these impacts, and they show that this sector has a large footprint when it comes to the climate. Oil palm expansion accounts for 6–17% of global anthropogenic land-use change emissions, with Indonesia and Malaysia alone contributing 340 (Indonesia) and 105 teragrams (Malaysia) of carbon per year from deforestation-related activities. Though plantations sequester about 10-15 tons of CO2 per hectare per year, they do not replace around 200-400 tons of CO2 per hectare worth of carbon that was stored in the original forests. These ecological limits produce essential conflicts with the profitability imperatives driving expansion [1].

2.4.2. TRADE-OFF ANALYSIS: ECONOMIC EXPANSION VS. ECOLOGICAL CONSERVATION

The cultivation of oil palm presents a fundamental economic-ecological trade-off. The commodity's unrivaled land-use efficiency producing 7.5 times as much oil per hectare as soybeans means that the economic incentives for expansion are extremely powerful. Profitability of between 15-25% per annum is manifestly attractive and with CPO prices above USD1,000 per ton significant investments are now being made. But those returns come partly from externalizing environmental costs. Timber extraction and capturing the land value for deforestation clearing yield profits quasi instantly, while ecological damage carbon release, biodiversity loss, or potential water contamination unfolds over decades in a socially lucrative way transfer to generations far beyond one's time horizon [1].

It also incentives expansion as CPO prices fluctuates. As prices rise, marginal land an area adjacent to forest is treated as economically viable for conversion. In contrast, during low-price periods intensification incentives are reduced to sluggish the take-up of productivity-enhancing technologies on existing land. These dynamic produces twisted incentive structures in which ecological sustainability hinges upon commodifying price controls, or regulatory intervention [2].

Integration offers potential mitigation pathways. Well managed silvopastoral systems can also lead to net-positive carbon balance through enhanced cycling of organic matter and a lower dependency on chemicals. Agroforestry integration mixing oil palms with fruit or timber trees enhances carbon sequestration, and diversifies production. Valorizing plantation biomass in circular economy approaches biogas from EFB, biochar from fronds minimizes waste-related emissions in emission hotspots while displacing fossil fuels. However, such practices demand significant management skill and capital investment alongside institutional support, which remains out of reach for many smallholders [3].

Long-term sustainability of the sector will necessitate the scaling up of production on degraded lands instead of more forest conversion. The total global potential for developing up to 300–500 million hectares of degraded land as sustainable oil palm without any further conversion of forests. But bringing this potential to fruition has to be driven by policy intervention, through land zoning, tenure security and targeted investment which are all too often insufficient across even the most productive regions. Approaches of integrating land-use at the landscape level that allocate regions for strict conservation, sustainable production, and restoration provide the conceptual frames to reconcile productivity with ecosystem goals [23], but their implementation is limited.

2.5. INTEGRATED SUSTAINABILITY PRACTICES: CERTIFICATION AND CIRCULAR ECONOMY

2.5.1. CERTIFICATION FRAMEWORKS AND GOVERNANCE STANDARDS

Three primary certification schemes govern sustainability practices across the global oil palm supply chain, each reflecting distinct governance philosophies [24].

RSPO (Roundtable on Sustainable Palm Oil) represents a global multi-stakeholder platform where producers, processors, traders, consumer goods manufacturers, retailers, and NGOs jointly establish standards. RSPO's Principles and Criteria version 4.0 (2024) comprises eight principles: transparency, compliance with law, rights and responsibilities, sustainability of natural resources, environmental responsibility, responsible employees and relations, responsible development of new plantings, and commitment to continuous improvement. Certification covers production, milling, refining, and supply chain custody, with annual audits by independent third parties. RSPO certification covered 2.3 million hectares in Indonesia as of 2021, though substantial expansion remains necessary [25].

ISPO (Indonesian Sustainable Palm Oil) functions as a national mandatory standard, legally required for all Indonesian oil palm producers since 2021, regardless of certification status. ISPO emphasizes greenhouse gas mitigation, the identification and protection of high conservation value (HCV) areas, and biodiversity conservation, integrated into plantation management plans. Compliance monitoring is conducted by government agencies, though enforcement variability across regions remains problematic. ISPO compliance theoretically guarantees baseline sustainability, though critics note that mandatory standards sometimes set minimum requirements rather than transformative sustainability leadership [24, 26].

MSPO (Malaysian Sustainable Palm Oil) establishes Malaysia's national standard, is increasingly recognized internationally, and is gaining market acceptance as companies seek supplier diversification. MSPO emphasizes environmental protection, social responsibility, and sustainable management, with standards comparable to international schemes, though tailored to the Malaysian context [24].

The coexistence of RSPO, ISPO, and MSPO creates compliance complexity. Smallholders navigating certification requirements face costs of $5,000-10,000 per group for the initial audit and documentation, plus annual surveillance costs—prohibitive for farmers earning $1,200-1,800 per hectare annually. Audit interpretations vary across certifiers, creating confusion regarding the application of the criteria. This fragmentation represents a structural barrier to smallholder inclusion, contradicting sustainability objectives emphasizing equity and livelihood improvement [22, 27].

2.5.2. CIRCULAR ECONOMY AND BIOMASS VALORIZATION

The palm oil industry produces enormous biomass: empty fruit bunch (EFB), fronds, trunks and kernels, all of which have commercial value when processed properly. Usual habits incinerate or otherwise misapply most of this potential. Zero-waste ambitions from circular economy approaches are achieved by cascading biomass across many value chains [8].

Streams of EFB and POME are especially useful. POME—the nutrient-dense effluent from the extraction of crude palm oil (CPO) is anaerobically digested to generate biogas, supplying methane which substitutes fossil fuels for generating electricity and heat. Well-designed POME treatment contributes to the elimination of environmental contamination while generating renewable energy; ways in which managing integration with all refining operations further decreases emission by a full cycle of production may lead to reductions up 804,946.60 tons CO2 emissions. Whereas in the case of EFB fibers, these are transformed into bioplastics, biochar (a soil enhancer with carbon sequestration potential) or cellulose-based materials for construction and packaging [28].

These cascades are increasingly optimized by Industry 4.0 technologies. Utilizing artificial intelligence and machine learning algorithms to address these complex multi-objective optimization problems, pre-treatment biomass allocation pathways are identified that maximize economic value at the same time as minimizing waste and emissions. IoT sensors allow for seamless monitoring of fermentation processes, quality parameters, and environmental compliance in real time so that the management can respond accordingly. Blockchain distributed ledger technologies (DLTs) help establish transparent records and traceability on biomass flows and their derived products of origin, potentially substantiating market premium claims for circular products [29].

But the technological complexity and capital requirements involved can exclude smallholders. Circular economy benefits accrue to large integrated processing facilities that dominate midstream and downstream operations, while smallholders remain primary input providers without participation in value-added processing. This concentration torpedoes asymmetries of value distribution across the wider supply chain [5].

2.6. PALM OIL SUPPLY CHAIN INTEGRATION AND SMALLHOLDER INCLUSION

2.6.1. HUB-AND-SPOKE MODELS AND SPECIAL ECONOMIC ZONE CLUSTERING

Hub-and-spoke architectures are becoming increasingly common for modern supply chain integration, which sees major mills (hubs) at the center of industrial ecosystems consisting of input suppliers, processing firms and logistics service providers (spokes). This clustering is formalized via Special Economic Zones (SEZs), which provide tax breaks, infrastructure building and regulatory concessions for concentrated industrial growth [9].

The SEZ strategy of Indonesia offers an example of this model. They include KEK Sei Mangkei in North Sumatra, which groups 37 business entities around CPO mills, refineries, oleochemical producers and renewable energy businesses. In 2023, the zone reached a downstream export value of IDR 5.4 trillion, with value creation collocated near processing plants. In Kalimantan and eastern regions, similar models are also at work, but implementation can struggle due to poor infrastructure, challenges in financing and the vast size of the SEZs which makes it difficult for small-scale farmers to be integrated effectively into supply chains [2].

Geographical clustering also lowers costs associated with transaction through shared infrastructure (such as ports, rail, utilities), knowledge spillovers from co-located competitors and suppliers and simpler supply chain coordination. Instead, large mills negotiate directly with smallholder groups rather than individual farmers, reducing transaction costs and improving quality consistency through collective accountability mechanisms. Formal supply contracts define criteria for FFB quality (e.g. ripeness, moisture and cleanliness), delivery schedules and prices, thus providing stability to parties [21].

Yet SEZ models pose the risk of marginalizing smallholders who cannot participate economically. Smallholder groups need formal registration, adherence to technical standards and regular supply volumes a condition difficult to achieve for small farmers spread across marginal lands. With SEZ participation dominated by large plantations that capture downstream value while smallholders, in contrast, remain upstream suppliers. This geospatial and economic concentration could worsen regional disparity without intentional inclusionary mechanisms being established [4].

2.6.2. INSTITUTIONAL BARRIERS AND POLICY FRAGMENTATION

Structural issues related to fragmented governance, tenure insecurity and low institutional support present challenges to integrating formality into smallholder supply chains. Ambiguity of land tenure is a fundamental challenge. Indonesia's patchwork of property rights, history of land tenants and grand legal reforms combined with aimless registration practices historically produced overlapping, sometimes contradicting claims on millions of hectares. If they do not hold a clear title, smallholders are unable to access bank credit, take part in formal contracts or become eligible for certification programs which require collateral [10].

Policy fragmentation compounds these barriers. Coordination on ISPO compliance and provincial sustainability regulations with local government environmental mandates is often lacking, leading to confusion over applicable rules and expectations for enforcement. Smallholders are required to meet national mandatory standards (equivalent of ISPO,) international voluntary standards (RSPO) when selling for premium markets and other additional increasingly corporate procurement policies. Each requirement requires independent documentation, audits, and fees squandering resources and attention disproportionately for small producers [10].

Extension services so vital for technology transfer and capacity building is weak across smallholder domains. Historical underfunding of public extension systems has led to further contractions in the face of decentralization and budget constraints. Although private-sector extension services are increasing in number, they focus around mill facilities and plantation operations near large holders, with little service to distant smallholders. The lack of information entails low-productivity management practices and hampers the adoption of better methods such as fertilizer efficiency, pest control, or silvopastoral integration that can boost profitability and sustainability at the same time [20].

Access to financing is another key constraint. The highest borrowing costs (10-15%+ interest rates), limited availability of credit, and collateral requirements that is hard to meet given tenure insecurity now known by smallholders. Although some cooperative financing schemes have been developed, they are insufficient to provide the extent of modernization investments irrigation, improved inputs and livestock purchases for integration to meet demand. Such finance gaps anchor smallholders into a low productivity trap and block transitions to higher-value, more integrated systems [20].

3. METHODOLOGY

3.1. QUALITATIVE LITERATURE REVIEW APPROACH

This is a qualitative rather than systematic literature review, focusing on thematic synthesis and conceptual integration rather than meta-analytic aggregation. Qualitative literature review allows for an exploratory inquiry into narratives, frameworks and theoretical contributions across different literatures academic journals, policy documents, institutional reports and practitioner knowledge without strict compliance with pre-defined protocols which constrain discovery [1].

The method emphasizes interpretive synthesis, mapping patterns, tensions and emerging concerns in selected sources rather than conducting an exhaustive review of all potentially relevant literature. This allows for engagement with context-specific knowledge that is especially important to inform Indonesian palm oil governance, smallholder practices, and regional economic development effects [3].

3.2. LITERATURE SEARCH STRATEGY AND SOURCE SELECTION

Source selection followed purposeful sampling that targeted publications addressing the multidimensional aspects of palm oil integration from several disciplinary perspectives, specifically sustainability science, development economics, supply chain management and environmental and policy analysis. The search was conducted through academic databases (Scopus, ScienceDirect, Google Scholar) and institutional repositories (BAPPENAS, Indonesian Ministry of Industry, RSPO secretariat, Malaysian Palm Oil Board) utilizing keyword combinations including "palm oil integrated production," "oil palm livestock integration," "supply chain governance," "ecological carrying capacity" as well as "downstream industrialization", etc. [1].

Inclusion criteria included peer-reviewed articles published in recognized academic journals and reputable institutional reports, yielding wealth of literature published from 2020 to 2025; with an emphasis on more recent scholarship demonstrating contemporary sustainability science and policy issues. Recent articles were added to landmark pre-2020 publications foundational for both conceptual frameworks (analysis of carbon balance, quantification of ecosystem services, smallholder economics) where necessary for context in the historical literatures [23] using data up until October 2023.

Journals indexing in Scopus Q1-Q4 journals were prioritized for source selection within the domain trustworthiness, allowing for rigorous analysis whilst taking diverse views from high-impact multidisciplinary journals (e.g., Frontiers in Sustainable Food Systems) to specialty publication genre (CABI Agriculture and Bioscience, Journal of Agriculture and Environmental Ethics). Indonesian-language government documents and institutional reports provide a balance to the English-language scholarship [2], which allows Indonesian policy contexts and regional perspectives to be represented comprehensively.

3.3. ANALYSIS AND SYNTHESIS PROCESS

Thematic coding allowed data to be grouped into conceptually meaningful codes that captured the goals of the research. Inductive codes were drawn from the content of sources mechanisms of integration, equity barriers, governance effectiveness, and ecological impacts while deductive codes derived from pre-established analytical frameworks (value chain analysis trade-off analysis; institutional analysis). Similarities and differences across integration models, stakeholder groups, and geographic contexts were identified through cross-case comparison. Causal chain mapping linked upstream management practices, midstream processing decisions, downstream product development, and final ecological and economic outcomes [5].

Critical appraisal evaluated quality of evidence, identified moderators and limitations, and stressed gaps in current literature. Narrative synthesis created coherent narratives of complex system dynamics, tension among competing goals (expansion versus conservation, profit versus equity), and possible paths toward more sustainable integrated systems [3].

3.4. VALIDITY AND TRUSTWORTHINESS

Triangulation across source types combining academic research, policy documents, industry reports, and statistical data strengthened findings and provided multiple perspectives on contested issues. Triangulation across stakeholder viewpoints incorporating government, business, smallholder, NGO, and academic perspectives mitigated potential bias toward particular interests. Temporal triangulation, examining historical evolution from 2000-2025, contextualized contemporary developments within longer-term trends [22].

Reflexivity statements acknowledged the author's positionality as an Indonesian researcher with a specialization in sustainability and applied linguistics, recognizing potential biases toward smallholder advocacy and toward regional context. Deliberate effort to represent diverse viewpoints, including perspectives from agribusiness constituencies and market-oriented development advocates, balanced this orientation.

4. FINDINGS: THEMATIC SYNTHESIS

4.1. THE MULTIDIMENSIONAL COMPLEXITY OF INTEGRATED PALM OIL SYSTEMS

4.1.1. DEFINING COMPLEXITY WITHIN AGRICULTURAL VALUE CHAINS

Complexity in integrated palm oil systems manifests across four interacting dimensions. Structural complexity reflects the multiplicity of interconnected actors, institutions, and technical processes spanning from seed development through consumer product formulation. Economic complexity emerges from value chains generating revenues exceeding $36 billion globally while internally distributing these revenues highly unequally, with smallholders capturing 10-15% of final consumer prices while large processors capture 40-50%. Ecological complexity involves non-linear feedback loops where upstream cultivation decisions (chemical inputs, land use, carbon stocks) determine downstream ecosystem capacity to regenerate resources and assimilate waste [4, 30, 31].

Institutional complexity arises from fragmented governance across multiple regulatory levels, competing certification standards, and weak enforcement mechanisms creating compliance confusion and opportunities for regulatory arbitrage. These dimensions interact synergistically: institutional fragmentation prevents unified environmental management, economic incentives drive expansion threatening ecological limits, and unequal value distribution undermines smallholder capacity to adopt sustainability practices [10, 32, 33].

4.1.2. ACTOR HETEROGENEITY AND ASYMMETRIC POWER RELATIONS

Acute heterogeneity exists among actors in palm oil systems. Large plantation companies (often in the form of multinational corporations) manage thousands of hectares with technical capacity, capital resources and access to markets. Medium-scale plantations (hundreds of hectares) take an intermediate position, occasionally integrated with processing facilities but overall, more capital light than multinational operations [3]. Smallholders, the smallest group by number of actors, farm on average 1-2 hectares with microcapitalization, limited access to technology and market information [9, 34, 35].

Such heterogeneity generates asymmetric power dynamics across supply chains. Large mills use their monopsony power to set FFB prices, aware that smallholders have limited marketing outlets. Input specifications and quality requirements established by plantation companies and integrated processors (types of firms that carry out the entire cocoa supply chain) must be met by smallholders without any technical support or notice given to standards being modified ahead of time. Larger operations have preferential access to credit, technology and extension information flows, reinforcing productivity differentials and income gaps [21, 36, 37].

Collective action in the form of cooperatives could, theoretically reduce power asymmetries, allowing smallholders to aggregate supply and share economies of scale with respect to input purchase economies of scale and collectively negotiate with mills. But cooperation is weak, often due to governance failures, elite capture, or improper organizational designs, and so limited in effectiveness across much of Southeast Asia. In multi-stakeholder cooperatives that do function, (as in Thailand's

RSPO-certified smallholder alliances), evidence of measurable changes to income and sustainability practice emerge [22, 38, 39].

4.1.3. SYSTEM EMERGENT PROPERTIES AND NON-LINEARITY

There is no system-level sustainability from individual plantation optimization. As one plantation adopts High Conservation Value (HCV) protection, reduces pesticide use, and improves worker welfare conditions, it may concurrently participate in landscape-scale deforestation through industry-wide expansion that fragments wildlife habitat and releases significant carbon stock. This emergent property where outcomes for the system as a whole cannot be anticipated based on component behaviors describes complex adaptive systems, such as integrated value chains [23, 40, 41].

Non-linearity further complicates management. Volatility in smallholder income arising from CPO delta price fluctuations of approximately ±50% year-on-year does not linearly map to livelihood stability; below specific income thresholds, farm households forgo sustainability practices and revert to subsistence-based survival strategies. Carbon sequestration trajectories in silvopastoral systems were determined to be non-linear as the primary benefits take time to accrue (average ca. 55% of total carbon received after year 10→25 years after livestock)–slowing significant accumulation. These fallacies mean that interventions which are effective at pilot scale might not provide proportionate results when applied universally [42, 43, 44].

4.2. INTEGRATION FORMS AND SUSTAINABILITY IMPACTS

4.2.1. VERTICAL INTEGRATION AND DOWNSTREAM VALUE CAPTURE

Vertical integration, in which plantation companies own or control processing facilities, fundamentally alters incentive structures and the distribution of value. Integrated companies secure downstream margins and therefore create more value in the aggregate system. Genus that integrates all the way from plantation to oleochemical production is able to optimize processing parameters that will meet desired qualities in final derivative product, capturing value lost by independent mills due to specification mismatches [5, 45, 46].

Vertical integration improves transaction costs and coordination of supply chain. Internal FFB flows bypass middlemen, lowering costs related to quality verification, transport and storage. A stable internal supply facilitates investment in specialization for processing machines and research capabilities on high-value derivatives. These quality consistency and traceability advantages over non-integrated competitors [47, 48, 49] arise for companies like Cargill or Asian Agri from extensive partnerships with smallholders along with owned processing capacity.

But vertical integration reduces the dispersion of value capture. Integrated processors are also dominating oleochemical and bioenergy production, where they have earned margins 1,000% the raw CPO value through fast value-add portfolio concentration. Smallholders, limited to upstream production, get commodity prices that take into account only the value of the primary product. Such concentration runs against sustainability goals that promote equitable value distribution and smallholder livelihood improvement [4, 50, 51].

4.2.2. SILVOPASTORAL INTEGRATION AND ENVIRONMENTAL CO-BENEFITS

When done correctly, livestock-crop co-management has many environmental benefits. Using targeted grazing removes up to 80% of herbicide use reducing contamination of the water systems (both underground and above ground) while also protecting beneficial soil organisms, increasing conservation in understory areas in plantations. Livestock dung sheds 100–150 kg of N Ha per year, lowering the need for synthetic fertilisers and subsequent GHG emissions [52, 53].

Carbon sequestration is an important ecological service. Known, healthy silvopastoral systems sequester 2-8 tons of CO2/ha/year via three mechanisms: reduced fossil fuel emissions (herbicide production & application), increased soil carbon storage and biomass generation for feed to livestock (displacing traditional feed that would otherwise need more land). Over a plantation cycle of 25 years, such differential sequestration could cancel out the land-clearing emissions in the beginning and achieve net positive carbon balance if it is applied consistently while not being stocked at excessive densities that cause soil degradation [54, 55].

Biodiversity improvements accompany chemical reduction. Reduced herbicide use allows understory vegetation to grow, which can provide habitat for insects, small mammals and birds that feed on plantation pests, offering biological control services. Integrated systems that maintain greater plant diversity result in overall biodiversity significantly exceeding that found in monocultures reaching levels of ecosystem services intermediate between plantations and natural forests[3, 56, 57].

But ecological benefits depend on sound management. Excessive stocking densities (>40 animal units per 125 hectares) pose an increased threat of soil compaction, which can impede water infiltration and root penetration, leading to degradation of plantation productivity. Disease transmission risks exist, for example, Ganoderma boninense (basal stem rot) may be spread via disturbance of sediments associated with livestock trampling. These risks demand technical knowledge of optimal stocking densities, rotation frequencies, and species selection by soil conditions—know-how lacking in most smallholders [48, 58, 59].

4.2.3. HORIZONTAL INTEGRATION AND COLLECTIVE ACTION

Horizontal integration collective action among farmers or processors, at similar value chain nodes has potential to also increase bargaining power and economies of scale. Cooperatives of farmers aggregating FFB from several smallholders can have volumes that are attractive to mills, and thus be settled in direct negotiation and lower transaction costs. Through bulk discounts, collectively purchasing inputs such as fertilizers, pesticides and seeds contributes to lower per-unit costs [21, 60, 61].

Certification alliances allow smallholders to obtain either RSPO or ISPO certification cooperatively, sharing the fixed cost of each audit and associated documentation across members of the group, so while it might cost U$1,000+ per on-farm audit for an individual grower, costs may decrease to between $50-200 (collective). The successful cooperative-NGO model of Thailand adopted an integrated support package that combines technical training, financing and collective marketing to scale RSPO certification from c. 0 to 9,593 smallholders in just 3 years [22, 62, 63]

But horizontal integration faces chronic hurdles. The bylaws, elaborate procedures for dealing with potential conflicts of interest and other safeguards are in place to allay the worst fears but co-operative governance difficulties—elite capture, mismanagement, benefit misappropriation—plague many collective institutions across rural Asia. Free-rider problems occur when members cannot benefit from collective efforts (like bulk purchasing or certification) and do not return to the mix of activities needed for the group. The geographic dispersion of smallholders adds to the transaction costs associated with collective meetings and coordination, in particular in remote areas [22, 64, 65].

4.3. ECOLOGICAL CARRYING CAPACITY AND PROFITABILITY DYNAMICS

4.3.1. QUANTIFYING TRADE-OFFS THROUGH CARBON BALANCE ANALYSIS

Carbon balance accounting crystallizes the relationship between the profitability of expansion and ecological sustainability. Forests are cleared for oil palm whose profits can be counted instantly, though timber sales and lower land-acquisition costs, and which emit 150-250 tons of CO2 equivalent per hectare through biomass burning and soil carbon release.[40] Then, oil palm plantations sequester around 10-15 tons CO2 per hectare annually [1, 41, 66].

This creates significant time-dependent opportunity costs. 12-20 years just to amortize emissions from land-clearing alone without even considering opportunity cost in lost forest carbon stocks (200-400 tons of CO2 / hectare for tropical forests) for a plantation sequestering 12 tons CO2 annually. From the climate impact standpoint, conversion can still be a losing proposition when plantations show positive sequestration, as cumulative carbon balances remain negative over multi-decadal timescales [1, 66, 67].

This time asymmetry creates twisted incentives. Investors earning 15-25% annual return on plantations could give a damn about carbon balance calculations over the next +25 years, they cash in and get out before the long-term impacts have come to full fruition. Market mechanisms carbon pricing might in theory align incentives, but existing prices ($10-20 per ton CO2) are too weak to counteract the driving force of expansion economics; for socioeconomic thresholds to fully cover ecological thresholds, prices would have to exceed $100 per ton [2, 41, 66].

4.3.2. ALTERNATIVE PATHWAYS: INTENSIFICATION VERSUS EXPANSION

Aligning with the expansion versus conservation tension, two major strategic pathways can be identified: increasing production on existing cleared land or expanding to degraded lands without primary forest conversion. Farm intensity intensification increases yield due to better technology, management practices and inputs on the plantation land that already exists and takes away pressure to have new land. 10Potential yield increases, by improved cultivars, precision fertilization and integrated pest management on existing plantations could realize a 30-50% productivity increase. This pathway retains the ecological functions of remaining forests, while achieving production growth [2, 66, 68].

However, intensification faces barriers. The adoption of technology involves capital investment and technical expertise that is beyond the means of many smallholders. Soil degradation caused by intensive management can ultimately result in a drop in yields and necessitate investments to restore ecological function. Intensification benefits are polarized in favor of large, commercial operations; smallholders often lack complements of resources or institutional support necessary for advanced practices [20, 69, 70].

Expansion on degraded lands is an alternative pathway that circumvents primary forest conversion. In total, 300-500 million hectares of degraded lands worldwide is still potentially suitable for sustainable oil palm cultivation. Improved management with organic amendments and silvopastoral integration can restore productivity on such lands and meet projected global demand growth (93–156 million tons by 2050) without further clearing of forests [1, 71, 72].

But this route is contingent upon intentional policy, which remains lacking throughout producing regions. It needs institutional capacity (and) land market reforms and investment capital which are beyond the means of many smallholders to identify, acquire and confidently obtain tenure for degraded lands. We are experts on various topics and have deep experience across sectors that span the government, nonprofits, academia, multilateral development banks and the private sector. In the absence of policy intervention directing expansion onto degraded lands, economic logic continues to mobilize remaining forests as the path of least resistance for land expansion [2, 73, 74].

4.3.3. INTEGRATION APPROACHES FOR SUSTAINABLE YIELD OPTIMIZATION

Frameworks are needed that can help reconcile contemporaneous productivity and conservation imperatives, such as integrated production systems. Landscape-level integration is an approach that transcends optimizing individual plantations into ecosystem levels, allocating strict conservation areas (High Conservation Value forests, peatlands), sustainable production (silvopastoral, agroforestry systems), and restoration (degraded land recovery) [23, 75, 76].

These approaches recognize that the long-term sustainability of systems requires keeping landscape-level ecological functions such as carbon holding, water regulation and biodiversity corridors in place while facilitating economic output. Based on the concepts of zoning, with enforcement mechanisms, community-based monitoring and benefit-sharing agreements can compromise otherwise competing goals. For example, Indonesia's Aceh province has implemented trials of landscape-scale planning which integrates protected forest reserves, production plantations and community-managed restoration areas, although implementation is still being finalized [23, 77, 78].

Carbon-smart agriculture is termed as the management practices that have been specifically designed to boost carbon sequestration while still maintaining productivity. In oil palm settings, this includes silvopastoral integration (integrated grazing that minimizes chemical emissions while adding carbon sinks), agroforestry (growing palms together with fruit or timber trees), and biomass valorization (taking plantation byproducts from waste to renewable energy and soil enhancers). Theoretically, well-designed carbon-smart systems could approach net-positive carbon balances, although achieving this potential requires significant management complexity and institutional support [8, 79, 80].

5. DISCUSSION AND ANALYSIS

5.1. SYNTHESIS: COMPLEXITY AS SYSTEMIC INTEGRATION CHALLENGE

Substantive complexity of integrated palm oil systems reflects fundamental tensions between economic logic driving expansion and ecological limits constraining sustainable intensification. Individual actors whether smallholders trying to maximize yields from small plot sizes or corporations seeking financial returns make locally rational decisions that result in collectively suboptimal outcomes. As smallholders are encouraged to adopt inputs in cash crops that can generate individual livelihood incentives, collectively this practice is speeding up the establishment of soil-deteriorating, chemical-dependent production economic models undermining ecosystem services. Driven by shareholder value, economically rational corporations pursue vertical integration and downstream diversification, concentrating value capturing in ways that exclude smallholders and exacerbate inequality [5].

Integration mechanisms vertical coordination, horizontal cooperation, silvopastoral co-management and SEZ clustering offer promising pathways toward more integrated systems with greater potential for local and collective optimization. Vertical integration allows for better alignment within supply chains, yet to be effective it necessitates a purposeful approach to ensure that best practices and mechanisms of integration do not omit the poorer producers. Horizontal cooperation through cooperatives and certification alliance increases smallholder bargaining power and cost efficiency but relies on supportive institutional environments and existing governance quality is generally low in a large part of Southeast Asia. Silvopastoral integration leads to lower chemical inputs and increased resilience, but requires management skills and institutional support arrangements that most smallholders lack [81, 82, 83].

Key take-away on integration dimensions is that none are in and of themselves resulting into sustainability; sustainability occurs from the simultaneous implementation across multiple dimensions within institutional context that enables smallholder inclusion and equitable sharing of value. On sustainability's behalf, a plantation that invests in workers' livelihood improvements while also being deforested on a landscape-level is an unsustainable one. Large integrated companies as certified sustainable producers profit at the expense of smallholders, undermining one of more equitable dimensions of sustainability. Working at the level of individual farms, livestock-crop integration produces environmental benefits but little economic viability. Smallholder livelihoods are mired in poverty [84, 85, 86].

5.2. ADDRESSING CORE RESEARCH QUESTIONS

The review’s core question: how does integration complexity mirrored and sought to address tensions between ecological carrying capacity and economic profitability? receives multi-faceted responses. First, the complexity of integration stems fundamentally from a paradox of productive efficiency in the commodity: highly efficient land-use creates economic logic for expansion that transcends ecological sustainability thresholds when implemented through continued conversion of forests.

Integration mechanisms are attempts to ease this constraint by enhancing productivity and profitability on existing land which in turn decreases the pressure to expand [3].

Second, integration only works if you have governance frameworks in place that account for environmental externalities. Market mechanisms alone even carbon pricing are inadequate; current carbon prices are orders of magnitude below those necessary to reverse the economics of forest conversion. Policy mechanisms need to actively steer expansion towards degraded lands, guard against further loss of forests and regulate sustainability standards. Indonesia's ISPO mandate and Indonesia-Malaysia-ASEAN regional coordination could provide institutional pathways, though fragmentation between RSPO, ISPO, and MSPO standards lessen their impact [24].

Third, smallholder inclusion is both a sustainability imperative and a stubborn challenge. In the transition to environmental sustainability, behavioral change among the seven million smallholders who manage 40% of global supply is essential; however, without livelihood concerns being met through institutional support and economic incentives for sustainable adoption little will happen. The gains of a sustainable transition must be shared broadly rather than concentrated in the hands of large operators' equity requires it. Existing integration models potentially marginalize smallholders through progressively stringent certification requirements, technology-intensive production modalities, and downstream value concentration [4].

Fourth, the review identifies that integration mechanisms themselves are still incomplete in terms of sustainability. Silvopastoral integration is associated with multiple co-benefits, but it remains to be adopted in <5 % of the potential plantation area because barriers, limiting implementation exist. Downstream industrialization then fogs up around large processors, with smallholders confined to upstream commodity production. SEZ clustering leads to economic development in a hub-and-spoke fashion that could strengthen the subordination of smallholders within their respective value chains. Each integration form yields sustainability advancements throughout its scope but often aggravates issues in unaddressed dimensions [20].

5.3. IMPLICATIONS FOR SUSTAINABILITY TRANSITIONS

The integration complexity analysis carries significant implications for sustainability policy and business strategy. For policymakers, the analysis suggests that command-and-control regulations (ISPO compliance mandates) without complementary support mechanisms are insufficient; smallholders require access to credit, extension support, infrastructure investment, and technology transfer to simultaneously achieve production and sustainability goals. Differentiated policy frameworks acknowledging the distinct capabilities and constraints of smallholders versus large operations enhance both effectiveness and equity. Land-use planning that integrates production, conservation, and restoration zones, coupled with enforcement mechanisms, offers more promising sustainability outcomes than production-only policies [20].

For certification schemes, the fragmentation across RSPO, ISPO, and MSPO creates compliance confusion, undermining goals; consolidation or harmonization of standards would reduce small-farmer burden while improving environmental effectiveness. Development of simplified "smallholder-friendly" certification pathways lower documentation requirements, lower audit frequencies, group-based auditing could substantially improve inclusion while maintaining rigor [10].

For plantation companies and processors, vertical integration provides leverage for sustainability implementation throughout supply chains, yet inclusive integration models ensuring smallholder access to downstream processing, capacity building, and benefit sharing enhance legitimacy and sustainability impact compared to exclusive models concentrating value [5].

For smallholder stakeholders, the findings underscore the urgency of collective action through functional cooperatives, NGO partnerships, and informal networks to improve bargaining positions, access information and credit, and pursue sustainability transitions that generate genuine livelihood improvements [22].

5.4. RESEARCH GAPS AND FUTURE AGENDAS

The paper also identifies a number of key research gaps. First, there is a lack of longitudinal studies measuring livelihood outcomes for certified and uncertified smallholders while controlling for confounding variables; existing cross-sectional meta-analyses cannot definitively assess the causal impact of certification. Second, at the landscape level: studies that explicitly quantify climate impacts of land-use configurations (e.g. forest conservation vs. extensive to intensive plantations vs. integrated silvopastoral systems compared with restoring degraded lands) remain few and far between making evidence-based climate-economic trade-offs harder53–55. Third, empirical studies of comparative governance effectiveness assessing which institutional arrangements (RSPO, ISPO, corporate standards and farmer-led schemes) are better able to propel sustainability outcomes under a variety of conditions are still in their infancy [24].

Fourth, the literature on smallholder agency and decision-making in relation to adoption barriers, incentive structures, and institutional prerequisites for real participation in integration and sustainability transitions is underdeveloped; much of the literature treats smallholders as passive recipients of policy rather than active agents. Fifth, research documenting successful

smallholder inclusion in downstream processing, technology development, and value-added activities via multiple organizational forms (e.g., cooperatives, enterprises, partnerships) using inclusive business model innovation would generate actionable evidence for replication [5].

6. CONCLUSIONS AND POLICY RECOMMENDATIONS

6.1. SUBSTANTIVE CONCLUSIONS

This qualitative literature review documents that integrated palm oil production systems including vertical coordination, horizontal cooperation, silvopastoral co-management and supply chain clustering are necessary but not sufficient paths to sustainability. Asking such questions can reveal the basic complexities of the sector hidden behind irreducible tensions between economic expansion logic and ecological carrying capacity limits, capital-intensive downstreaming concentration and smallholder livelihood inclusion, regulatory coordination imperatives and fragmented governance realities.

They include the realisation of tangible benefits through integration mechanisms: silvopastoral systems improve carbon sequestration capacity and reduce chemical dependency; vertical integration optimises supply chain coordination, supporting downstream value capture; SEZ clustering promotes growth across the economy and jobs. Nevertheless, these benefits are limited due to hurdles to implementation, unequal distribution and incomplete scope relative to systemwide sustainability needs.

Indonesia's downstream industrialization strategy, which identified 200 derivative products for development by 2030, is pragmatic in terms of economic growth aspiration despite limited prospects for successful application to most smallholders without more inclusive models such as contract farming or integrated enterprise development providing a path into adding value. Alternatively, downstreaming would increasingly be concentrated in the hands of larger integrated corporations and marginalize smallholders further, leaving entrenched inequality that limits legitimacy for sustainability.

The trajectory toward a sustainable sector relies critically on policy frameworks that: (1) proactively steer expansion onto degraded lands, nullifying incentives for forest conversion; (2) create differentiated incentives to support smallholder participation in integrated production and value addition; (3) streamline governance frameworks to minimize compliance fragmentation; and (4) introduces landscape level planning approaches that balance the nexus of production, conservation and restoration across ecosystems.

6.2. POLICY RECOMMENDATIONS

6.2.1. FOR THE INDONESIAN GOVERNMENT

Consolidate and harmonize standards: Streamline requirements across ISPO (national mandatory), RSPO (international voluntary), and corporate standards by developing a unified baseline of criteria, reducing the compliance burden on smallholders while maintaining environmental rigor. Differentiated pathways could acknowledge varying smallholder capacities without compromising environmental outcomes.

Invest in smallholder institution building: Allocate public resources toward cooperative strengthening, capacity development in farm management and market access, and infrastructure investments (rural roads, storage facilities, processing equipment), enabling smallholder productivity improvement and market engagement. Public investment in cooperatives could achieve far greater sustainability impact per rupiah than top-down regulation.

Integrate downstream industrialization with upstream smallholder productivity: Link SEZ development incentives (tax breaks, infrastructure support) to commitments for smallholder access to processing facilities, technology transfer, and benefit sharing. Require integrated plantation companies receiving government support to demonstrate inclusive value distribution models.

Implement landscape-level land-use planning: designate areas for strict conservation (forests, peatlands), sustainable production (silvopastoral systems, agroforestry), and degraded land restoration, through participatory processes that ensure community input. Enforce zoning through a combination of spatial planning, protected area designation, and economic incentives, directing investment toward planned development zones.

6.2.2. FOR CERTIFICATION BODIES AND PRIVATE SECTOR

Develop smallholder-friendly certification pathways: Create simplified certification schemes for smallholder groups with lower documentation requirements, group-based auditing, and proportionate fees. The RSPO's Independent Smallholder Standard v2.0 offers a foundation that could be strengthened through further simplification and affordability improvements.

Invest in supply chain transparency technology: Support blockchain, IoT, and traceability platforms that enable real-time visibility into smallholder supply chains, support direct farmer-company relationships, and reduce collector margin extraction. These technologies can simultaneously improve quality, traceability, and transparency in farmer compensation.

Advance inclusive business models: Document and disseminate best practices regarding smallholder participation in downstream processing through case studies of successful cooperative-processor partnerships, equity-sharing arrangements, and technology licensing models. Evidence on what works under different contexts could guide broader replication.

6.2.3. FOR RESEARCH COMMUNITY

Conduct longitudinal impact evaluation studies: Implement multi-year studies tracking livelihood changes among certified and uncertified smallholders across different contexts, controlling for confounding variables and examining the pathways through which certification affects outcomes. Focus particular attention on equity dimensions and examine distributional outcomes across different farmer types.

Quantify landscape-level carbon balances: Develop comprehensive accounting frameworks comparing climate impacts across different land-use scenarios (continued forest conversion, intensive monoculture plantations, silvopastoral-integrated systems, degraded land restoration) over 50+ year horizons, enabling evidence-based climate-economic trade-off analysis.

Examine smallholder agency and institutional requirements: Conduct in-depth qualitative research on smallholder decision-making, adoption barriers, and institutional arrangements that support meaningful participation in integrated production systems and sustainability transitions. Go beyond treating smallholders as passive recipients of top-down programs.

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