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Beyond Food versus Fuel: Oil Palm as a Strategic Platform for Indonesia's Food–Energy Resilience and Sustainable Bioeconomy

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ABSTRACT

Indonesia's oil-palm sector is usually assessed through separate debates concerning edible oils, biodiesel, exports, rural livelihoods, deforestation, or sustainability certification. Such fragmentation obscures its potential role within a broader national resilience system. This qualitative literature review critically examines whether and under what conditions oil palm can function as a strategic platform for strengthening Indonesia's food and energy resilience. Drawing primarily on peer-reviewed literature published during 2020–2026, the review integrates seven interconnected themes: food-system resilience, bioenergy security, sustainable land intensification, smallholder livelihoods, plantation diversification, circular bioeconomy, and environmental governance. The synthesis indicates that oil palm's strategic value extends beyond crude palm oil because existing plantation landscapes can potentially support intercropping during replanting, livestock integration, biomass valorization, biogas, biodiesel, waste-derived fuels, and downstream industries. However, these benefits are conditional rather than automatic. Higher biofuel demand can intensify food–fuel and land-use pressures, while inadequate replanting finance, low smallholder productivity, tenure insecurity, weak traceability, peat degradation, and unequal access to certification can undermine resilience. The review proposes a Food–Energy–Land–Livelihood Resilience Nexus in which productivity-led replanting, temporary diversification, circular resource use, smallholder inclusion, and zero-deforestation safeguards constitute mutually reinforcing pillars. Indonesia should therefore prioritize intensification and value creation over frontier expansion and develop regionally differentiated pilot programs before nationwide scaling.

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Introduction

Indonesia occupies a unique position in the global vegetable-oil economy because oil palm simultaneously functions as an agricultural commodity, food ingredient, industrial feedstock, export product, rural livelihood source, fiscal resource, and increasingly important renewable-energy feedstock. This multifunctionality differentiates oil palm from a conventional plantation commodity.

At the same time, its expansion has been associated with deforestation, peatland conversion, biodiversity decline, greenhouse-gas emissions, land conflicts, and difficult sustainability-governance questions. Consequently, policy discussion has often polarized around whether palm oil should be regarded primarily as an economic asset or an environmental liability.

A more useful analytical question is whether Indonesia can reorganize its already extensive oil-palm production system so that existing plantation landscapes provide greater food, energy,

livelihood, and environmental resilience without relying on continued frontier expansion. A broad synthesis of the oil-palm boom likewise concludes that productivity growth, rainforest protection, secure land rights, certification, and smallholder inclusion must be pursued together to reduce sustainability trade-offs [1-5].

The scale of this challenge has increased because Indonesia is simultaneously seeking greater food self-reliance, stronger domestic renewable-energy supply, continued export competitiveness, higher rural incomes, and compliance with more demanding sustainability requirements. The tension is particularly visible in biodiesel. Palm-based biodiesel can substitute imported petroleum diesel, retain more agricultural value domestically, stimulate downstream investment, and create demand for crude palm oil (CPO), but additional biodiesel demand also reallocates palm oil that could otherwise enter food or export markets. Dynamic modeling therefore suggests that food, energy, exports, government expenditure, land use, and environmental performance cannot be optimized independently; a higher blending mandate inevitably changes the balance among these objectives [6-9].

The problem becomes more consequential when the age structure of Indonesia's oil-palm plantations is considered. A substantial area cultivated by smallholders is approaching or has exceeded the economically optimal age for production. Replanting is therefore

not merely an agricultural maintenance problem; it is a strategic transition in which Indonesia must decide what kind of plantation landscape it wants for the next 25–30 years. Replanting creates an opportunity to replace low-quality planting materials, redesign spacing and infrastructure, introduce better agricultural practices, restore ecological functions, improve farmer organization, and diversify household income. Yet smallholders commonly face capital shortages, uncertain eligibility for subsidy programs, limited access to certified seedlings, weak extension services, and severe income losses while replacement palms remain immature [10-13].

This replanting transition is central to the conceptual proposition examined in this review. Young or newly replanted oil-palm areas create a temporary window in which sunlight and inter-row space may support food crops, horticulture, livestock, and other complementary production. These activities can be connected with refining, bioenergy production, resource recycling, local revenues, and public fiscal benefits as elements of an integrated mixed-farming and industrial system rather than as disconnected activities.

These propositions are sufficiently important to merit academic examination, but they should not be interpreted as proven national production estimates. Agronomic feasibility differs among soils, rainfall zones, plantation ages, planting densities, slope classes, crop species, labor markets, and market-access conditions. Emerging empirical work nevertheless supports the broader proposition that diversification is possible. Smallholders in Indonesian peatland landscapes have been observed intercropping food crops with young palms partly to secure consumption and income before the palms mature, while oil-palm agroforestry and ecological enrichment experiments demonstrate that plantation landscapes can be substantially more multifunctional than conventional monocultures [14-16].

The resilience implications extend beyond primary agricultural output. Indonesia's oil-palm system generates large volumes of empty fruit bunches, fibers, shells, fronds, trunks and palm-oil mill effluent (POME). These materials may be used for energy, biogas, biochar, soil amendments and higher-value bioproducts instead of being regarded merely as waste. Oil-palm biomass therefore creates opportunities for a circular bioeconomy in which material and energy flows are cascaded across plantations, mills, livestock enterprises, energy facilities and downstream industries [17-20].

However, defining oil palm as strategically important does not mean that any expansion of palm-oil production necessarily enhances resilience. A resilient food–energy strategy must remain functional under climatic shocks, price volatility, geopolitical disruptions, regulatory changes, ecological degradation and social conflict. If increased energy demand stimulates new forest conversion, if smallholders cannot finance replanting, or if certification and traceability requirements remove poorer farmers from formal markets, greater output can coexist with lower systemic resilience. Research increasingly emphasizes that sustainability outcomes depend on governance quality, production location, farm heterogeneity and the ability of institutions to distribute costs and benefits fairly [21-24].

Accordingly, this review asks: How, and under what economic, agronomic, environmental, technological and institutional conditions, can Indonesia's oil-palm sector operate as a strategic platform for strengthening national food and energy resilience sustainably? Supporting questions examine food

and energy pathways, replanting and diversification, circular biomass utilization, smallholder livelihoods, food–fuel trade-offs, environmental safeguards, and governance arrangements. The objective is not to demonstrate that palm oil is intrinsically beneficial or harmful. Instead, the article develops a conditional framework specifying the circumstances in which Indonesia can convert an extensive commodity-production base into a diversified resilience platform.

Literature Review

From Security to Resilience

Food security and energy security are frequently understood in terms of sufficient supply. Resilience provides a broader analytical perspective because it includes the ability of a system to absorb disturbances, adapt its structure and, where necessary, transform its underlying organization. A food system can be temporarily self-sufficient yet vulnerable if production depends excessively on a single input, region or ecological condition. Similarly, an energy system may contain substantial domestic feedstock but remain fragile if processing capacity, infrastructure, fiscal support or feedstock allocation cannot accommodate price and supply shocks. In this article, resilience therefore denotes the capacity of Indonesia's food–energy system to maintain essential functions under disturbance while adapting without transferring unsustainable costs to ecosystems or vulnerable rural households.

Oil palm enters this framework through several channels. Palm oil is directly consumed as edible oil and indirectly embedded in many food products. Income generated from oil palm also affects food access through household purchasing power. Palm-derived biodiesel contributes to domestic fuel substitution, while biomass and POME create decentralized energy opportunities. Meanwhile, the plantation economy generates employment, farm income, export earnings and tax-related revenues that influence the broader capacity of households and the state to withstand shocks. Empirical work in Sumatra has found that oil-palm cultivation can improve nutrition, education expenditure, household assets and electricity consumption among participating smallholder households, although benefits vary and environmental externalities remain important. Longitudinal evidence also shows that oil-palm cultivation can raise household living standards while reducing downside economic risk through greater participation in off-farm activities and income diversification [25-27].

Livelihood resilience also has an intra-household dimension. Income gains do not automatically translate into equal empowerment. Mehraban et al found that the comparatively low labor requirement of oil palm can reduce women's agricultural workload, yet the shift can simultaneously reduce women's influence over farm management and income control. This finding is important because resilience should not be measured only as aggregate household income; it should also consider who controls productive resources and whether economic transformations strengthen or weaken the adaptive capacity of different household members [28].

The Food–Energy–Land Nexus

The food–energy nexus is particularly relevant to palm oil because the same primary feedstock can be directed toward edible products, oleochemicals, exports or biofuel. When total production is fixed in the short term, increasing one use affects availability for others. Hidayatno et al. and Mayandi and Suharjito demonstrate through modeling that palm-oil allocation decisions involve interdependent outcomes across biodiesel, food consumption and export markets. This means that energy resilience cannot be assessed solely by

calculating displaced fossil diesel. It must also account for the opportunity cost of CPO, edible-oil affordability, export revenues, fiscal support and potential land-use responses.

The implications become even clearer when land is included. Halimatussadiyah et al. showed that aggressive biodiesel scenarios can impose substantial land requirements if increased feedstock demand is satisfied predominantly through area expansion. Xin et al similarly demonstrated that growing palm-oil demand must be reconciled with forest and peatland conservation. Consequently, the strategic question is not simply whether Indonesia possesses enough land to produce more palm oil, but whether additional demand can be satisfied primarily through replanting, closing existing yield gaps, improved management, waste-based feedstocks and higher value addition.

Sustainable Intensification and Replanting

Sustainable intensification seeks to increase output or economic value from existing agricultural land while reducing additional environmental pressure. In Indonesian oil palm, significant differences in productivity exist among farms and plantation types, suggesting scope to increase production without proportionate land expansion. Yet yield improvement is not simply a technological problem. Lim et al found that many Indonesian independent smallholder fields receive nutrient inputs that are both insufficient and poorly balanced, particularly for potassium and magnesium, while Mettau et al showed considerable heterogeneity in management practices and economic performance. De Vos et al demonstrated that harvest intervals also reflect intertwined agronomic, labor, transport and incentive constraints. These findings imply that closing yield gaps requires extension, input access, logistics and institutional coordination alongside improved genetics or fertilizer recommendations [29-31].

Replanting magnifies these issues because farmers must incur substantial expenditure before replacement palms generate normal cash flow. Petri et al identify knowledge, finance and access to appropriate inputs as recurrent replanting barriers, while Siregar et al find that experience, land documentation and socioeconomic characteristics influence willingness to participate. Hendrawan and Musshoff further show that smallholders respond to the specific design of replanting subsidies, indicating that policy effectiveness depends not only on the amount transferred but also on program attributes and farmer circumstances.

Plantation Diversification and Agroecological Intensification

Sustainable intensification need not mean maximizing monocultural CPO output. Understory vegetation, agroforestry, temporary food cropping and livestock integration can increase the number of functions supplied by a given landscape. Thoumazeau et al found that maintaining understory vegetation in Indonesian smallholder plantations was associated with improved soil-structure indicators without evidence of inevitable yield sacrifice in the studied conditions. Iddris et al similarly found that replacing herbicides with mechanical weeding and reducing fertilizer use in an industrial plantation could improve ecosystem multifunctionality, biodiversity and profitability while maintaining yields.

At larger spatial scales, ecological enrichment can provide additional gains [32,33].

Zemp et al established native-tree islands within a Sumatran oil-palm landscape and found improvements across biodiversity and ecosystem-function indicators without reducing landscape-scale

palm yields. The experiment does not imply that tree enrichment substitutes for intact-forest conservation; instead, it demonstrates that existing plantation landscapes need not remain ecologically homogeneous. Rahmani et al similarly reported promising financial and ecological characteristics for oil-palm agroforestry in Jambi. Livestock represents another pathway. Azhar et al argue that oil palm–livestock integration can generate meat, improve weed control, recycle nutrients and diversify farm revenue. Evidence from South Kalimantan nevertheless shows that livestock integration presents management, institutional and biophysical constraints, emphasizing the need for locally appropriate stocking densities, animal-health services, plantation access arrangements and farmer capabilities [34,35].

Circular Bioeconomy

A circular bioeconomy extends sustainable intensification beyond the field. The palm-oil processing chain generates biomass and wastewater containing considerable stored carbon and energy. Nabila et al review opportunities to convert empty fruit bunches, shells, fibers, trunks and fronds through processes including torrefaction and pyrolysis, while Norrrahim et al describe routes toward biochar, activated carbon, bio-oil, bioplastics, nanocellulose, sugars and other value-added products. These pathways create a conceptual shift from “waste management” to cascading material utilization. Recent research further emphasizes circular-bioeconomy and decarbonization pathways that combine waste-to-energy technologies with recovery of higher-value bioproducts, thereby linking waste reduction with resource efficiency and emissions mitigation [36].

POME is especially important because untreated wastewater can generate substantial methane emissions, whereas controlled anaerobic digestion can convert the same organic load into biogas. Nasrin et al identify significant technical and environmental potential for POME-derived biogas, while Sodri and Septriana using an Indonesian case, demonstrate the possibility of electricity generation and substantial greenhouse-gas mitigation although project profitability can remain challenging. Circularity therefore requires economic institutions as much as conversion technology. Techno-economic simulation of integrated mill configurations further indicates that combining POME treatment, empty-fruit-bunch composting, and residual-oil recovery can improve both environmental performance and project economics when the processes are designed as a unified system [37].

Waste cooking oil provides an additional bridge between food and energy systems. Instead of increasing first-generation demand for fresh CPO, collection of used cooking oil can recover value after the edible-oil stage. Rahman et al conclude that Indonesian waste cooking oil has meaningful biodiesel potential but requires stronger collection systems, regulation, pretreatment infrastructure and lifecycle management. Diversifying feedstock sources is thus one way to reduce the marginal pressure that higher biodiesel mandates could otherwise place on fresh palm oil and agricultural land [38].

Governance, certification and legitimacy

The sustainability of palm oil is also shaped by interactions among government regulation, voluntary standards, companies and smallholder institutions. Certification may improve some environmental management practices, but adoption is uneven. Watts et al identify significant structural barriers faced by independent Indonesian smallholders, while Apriani et al. show their dependence on external organizations for certification support.

De Vos et al find that land documents, licensing complexity, organizational experience and access to facilitators strongly influence preparedness for certification [39].

Certification outcomes also differ according to local context. Santika et al find that certification was associated with improved poverty outcomes in some market-oriented villages but not uniformly in communities dominated by subsistence livelihoods. Reich and Musshoff further emphasize the importance of training and financial incentives for smallholder certification uptake. Hence certification should be considered one component of a broader transition system rather than an autonomous solution [40,41].

Institutional fragmentation adds another challenge. Choiruzzad et al Brandi Putri et al and Grabs and Garrett demonstrate that public and private sustainability regimes interact in complex ways and may contain internal inconsistencies or implementation gaps. More stringent commitments can also have limited reach. Chandra et al drawing on 1,541 Indonesian farm households, found low awareness of zero-deforestation commitments among many producers and weak bottom-up traceability and capacity building, particularly among independent smallholders [42–44].

Method

Review Design

This study employs a qualitative literature review, not a systematic literature review or meta-analysis. The objective is interpretive and integrative: to connect bodies of literature that are often examined separately, including food security, bioenergy, replanting, smallholder livelihoods, agroforestry, biomass utilization, environmental sustainability and governance. Consequently, the review does not claim exhaustive retrieval of every publication, does not employ PRISMA screening, and does not produce pooled quantitative effect sizes. Instead, literature is selected for conceptual relevance, empirical credibility, and its capacity to illuminate complementarities and trade-offs across the Food–Energy–Land–Livelihood Nexus.

The review was guided by an integrated conceptual proposition linking temporary land intensification during replanting with mixed farming, food-crop and livestock integration, post-refinery energy production, circular treatment of residues, organizational partnerships, profitability, decentralized processing, financing, and pilot implementation. These propositions were treated as analytical hypotheses to be evaluated against peer-reviewed evidence rather than as independently verified national production estimates.

Literature Identification and Thematic Synthesis

Peer-reviewed research published predominantly between 2020 and 2026 was prioritized. Search concepts combined oil palm, palm oil and Indonesia with terms including food security, food–fuel, biodiesel, bioenergy, replanting, smallholder, agroforestry, intercropping, livestock integration, biomass, POME, circular economy, certification, deforestation, biodiversity, governance and resilience. Priority was given to peer-reviewed articles in internationally recognized journals and to Indonesian empirical studies where available. Comparable Southeast Asian studies were included when they provided transferable evidence on oil-palm production systems.

The analysis proceeded through seven thematic categories: (1) food-system resilience, (2) energy resilience, (3) land productivity and replanting, (4) smallholder livelihood resilience, (5) diversification and mixed farming; (6) circular biomass and industrial ecology, and (7) ecological and institutional safeguards. Findings were

then compared across themes to distinguish synergies from trade-offs. This interpretive procedure is especially appropriate for a question in which agronomic, economic, technological, social and environmental evidence cannot readily be reduced to a common quantitative metric.

Results

Theme 1: Oil Palm Already Performs Multiple Resilience Functions

The literature indicates that oil palm's national importance cannot be understood solely through CPO tonnage. Its first resilience function is food supply. Palm oil is a major source of edible vegetable oil and is embedded in numerous processed foods. Its relatively high oil yield per unit of land is strategically relevant because replacing palm oil with substantially lower-yielding oil crops could transfer land demand elsewhere rather than eliminate it. Yet high land-use efficiency does not cancel the environmental consequences of where plantations are established; oil palm's comparative productivity strengthens the argument for intensifying existing plantations rather than converting high-carbon or high-biodiversity.

A second pathway is economic access to food. Smallholder households do not consume only what they grow; income determines their ability to purchase diverse diets, education, healthcare and other resilience-enhancing goods. Chrisendo et al find that oil-palm cultivation in Sumatra improved nutrition, dietary quality, education expenditure, assets and electricity consumption. Hendrawan et al similarly emphasize that oil-palm smallholders have benefited economically but remain exposed to aging plantations, climate risks and changing market requirements. These findings suggest that food resilience includes the purchasing-power effects of oil palm as well as direct food production.

The third pathway is macroeconomic. Palm-oil value chains generate domestic processing activity and foreign exchange. Purnomo et al show that the sector's economic role spans smallholders, companies and broader value-chain activity, while simultaneously demonstrating that environmental outcomes differ considerably across policy scenarios. Strategic importance is therefore not equivalent to immunity from reform. On the contrary, the larger a commodity's contribution to national welfare, the greater the importance of protecting its productive base from ecological degradation, reputational shocks and regulatory exclusion.

Theme 2: The Replanting Cycle Creates a Food-Production Opportunity, But Not a Uniform National Formula

One of the strongest propositions in the literature is that replanting temporarily opens land and sunlight between young oil palms, creating a potential production window for food and feed crops. Contemporary research supports the general mechanism. Beaudet et al. [15] report that Indonesian smallholders in peatland landscapes commonly intercrop young, non-producing palms with crops such as cassava, chili, pineapple, and other species to provide food and income before palm production begins. The research also demonstrates that diversification is heterogeneous: farmers respond differently according to soil conditions, available labor, markets, crop competition and livelihood priorities.

This finding is critical for evaluating proposals to intercrop sorghum, cassava, maize, soybean or horticultural crops during replanting. The correct policy question is not whether a single intercrop can be prescribed for millions of hectares; it is which crop portfolios are agronomically and economically appropriate

within specific plantation landscapes. Light availability declines as the palm canopy develops, and competition for nutrients and water varies among species. Consequently, diversification must be designed around the age of palms, soil characteristics, hydrology, labor availability and local off-taker markets.

Replanting nevertheless creates a rare moment when plantations can be redesigned. Petri et al emphasize that replanting can close yield gaps and improve future livelihoods, while Jelsma et al show that farmer organizations can facilitate—but do not automatically guarantee—successful transitions. Siregar et al demonstrate that land certification and farmer experience influence participation. These results suggest that integrating food cropping with replanting policy could serve two objectives simultaneously: reducing the income gap before new palms mature and increasing local food or feed production.

The evidence suggests that oil-palm replanting should be interpreted as a sequence rather than an isolated planting event. The amount and type of complementary production possible are highest after clearing and during the early immature period, then progressively decline as palm canopy and root competition increase. Diversification policy should therefore synchronize crops and livestock with biological plantation stages rather than impose a static mixed-farming design.

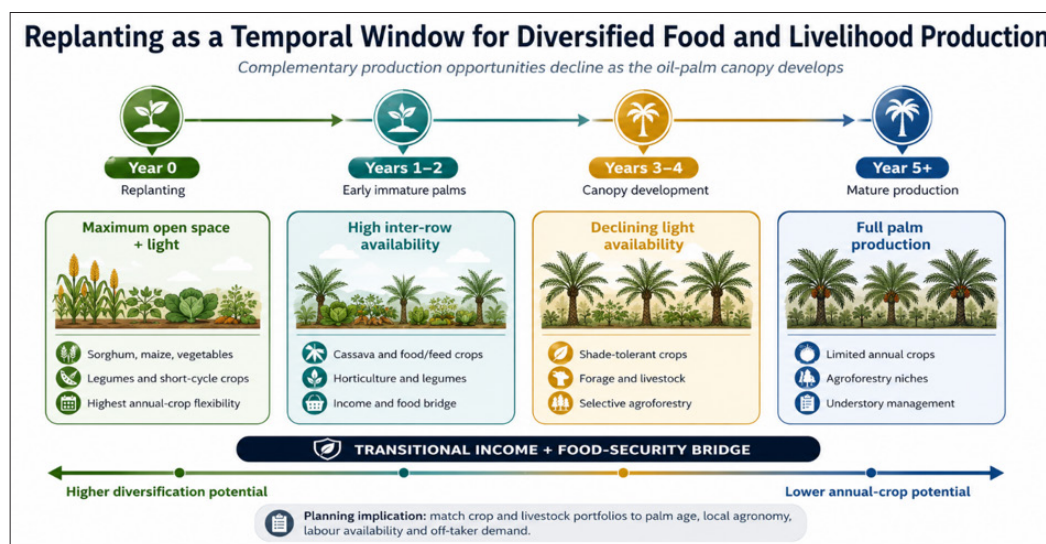


Figure 1: Replanting as a Temporal Window for Diversified Food and Livelihood Production

Figure 1: Translates the Land-Intensification Proposition into a Biological Transition Framework. The figure deliberately avoids assigning fixed percentages of nationally available land because such values require verification for regional palm age, spacing, topography, and crop light requirements. Instead, it identifies a declining opportunity gradient. Early years provide the strongest potential for annual crops; subsequent diversification may require shade-tolerant crops, livestock, or more permanent agroforestry components. Evidence from Indonesian farmers already using young-palm spaces for food crops supports the feasibility of the principle, although rigorous crop-specific trials remain necessary.

Theme 3: Productivity Improvement is the Principal Alternative to Expansion

The food–energy resilience argument becomes unsustainable if meeting additional CPO demand requires continuous plantation expansion. Indonesia therefore has strong incentives to prioritize productivity on existing agricultural land. Lim et al document substantial nutrient-management deficiencies in independent smallholder farms, while de Vos et al identify harvest management as another source of avoidable losses. Mettauer et al further demonstrate substantial variation in farm-management efficiency. These findings imply that a considerable portion of the production challenge is institutional and managerial rather than purely biophysical.

Replanting is particularly powerful because improved planting materials can raise productive potential for decades. However, capital constraints create a paradox. Farmers with old and low-yielding plantations may be those least able to surrender several years of harvest income. Hendrawan and Musshoff show that replanting support design affects farmer preferences, while Petri et al emphasize financing and input access. Without transition support, farmers may postpone replanting, maintain low productivity or seek additional land to compensate for declining output.

Fosch et al provide a particularly important landscape-level perspective. Their analysis of Sumatran villages suggests that replacing unproductive plantation areas with viable smallholder production can generate benefits across several Sustainable Development Goals, but the positive results depend on the replanted areas becoming productive rather than failing again. This reinforces the need to link replanting finance with quality seed, extension, land legality, fertilizer management and organizational support.

The environmental logic is equally strong. Ekayani et al argue that increasing productivity and value addition can reduce the pressure to meet economic targets through continuous expansion. Xin et al reach a similar conclusion through long-term demand and conservation analysis. Intensification therefore represents a strategic form of land conservation only when policy simultaneously restricts rebound effects—that is, when higher profitability does not simply stimulate additional clearing [45–46].

Theme 4: Palm-Based Bioenergy Strengthens Energy Resilience but Intensifies Allocation

Trade-Offs

Indonesia's biodiesel strategy demonstrates the most direct connection between oil palm and energy resilience. Biodiesel allows domestic biomass to replace part of the petroleum diesel consumed in transportation and industry Wirawan et al emphasize the importance of technical quality, feedstock supply, economics and regulation for sustaining high biodiesel blends.

Papilo et al similarly identify energy security as a central driver of palm-based bioenergy policy in Indonesia and Malaysia Nevertheless, biodiesel is not automatically a net economic or environmental gain at every blending level. Halimatussadiyah et al demonstrate that diesel-import savings must be compared with foregone exports, fiscal support and possible land expansion. Hidayatno et al show that food and fuel allocation must be treated within an integrated sustainability model. Mayandi and Suharjito similarly highlight the need to balance biodiesel with food and export requirements. Taken together, this evidence suggests that an adaptive blending policy is preferable to an isolated volume target [47].

Lifecycle performance also matters Wahyono et al demonstrate that palm biodiesel can generate environmental impacts across its production chain, making plantation management and processing

efficiency integral to the fuel's sustainability assessment Consequently, the appropriate comparison is not simply renewable versus fossil carbon at the tailpipe Feedstock origin, land-use change, fertilizers, milling, transport, methane management and co-product allocation determine the lifecycle outcome [48].

Industry-level mitigation measures can materially lower greenhouse-gas emissions, but their effectiveness depends on implementation across cultivation, milling, methane management, and downstream operations rather than on a single processing intervention [49].

The resilience value of palm-based energy can therefore be increased by diversifying beyond first-generation CPO. Waste cooking oil can recover energy value after edible oil has already served the food system. POME can produce biogas, and solid biomass can generate fuels or electricity. This sequence reduces direct competition between food and energy compared with a system in which every additional unit of bioenergy requires new virgin CPO production A useful policy distinction is therefore between linear and cascading palm-oil energy systems. A linear system allocates fresh CPO directly between food and fuel. A cascading system seeks food and high-value uses first where appropriate, then recovers residues, effluent, post-consumer oils and other by-products for energy and material applications.



Figure 2: From a Linear Palm-Oil Chain to a Circular Food–Energy Bioeconomy

Figure 2 Demonstrates why the strategic contribution of oil palm should not be measured only by CPO-based biodiesel volumes Nabila et al and Norrrahim et al show that solid oil-palm biomass can support multiple material and energy pathways, Nasrin et al and Sodri and Septiana demonstrate the importance of capturing POME methane, and Rahman et al identify waste cooking oil as a potentially important secondary biodiesel feedstock The resilience advantage arises from extracting more services from each unit of biological production rather than continuously increasing primary feedstock demand.

Theme 5: Mixed Farming can Strengthen Food and Income Resilience

Oil-palm landscapes are frequently discussed as monocultures, yet several types of mixed production are possible. Temporary intercropping during replanting is the most intuitive because canopy closure has not occurred. More permanent agroforestry can incorporate tree crops or biodiversity-oriented vegetation, while livestock may use understory biomass. Rahmani et al demonstrate that an oil-palm agroforestry configuration can potentially provide financial and ecological advantages in an Indonesian landscape. Beaudet et al show that diversification is already incorporated into smallholder livelihood strategies, even when farmers do not formally identify their practices as “agroforestry.”

The mixed-farming perspective extends this principle into an architecture in which oil palm, seasonal crops, and livestock generate primary products and by-products, while residues are recycled and downstream food and energy industries generate additional value. The academic literature supports several components of this architecture, but also demonstrates that integration should be modular.

Livestock integration, for example, may reduce weed-control costs and provide meat and manure, but grazing intensity and animal management must be adapted to plantation age and soil conditions. Mixed farming can be especially valuable during the non-bearing replanting period because it addresses liquidity rather than merely agricultural diversity. A farmer may rationally reject replanting if several years of palm income disappear and no substitute cash flow exists. Intercrops, livestock, temporary employment, or conditional income support can reduce this transition cost. Thus, food-production policy and replanting policy should be designed jointly rather than administered through completely separate programs.

Theme 6: Ecological Diversification can Increase Resilience Within Existing Plantations

A resilience strategy must also address ecosystem functions. Conventional monocultural oil-palm landscapes can reduce habitat complexity and biodiversity, while intensive herbicide use can simplify understory vegetation. Yet evidence from Indonesia shows that management modifications can improve ecological function without necessarily causing large yield penalties. Iddris et al found that mechanical weeding and reduced fertilizer management improved multifunctionality and profitability in a Jambi plantation. Thoumazeau et al found positive relationships between understory vegetation and soil-health indicators in smallholder plots. Large-scale environmental analytics similarly indicate that sustainability assessment must account for land-use, emissions, and ecosystem consequences alongside the crop's high land productivity [50].

Zemp et al provide stronger experimental evidence at the landscape level. Native-tree islands increased biodiversity and multiple ecosystem functions without reducing overall landscape oil-palm yield. Such evidence is highly relevant to resilience because biodiversity, soil structure, infiltration and microclimate regulation influence the long-term capacity of plantations to withstand climatic variability. However, ecological enrichment of plantations cannot compensate for the loss of intact tropical forests; restoration inside plantations should complement, not substitute for, forest protection. Complementary landscape-scale evidence shows that tree-island heterogeneity can increase multi-taxa diversity and that below-ground biota are central to restoration outcomes, while tree identity and canopy openness can alter insect-mediated functions such as herbivory and pollination. Dalheimer et al similarly demonstrate that smallholder production contains opportunities to improve biodiversity performance without simply reducing agricultural output. Their analysis suggests that economic instruments such as payments for ecosystem services could potentially reward biodiversity conservation. A future food–energy resilience program could therefore include ecological performance payments alongside conventional production subsidies [51–53].

Theme 7: Smallholders Determine Whether Resilience is Inclusive

Smallholders manage a major share of Indonesian oil-palm landscapes, making their productive capacity and welfare integral to national resilience. However, smaller producers frequently experience lower yields, weak bargaining positions, limited access to finance and uneven exposure to sustainability initiatives. Li argues that stronger support for independent smallholders can improve livelihoods without requiring further deforestation, while Hendrawan et al show that farmer resilience depends on a broader bundle of livelihood assets rather than income alone [54].

Certification illustrates the distributional challenge. Watts et al find significant structural disadvantages among independent farmers pursuing sustainable-palm certification. De Vos et al find that formal documentation and prior organization are key prerequisites, and Apriani et al show the continuing importance of external facilitation. Reich and Musshoff further identify training and premiums as influential factors in certification uptake. A resilience strategy that imposes additional standards without financing compliance can therefore weaken rather than strengthen smallholder market access.

Recent evidence reinforces this point. Chandra et al find that corporate zero-deforestation commitments have limited penetration into many Indonesian smallholder communities: awareness, targeted training, bottom-up traceability and differentiated price incentives remain weak, particularly among independent producers. Stronger environmental regulation is thus necessary but insufficient; it must be accompanied by technical assistance, legal support and incentive structures that make compliance feasible.

Discussion and Analysis Oil Palm Should be Understood as Infrastructure for Resilience, not Merely a Commodity

The principal synthesis emerging from this review is that Indonesia's strategic advantage is not simply that it produces large quantities of palm oil. Its deeper advantage lies in the existence of a vast, already established biological and industrial system containing plantations, farmer communities, mills, refineries, biodiesel plants, logistics networks and downstream industries. The resilience question is therefore how to increase the number and diversity of useful services generated by this installed platform while decreasing ecological and social externalities.

This perspective changes the policy objective. Conventional commodity strategy tends to maximize CPO production or exports. A resilience strategy optimizes multiple outcomes simultaneously: edible-oil availability, energy substitution, farmer income, local food production, foreign exchange, carbon performance, biodiversity, soil quality and supply-chain legitimacy. No single indicator can capture these goals, which explains why food-versus-fuel modeling consistently reveals trade-offs.

The appropriate conceptual sequence is therefore productivity → diversification → circularity → value addition, bounded by ecological safeguards. Productivity reduces the need for additional land. Diversification reduces dependence on one commodity stream and can bridge replanting-income gaps. Circularity extracts energy and material value from residues and waste. Value addition allows Indonesia to capture more economic value from a given quantity of biological feedstock. This sequence is preferable to treating expansion as the default response to rising food, fuel and export demand.

Reassessing the Initial Land-Intensification Proposition

Scenario-based land-intensification arguments estimate potential areas for food crops by combining plantation area, a replanting cycle, and assumptions about the percentage of land available during successive years. The conceptual logic is useful, but numerical results should be treated as scenarios rather than observed national capacity. A rigorous nationwide estimate would require spatially explicit information on plantation age distribution, actual annual replanting rates, planting systems, slope, soil type, hydrology, ownership, roads, crop calendars, and solar interception.

Nevertheless, the underlying opportunity is significant. Replanting represents land already embedded in agricultural use; using available inter-row space for temporary crops differs fundamentally from converting new forests or peatlands into agriculture. If suitable intercropping can generate food and income without compromising palm establishment, the same hectare temporarily delivers more functions. This is a form of temporal land intensification.

The strongest early candidates are not necessarily the same everywhere. Sorghum may be attractive in areas with suitable agronomy and off-takers; cassava may fit other locations; legumes may offer soil and nitrogen benefits; maize can connect to feed markets; vegetables can generate high value near urban markets; and forage may be more appropriate where cattle systems already exist. The relevant unit of planning should therefore be the regional replanting cluster, not the national hectare.

Food Versus Fuel Should be Reframed as Portfolio Management

The conventional food-versus-fuel framing assumes a binary allocation of palm oil. That is analytically useful but incomplete. Indonesia possesses several mechanisms to soften the trade-off. First, productivity improvements can increase supply without proportional land expansion. Second, downstream food and industrial efficiency can reduce losses. Third, used cooking oil can be recovered after food use. Fourth, POME and solid biomass can produce energy without diverting edible CPO. Fifth, blending mandates can be adaptive rather than mechanically increased regardless of feedstock balance.

The resulting strategy resembles portfolio management CPO should be allocated across food, energy, exports and industrial uses according to minimum domestic food requirements, energy-security objectives, market conditions and sustainability thresholds. Residues and secondary oils should then be prioritized where they provide additional energy without intensifying first-generation feedstock competition. Wirawan et al Halimatussadiah et al and Rahman et al collectively support the need for feedstock diversification, lifecycle accounting and economic evaluation rather than relying exclusively on fresh CPO.

A “No New Deforestation for Resilience” Principle is Essential

The resilience narrative loses credibility if food or energy security becomes a justification for converting intact forests or carbon-rich peat. The most defensible strategy is therefore to establish a strong ordering principle: existing plantations first, degraded agricultural areas second, ecological restoration where required, and no conversion of high-conservation-value or high-carbon ecosystems.

This position is supported economically as well as environmentally. Xin et al show that Indonesia needs to reconcile demand growth with conservation, while Ekayani et al emphasize intensification and downstream value addition as alternatives to simple area expansion. Zemp et al demonstrate that ecological functions can even be restored within existing plantation landscapes. Remote-sensing evidence of oil-palm expansion into carbon-rich forests in Indonesia and Malaysia reinforces the need to make this boundary explicit in future production and energy policy [55].

Governance complications remain substantial because plantation legality and forest zoning are contested in some regions. Astuti et al show that improved spatial visibility of plantations can expose difficult choices concerning illegality, legalization,

corporate interests, smallholder livelihoods and forest protection. Sustainable resilience therefore requires transparent spatial planning and differentiated treatment of vulnerable farmers and large commercial actors rather than indiscriminate regularization or enforcement [56].

Environmental Legitimacy is Part of Economic Resilience

International sustainability requirements are sometimes portrayed as external constraints on Indonesian sovereignty. A resilience framework suggests a more nuanced interpretation. Because Indonesia depends on long-lived plantations and global markets, environmental legitimacy is itself an economic asset. Deforestation, peat degradation, unresolved community conflicts and weak traceability increase the probability of market restrictions, stranded investments and reputational risk.

Certification contributes to managing these risks but cannot solve them alone Choiruzzad et al identify ambiguities within Indonesian sustainability governance, while Brandi demonstrates the complex interaction between public and private standards. Grabs and Garrett show that goal-based corporate sustainability commitments can produce governance paradoxes. Putri et al similarly emphasize broader policy-coordination challenges.

The social legitimacy dimension is equally important Afrizal et al find significant limitations in access to effective conflict resolution under the RSPO mechanism. A system that produces large quantities of certified or traceable commodities while leaving land conflicts unresolved cannot reasonably be described as fully resilient. Resilience must therefore include access to justice, transparent tenure arrangements and mechanisms for affected communities to negotiate benefits [57].

The Smallholder Transition Should be Treated as Strategic Infrastructure

Smallholder replanting is often administered as an agricultural subsidy program. It should instead be viewed as strategic infrastructure for the next generation of the national palm-oil economy. Poor replanting today locks in low productivity, weak traceability and livelihood vulnerability for decades. Successful replanting can lock in improved genetics, better field layouts, diversification opportunities, stronger farmer institutions, environmental safeguards and digital traceability.

Financing must therefore cover more than seedling purchase. A realistic transition package should combine replanting capital, temporary income support, intercrop working capital, extension, verified planting material, land-document assistance, cooperative strengthening and guaranteed or facilitated off-take. This directly responds to the implementation barriers identified both in recent research and in the initial literature Petri et al Hendrawan and Musshoff Siregar et al and Jelsma et al collectively demonstrate why finance, farmer organization, knowledge and institutional design must be treated jointly.

Proposed Food–Energy–Land–Livelihood Resilience Nexus

The evidence can be integrated into a four-domain resilience framework. Food resilience comprises edible palm oil, temporary food crops, feed and livestock products. Energy resilience comprises biodiesel, POME biogas, solid biomass and waste-derived fuels. Land resilience comprises yield-gap closure, replanting, soil health, agroforestry and ecological restoration. Livelihood resilience comprises farmer income, diversified cash flow, organization, market access and human capital. Circularity

links the four domains, while governance establishes ecological and distributive boundaries.

Figure 3 synthesizes the article's central analytical proposition: oil palm strengthens national resilience only when food, energy, land and livelihoods reinforce one another and are constrained by sustainability safeguards. Maximizing a single domain—for example biodiesel volume—while degrading another—for example, forests or household food affordability—represents optimization of a sector, not resilience of the system.

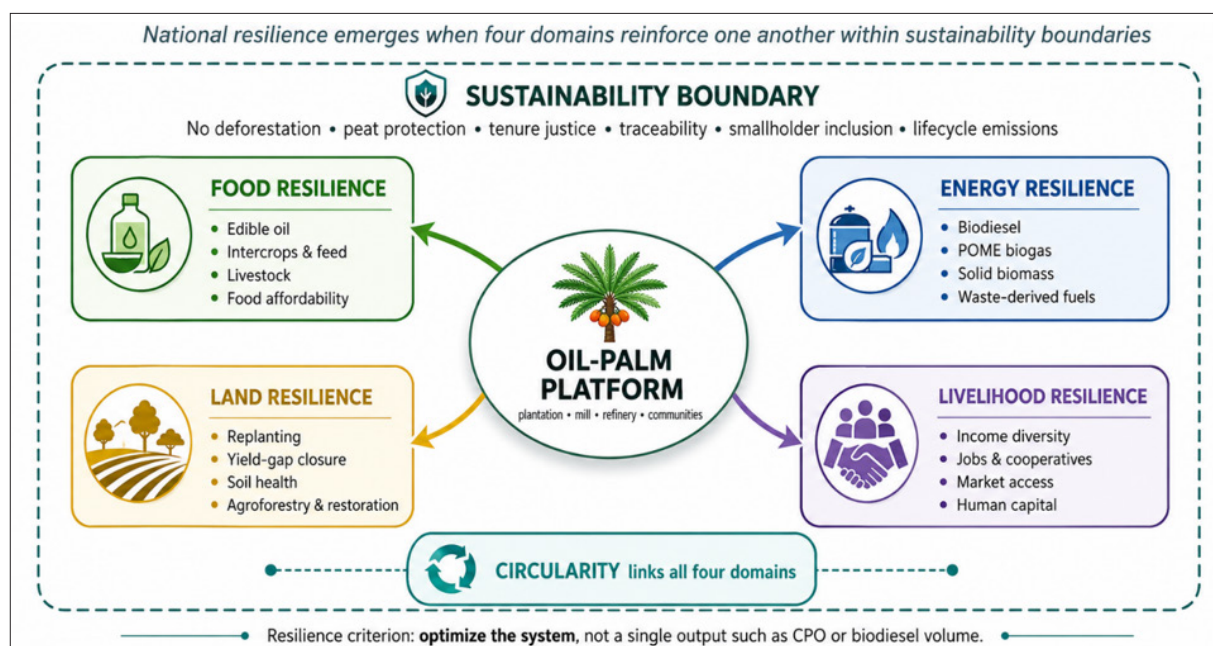


Figure 3: Food–Energy–Land–Livelihood Resilience Nexus for Indonesian Oil Palm

Figure 3: highlights why the four components are interdependent. Food production without viable farmers is unstable; biodiesel without lifecycle safeguards can externalize environmental costs; high CPO yields without legitimate land governance can create social and market risks; and ecological protection without feasible livelihood alternatives can produce resistance or exclusion. The central policy task is therefore coordination across ministries and levels of government rather than isolated commodity interventions.

From Pilot Projects to National Scaling

The reviewed evidence supports pilot projects as an essential step before large-scale implementation. A national program should not begin by extrapolating theoretical intercropping potential to the entire oil-palm area. It should establish representative pilot landscapes covering contrasting mineral soils, peat landscapes where legally appropriate, rainfall regimes, smallholder systems, plantation-company partnerships, and market-access conditions. Each pilot should compare a conventional replanting control with several diversified designs. Indicators should include intercrop yield, oil-palm establishment, labor requirements, input costs, farm cash flow, household food consumption, soil condition, biodiversity, water use, greenhouse-gas performance, logistics and marketability. The crucial outcome should be net household and system resilience, not merely tonnes of intercrop produced. Scaling should occur only after agronomic and economic thresholds are demonstrated. For example, an intercrop should not be promoted nationally simply because it grows between palms; it should demonstrate reliable yields, acceptable impact on palm growth, realistic market absorption and positive farmer cash flow after labor and logistics costs.

Governance Architecture for Implementation

A workable governance model requires different actors to perform functions aligned with their comparative advantages. National government should establish food–energy allocation objectives, environmental safeguards and financing rules. Provincial and district governments should identify suitable replanting clusters, facilitate land documentation and coordinate extension. Research organizations should validate crop combinations and processing technologies. Financial institutions should design loans consistent with oil-palm maturity cycles. Cooperatives should aggregate inputs, production and market information. Plantation companies and processors can act as off-takers where partnerships are transparent and equitable.

Traceability should be integrated from the beginning rather than retrofitted after production. Chandra et al show that current zero-deforestation commitments often fail to penetrate deeply into independent smallholder supply chains. Digital farm registration, geospatial boundaries, legality support, and transaction records can connect food–energy resilience programs with sustainability compliance, but smallholders require assistance to participate rather than merely being instructed to comply.

The transition should consequently be understood as a staged governance process. Pilot design generates evidence; verified models are replicated at district scale; financing and off-take arrangements permit provincial expansion; and national adoption occurs only after environmental, social and economic safeguards are validated.

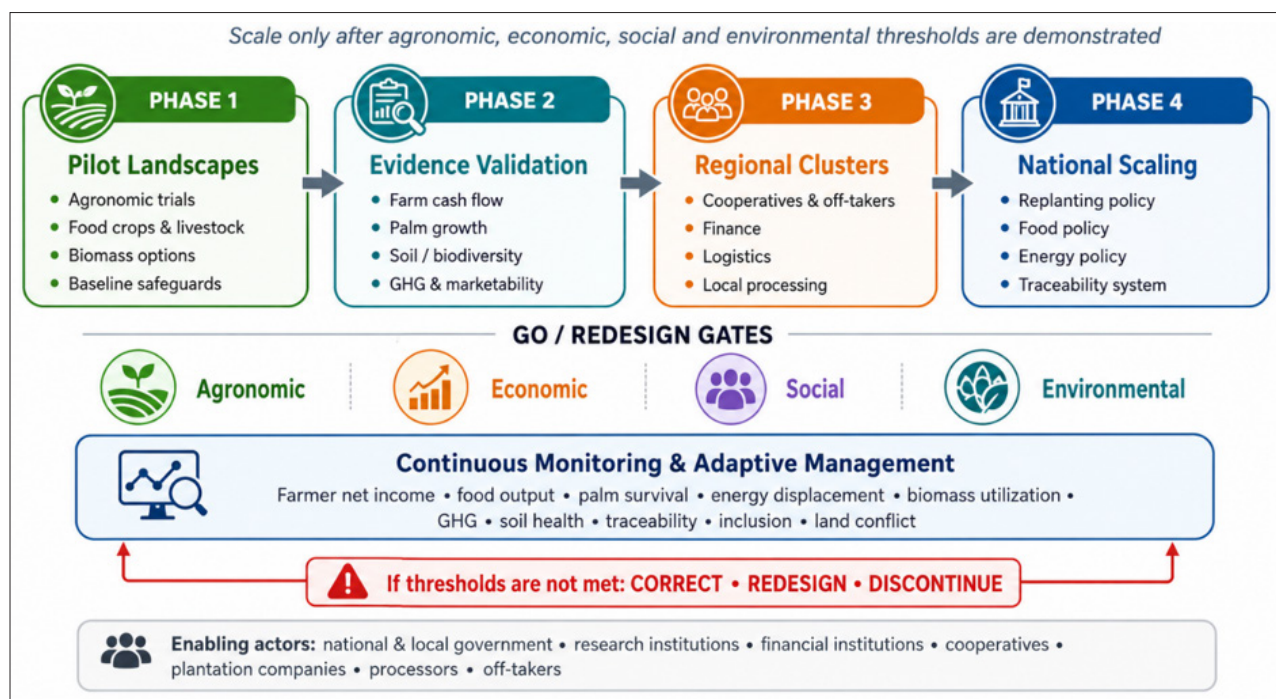


Figure 4: Pilot-To-Scale Governance Architecture for Food-Energy Resilience

Figure 4: Treats scaling as conditional. A pilot that fails economically, ecologically, or socially should be redesigned rather than expanded for political reasons. Performance indicators should include farmer net income during the immature-palm period, food output per hectare, palm survival and growth, fossil-energy displacement, biomass utilization, lifecycle emissions, soil-health indicators, traceability, female participation, smallholder inclusion and the incidence of land conflict.

Conclusion and Policy Recommendations

Indonesia's oil-palm sector is strategically important to national resilience because it sits at the intersection of food supply, renewable energy, rural livelihoods, industrial development, trade and land management. Its strategic value, however, does not derive simply from the size of plantation area or CPO production. It derives from the possibility of converting an already established agricultural and industrial system into a more productive, diversified and circular platform capable of delivering multiple services from the same landscape. The first policy priority should therefore be productivity-led replanting rather than frontier-led expansion. Aging and low-yielding plantations represent both a vulnerability and an opportunity. Replanting can increase future output, but it should be accompanied by income protection, quality planting material, extension, land documentation and farmer organization. The temporary period before canopy closure should be evaluated systematically for food crops, feed, horticulture and other locally appropriate enterprises. Second, food and energy strategies should be integrated. Palm-based biodiesel can materially strengthen energy resilience, but the objective should not be maximization of biodiesel volume in isolation. Feedstock allocation must protect domestic food affordability, export resilience and environmental commitments. Greater use of waste cooking oil, POME biogas, solid biomass and other secondary feedstocks can increase energy output without proportionately increasing demand for virgin

CPO. Third, Indonesia should shift from a waste-management paradigm toward a circular palm bioeconomy. Empty fruit bunches, shells, fibers, fronds, trunks, wastewater and post-consumer oils can become energy, soil amendments or higher-value industrial feedstocks. This creates additional economic output while improving resource efficiency and, where properly managed, environmental performance. Fourth, smallholders must be positioned at the center of the transition. Replanting finance, market access, traceability, extension and certification should be designed as components of one support architecture. Environmental requirements that independent farmers cannot practically satisfy risk producing exclusion rather than sustainability. Fifth, a national resilience strategy must contain an explicit no-new-deforestation safeguard. Productivity improvement, land rehabilitation, ecological enrichment, circularity and downstream value creation should be exhausted before additional plantation expansion is considered. Forest and peat protection are not external constraints on resilience; they are essential to maintaining climatic, hydrological, reputational and market stability. Finally, Indonesia should proceed through evidence-based pilot landscapes rather than immediate nationwide extrapolation of theoretical land potential. The integrated vision assessed in this review, combining oil palm with seasonal crops, livestock, food processing, renewable energy, circular residue management, partnerships, and local economic value, is conceptually compelling. Its national significance will depend on demonstrating that such systems generate positive farmer cash flow, meaningful food or energy output, healthy soils, manageable logistics, and verifiable environmental safeguards under Indonesia's diverse regional conditions. Under these conditions, oil palm can evolve from a primarily commodity-oriented plantation system into an integrated platform for food-energy resilience and a sustainable national bioeconomy.

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