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# Beyond the Blend: A Review of the Systemic Challenges to Implementing Indonesia's B50 Biodiesel Programme

**Loso Judijanto**
IPOSS Jakarta, Indonesia, https://orcid.org/0009-0007-7766-0647

**ABSTRACT:** Indonesia's mandatory B50 biodiesel programme, officially launched in July 2026, represents one of the world's most ambitious attempts to substitute petroleum diesel with a domestically produced biofuel. The policy is intended to strengthen energy security, reduce diesel imports, deepen palm-oil downstreaming, support rural livelihoods, and lower greenhouse-gas emissions. Yet moving from B40 to B50 changes more than the blending ratio. It increases the coupling between the national energy system and the palm-oil economy, thereby intensifying interactions among feedstock availability, plantation productivity, smallholder replanting, crude palm oil (CPO) allocation, commodity prices, biodiesel quality, storage and distribution infrastructure, engine compatibility, fiscal support, environmental safeguards, traceability, and international trade rules. This article conducts a qualitative integrative literature review, rather than a systematic literature review, drawing primarily on peer-reviewed studies published from 2020 to 2026 and triangulating them with current government sources. The review identifies nine interconnected challenge domains and argues that the principal risk is not any single bottleneck but the migration of bottlenecks across the upstream-to-downstream system. B50 can improve energy resilience, but its durability depends on productivity-led feedstock growth, smallholder-inclusive replanting, end-to-end fuel-quality assurance, resilient financing, credible lifecycle sustainability, and adaptive governance. The article proposes a policy architecture in which the mandate is supported by monitored thresholds for feedstock, prices, fiscal exposure, technical performance, distribution reliability, and environmental integrity.

**KEYWORDS:** B50 biodiesel; palm oil; energy security; renewable energy; smallholders; CPO; replanting; sustainability; biofuel policy; Indonesia
**JEL Classification :** Q42 ; Q48 ; Q18 ; O13 ; Q56

## 1. INTRODUCTION

### 1.1 Background: from incremental blending to a system transition

Indonesia has progressively converted palm oil from an export-oriented agricultural commodity into a strategic input for domestic energy policy. The biodiesel mandate evolved through successive blending stages, with B30 implemented nationally in 2020, B35 in 2023, B40 in 2025, and B50 launched in July 2026. The policy trajectory reflects a deliberate attempt to use domestic renewable feedstock to reduce exposure to imported petroleum diesel while simultaneously creating a large internal market for crude palm oil and its derivatives (Silalahi, Simatupang and Siallagan, 2020a; Wirawan et al., 2024). In official projections accompanying the B50 launch, the Government of Indonesia estimated annual biodiesel demand at roughly 16.7-18 million kilolitres and associated CPO requirements at about 15.2-16.3 million tonnes, while projecting larger foreign-exchange savings, employment effects and emissions reductions than under B40 (Ministry of Energy and Mineral Resources, 2026a). These figures should be interpreted as policy projections rather than realised long-run impacts because the nationwide programme is still in its early implementation phase.

The transition is unusually important because Indonesia is both the world's largest palm-oil producer and a large diesel-consuming economy. This dual position creates a policy opportunity that is difficult to replicate elsewhere: a domestically abundant vegetable oil can be transformed into fatty acid methyl ester (FAME) and blended at scale into diesel fuel, linking agricultural development and national energy strategy. However, the same linkage also creates vulnerability. Greater biodiesel demand ties the energy system more tightly to the productivity of oil-palm plantations, the structure of local fresh fruit bunch (FFB, or TBS in Indonesian terminology) markets, the allocation of CPO between food, energy, oleochemicals and exports, and the fiscal mechanisms used to bridge differences between biodiesel and fossil-diesel economics (Halimatussadiah et al., 2021; Sahara et al., 2022; Hidayatno et al., 2025).

The literature review provides a useful practitioner framing for this problem. It portrays biodiesel as a strategic pillar of the economy, energy sovereignty and the CPO market, while also identifying practical constraints involving feedstock availability, CPO-use trade-offs, price volatility, biodiesel production and blending infrastructure, vehicle compatibility and financing. Importantly, the literature review cautions that the apparently simple sequence "B50 raises CPO demand, CPO prices rise, and farmers receive higher FFB prices" is mediated by a long marketing chain, adjustment costs and imperfect market structures. It further characterises the FFB market as oligopsonistic in many locations, meaning that a higher CPO price need not be transmitted immediately or symmetrically to independent smallholders (Gultom, 2026). This practitioner diagnosis is broadly consistent with the wider literature on uneven bargaining power, smallholder market access and certification constraints in Indonesia's palm-oil economy (Watts et al., 2021; Dharmawan et al., 2021; Pramudya et al., 2022).

B50 therefore needs to be understood as more than a fuel specification. It is a coupled socio-technical and political-economic transition that begins in plantation landscapes, passes through mills, refineries, biodiesel plants, blending terminals and fuel-distribution systems, and ends in a heterogeneous fleet of road vehicles, heavy equipment, vessels, trains, agricultural machinery and power generators. The programme also operates inside a wider institutional environment composed of export levies, biodiesel compensation, sustainability certification, land-governance rules, trade regulations, lifecycle-carbon claims and international due-diligence requirements. Any serious assessment of implementation challenges must follow these connections rather than isolate the fuel from the value chain that produces and distributes it.

### 1.2 Urgency and strategic rationale

The strongest rationale for B50 is energy security. Indonesia has experienced declining domestic crude-oil output relative to demand and has historically relied on imported petroleum products. Substituting domestically produced FAME for a larger share of diesel consumption can reduce direct exposure to imported diesel and may improve the resilience of the current account when international oil prices rise (Silalahi, Simatupang and Siallagan, 2020a; Sahara et al., 2022). At the same time, the policy can create a stable domestic demand floor for palm oil, potentially moderating the sector's dependence on external markets. This is strategically attractive in an era when trade policy, sustainability regulation and geopolitical fragmentation create uncertainty for globally traded commodities.

Yet energy-security benefits are not synonymous with economy-wide welfare gains. Halimatussadiah et al. (2021) demonstrate that progressive biodiesel mandates can reduce diesel-import expenditure while also reducing potential CPO exports and increasing subsidy requirements, depending on relative prices and policy design. General-equilibrium analysis likewise shows that biodiesel policy creates sectoral and regional reallocation effects rather than a single national dividend (Sahara et al., 2022). More recent system-dynamics work on the food-versus-fuel problem concludes that no policy scenario simultaneously maximises energy independence, economic, social and environmental outcomes, underscoring the importance of explicit trade-off management (Hidayatno et al., 2025). The central policy question is therefore not whether B50 has benefits, but under what conditions those benefits can remain greater than the financial, environmental and distributional costs over time.

The urgency is also agricultural. Oil palm is a perennial crop with a long productive cycle, so today's feedstock availability reflects planting and replanting decisions made years or decades earlier. A significant share of smallholder plantations faces ageing trees and yield gaps, while replanting requires capital, good planting material, technical knowledge, administrative eligibility and an income bridge during the immature period (Petri et al., 2024; Siregar et al., 2024). Agronomic evidence indicates that substantial yield gaps remain in independent smallholder fields and that improved fertilizer management, harvest practices, planting material and other good agricultural practices can raise output on existing land (Monzon et al., 2023; de Vos et al., 2023). Consequently, B50's feedstock challenge is fundamentally a productivity and institutional challenge, not simply a question of whether Indonesia has a large planted area.

A third source of urgency is environmental legitimacy. Palm-based biodiesel can displace fossil diesel, but its lifecycle performance depends on plantation management, fertilizer use, mill emissions, methane management, transport, conversion energy and, most consequentially, land-use history. Indonesian LCA research identifies the plantation stage as a major environmental hotspot in the biodiesel life cycle (Wahyono et al., 2020). Studies of land-use change further demonstrate that oil-palm expansion has historically contributed to forest conversion and carbon-stock loss, although the magnitude and trajectory vary over time and with commodity prices and governance conditions (Cisneros, Kis-Katos and Nuryartono, 2021; Gaveau et al., 2022; Xu et al., 2022). As a result, scaling biodiesel without credible safeguards could weaken the climate rationale of the programme and complicate access to markets that demand traceability and deforestation-free supply chains.

### 1.3 Research problem, objectives and questions

The literature relevant to B50 is fragmented across disciplines. Energy-policy studies examine import substitution, subsidies and macroeconomic impacts; agricultural studies investigate smallholder productivity and replanting; engineering studies examine fuel stability, combustion and emissions; environmental research focuses on lifecycle impacts and land-use change; and governance research studies certification, legality and smallholder inclusion. A high-blend programme such as B50 integrates all of these domains in practice, yet they are rarely synthesised in one upstream-to-end-use analytical framework.

A second problem is temporal. B50 was officially launched in July 2026 and nationwide distribution has been transitional rather than instantaneous. On 9 July 2026, the

Directorate General of New, Renewable Energy and Energy Conservation reported that 3,696 of 6,412 Biosolar stations were already distributing B50, while 2,716 were still distributing B40 and were given a transition period through 30 September 2026 to exhaust stocks (Directorate General of EBTKE, 2026). This means that mature ex-post evidence on B50's nationwide impacts does not yet exist. The present review therefore distinguishes among evidence from earlier Indonesian mandates, B50-specific technical testing and storage research, early implementation observations, and projections. This distinction is necessary to avoid presenting anticipated outcomes as established facts.

The article has three objectives. First, it identifies the main upstream, midstream, downstream, market, fiscal, technical, environmental, social and institutional challenges facing B50. Second, it analyses how those challenges interact and produce feedback effects among energy security, smallholder welfare, industrial competitiveness, food and oleochemical supply, fiscal sustainability and environmental integrity. Third, it develops a policy framework for making implementation adaptive rather than mechanically dependent on a single blending target. These objectives are addressed through four research questions: (1) What challenge domains shape B50 implementation? (2) How do these challenges interact and redistribute risks and benefits? (3) What interventions are required to reduce the most consequential constraints? and (4) What form of adaptive governance can maintain programme sustainability when feedstock, prices, fiscal capacity, technical performance or external regulations change?

## 2. LITERATURE REVIEW AND CONCEPTUAL FOUNDATIONS

### 2.1 Biodiesel as a renewable fuel product

Biodiesel in the Indonesian mandate is predominantly FAME produced from palm-oil feedstocks. FAME is chemically distinct from petroleum diesel, and this matters increasingly as the blend ratio rises. Biodiesel typically has higher oxygen content, different viscosity and density characteristics, greater affinity for water, and greater susceptibility to oxidation than fossil diesel. These properties can improve some combustion and lubricity characteristics while also creating storage, deposit, material-compatibility and maintenance concerns if the fuel is poorly produced, stored or handled (Longanesi et al., 2022; Wahyono et al., 2022). The technical challenge is therefore not captured by the binary question of whether a diesel engine can operate on B50; it concerns whether fuel quality remains within specification throughout production, transport, storage and end use under heterogeneous operating conditions.

Engine studies generally show that palm biodiesel blends can reduce carbon monoxide, unburned hydrocarbons and smoke under many conditions, while changes in brake-specific fuel consumption, thermal efficiency and nitrogen oxides depend on blend level, engine calibration and operating parameters (Uslu, 2020; El-Shafay et al., 2022; Sundar et al., 2022). Much of the experimental literature, however, concerns B20 or lower blends, laboratory engines or controlled test cycles. Such evidence is useful for understanding mechanisms but should not be extrapolated uncritically to a nationwide B50 fleet. Indonesian authorities have attempted to close this evidence gap through multi-sector testing involving road vehicles, mining equipment, agricultural machinery, rail, marine transport and power generation. Heavy vehicles were tested to 40,000 km and light vehicles to 50,000 km before the national launch, providing important evidence of technical readiness for tested categories (Directorate General of EBTKE, 2026). Nevertheless, long-term field performance across older engines, remote distribution chains and variable maintenance regimes remains an implementation issue rather than a closed scientific question.

Storage stability is particularly relevant in a humid tropical archipelago. Oxidation can change acidity and viscosity and create degradation products that contribute to deposits and filter or injector problems, while water contamination can exacerbate microbial and fuel-quality risks. Longanesi et al. (2022) identify molecular composition, contaminants, temperature and light exposure as important drivers of biodiesel oxidation. Indonesian research on palm biodiesel similarly demonstrates that quality changes during prolonged storage require active management (Wahyono et al., 2022). Additive-focused work further shows that oxidation stability can be materially influenced by antioxidant chemistry and dosage, reinforcing the need for formulation and storage-control protocols rather than reliance on blending ratio alone (Lau et al., 2024). B50-specific research by Yuwono et al. (2026) is especially valuable because it evaluates long-term stability under humid tropical storage conditions. Together, these studies suggest that the policy unit of analysis should extend beyond refinery-gate compliance toward end-to-end fuel integrity.

### 2.2 Renewable-energy transition, energy security and political economy

B50 belongs to a broader class of renewable-energy policies in which governments seek multiple objectives simultaneously: import substitution, domestic industrial development, emissions mitigation and rural income support. This multiplicity creates policy complementarities but also makes evaluation difficult. A mandate can be successful in reducing petroleum imports while simultaneously increasing fiscal exposure or opportunity costs in commodity exports. It can increase demand for agricultural feedstock while transmitting benefits unevenly across producers. It can reduce direct fossil-carbon use while creating indirect land-use pressures. Consequently, evaluating B50 requires a multi-criteria framework rather than a single metric such as litres blended or foreign exchange saved.

The political economy of biodiesel financing is central to this framework. Indonesia has used palm-oil-related levies and public fund management to support the price differential between biodiesel and petroleum diesel. System-dynamics analysis shows that fund sustainability is sensitive to CPO production, export volumes, biodiesel demand, price differentials and levy design (Silalahi, Simatupang and Siallagan, 2020b). Progressive blending can therefore create a recursive relationship: higher domestic CPO absorption changes exportable supply and prices; those changes affect levy receipts and biodiesel economics; and the financing mechanism in turn affects the viability of the mandate. Fiscal sustainability is thus endogenous to the market that the policy itself reshapes.

Commodity-price linkages add another layer of complexity. Indonesian evidence indicates that the relationship between crude oil and CPO prices varies across biodiesel policy periods, reflecting the growing connection between vegetable oils and energy markets (Limbong and Halimatussadiah, 2022). Higher blending can strengthen domestic demand, but the price outcome depends on international vegetable-oil markets, crude-oil prices, exchange rates, harvest conditions, export rules and inventory responses. For smallholders, even a rise in CPO prices does not ensure a proportional rise in FFB prices because local marketing chains, quality deductions, transport costs and buyer concentration shape transmission. This is why the literature review emphasis on oligopsony and asymmetric transmission deserves integration with the broader literature rather than treatment as a minor implementation detail (Gultom, 2026).

### 2.3 Upstream productivity, replanting and smallholder inclusion

The long-term physical foundation of B50 is the productivity of existing oil-palm land. Indonesian smallholders are heterogeneous in farm size, market access, agronomy, land legality, farmer-organisation membership and links to mills. Spatial heterogeneity is associated with different productivity outcomes, meaning that a national average obscures highly variable capacities to respond to stronger demand (Sibhatu et al., 2022). Farm-level evidence identifies agronomic management as a major source of yield gaps and indicates considerable scope for sustainable intensification on existing land (Monzon et al., 2023). Other Indonesian studies likewise document technical inefficiency, uneven prosperity-productivity relationships and multidimensional sustainability gaps among smallholder systems, underscoring that the feedstock response depends on farm capability as much as planted area (Abdul et al., 2022; Herdiansyah et al., 2020; Suardi et al., 2022; Sukiyono et al., 2022; Supriatna et al., 2024). This is strategically important because productivity growth can increase feedstock without reproducing the land-expansion pathway that has historically generated environmental conflict.

Replanting is the pivotal transition mechanism. When trees become old, declining yields and increasing harvest costs eventually make replacement economically desirable, but replanting creates several years of lost or reduced income before new palms mature. Petri et al. (2024) identify finance, knowledge and access to inputs as recurring constraints, while Siregar et al. (2024) show that smallholder willingness to participate in replanting programmes depends on more than the nominal availability of public support. Administrative complexity, land documentation, organisational requirements, alternative livelihood options and trust in institutions influence participation. A successful B50 strategy therefore cannot rely on higher CPO prices alone to trigger timely replanting; it requires a coordinated institutional package.

The distributional importance of smallholders extends beyond production. Oil-palm cultivation has contributed to household welfare and human-capital formation in many producing regions, although benefits and risks vary by household and market conditions (Mehraban et al., 2021; Chrisendo, Siregar and Qaim, 2022). Organisational capacity can strengthen smallholder bargaining power and improve access to finance, extension and sustainability certification (Raharja et al., 2020). If B50 creates additional value but that value is captured disproportionately by processors, traders or better-connected producers, the programme may achieve national energy goals without delivering the rural-development narrative often associated with it. Distribution is therefore part of implementation performance, not a secondary social issue.

### 2.4 Sustainability, certification and global market governance

Palm-oil sustainability is governed by overlapping national, private and international standards. Indonesia's ISPO scheme represents state-led mandatory certification, while RSPO is a transnational multi-stakeholder system. Research identifies ambiguities and governance tensions in the relationship among state regulation, private certification and international market expectations (Choiruzzad, Tyson and Varkkey, 2021). Independent smallholders often face the greatest difficulty because certification presupposes land legality, documentation, farmer organisation, record keeping, good agricultural practices and financial capacity that cannot be taken for granted (Watts et al., 2021; Dharmawan et al., 2021).

Certification can produce benefits, but evidence does not support the assumption that certification automatically generates large welfare gains. Santika et al. (2021) find context-dependent village-level effects, while Oliphant and Simon (2022) highlight the costs faced by smallholders considering RSPO certification. More recent panel evidence suggests modest economic benefits and changes in agrochemical use among certified smallholders rather than transformative effects (Renner et al., 2024). These findings imply that traceability and sustainability requirements should be designed as enabling systems rather than compliance filters that exclude independent farmers from formal supply chains.

International regulation reinforces this imperative. The global dependence of downstream economies on Indonesian palm oil means that environmental burdens and trade exposure are transmitted well beyond producing landscapes (Shigetomi, Ishimura and Yamamoto, 2020). Geospatial plantation datasets also demonstrate that the extent and age of oil-palm establishment can increasingly be monitored at landscape scale, providing a technical foundation for better traceability even though farm-level legal and transactional data remain necessary (Danylo et al., 2021). The European Union Deforestation Regulation covers palm oil and requires covered products placed on the EU market to be deforestation-free and legally produced. Following amendments adopted in 2025, the regulation is scheduled to apply from 30 December 2026 to large and medium operators and from 30 June 2027 to most micro and small operators (European Commission, 2026a). Separately, the EU's renewable-energy framework continues to treat oil palm as a high indirect land-use-change-risk feedstock for counting toward renewable-energy targets, subject to specified conditions and a phase-down pathway (European Commission, 2026b). These rules do not directly determine Indonesia's domestic B50 mandate, but they shape the reputational, traceability and export context in which the same upstream palm-oil system operates.

### 2.5 Conceptual framework: B50 as an interconnected system

Recent palm-bioenergy reviews similarly emphasise that sustainability outcomes emerge from interactions among feedstock, technology, policy, economics and environmental governance rather than from fuel conversion alone (Papilo et al., 2022). The review therefore conceptualises B50 through nine connected domains: (1) feedstock availability and productivity; (2) CPO allocation and price dynamics; (3) smallholder welfare and price transmission; (4) fuel quality and end-use compatibility; (5) industrial and logistics infrastructure; (6) fiscal financing; (7) environmental and lifecycle integrity; (8) certification, traceability and market access; and (9) institutional coordination and adaptive governance. These domains are evaluated against five desired outcomes: technical reliability, energy security, economic and fiscal viability, social inclusion, and environmental integrity.

The system perspective is illustrated in Figure 1. Rather than treating B50 as a transaction between a biodiesel plant and a fuel blender, the figure maps the material chain from plantations to end users and overlays the policy, price, trade and sustainability systems that influence it.

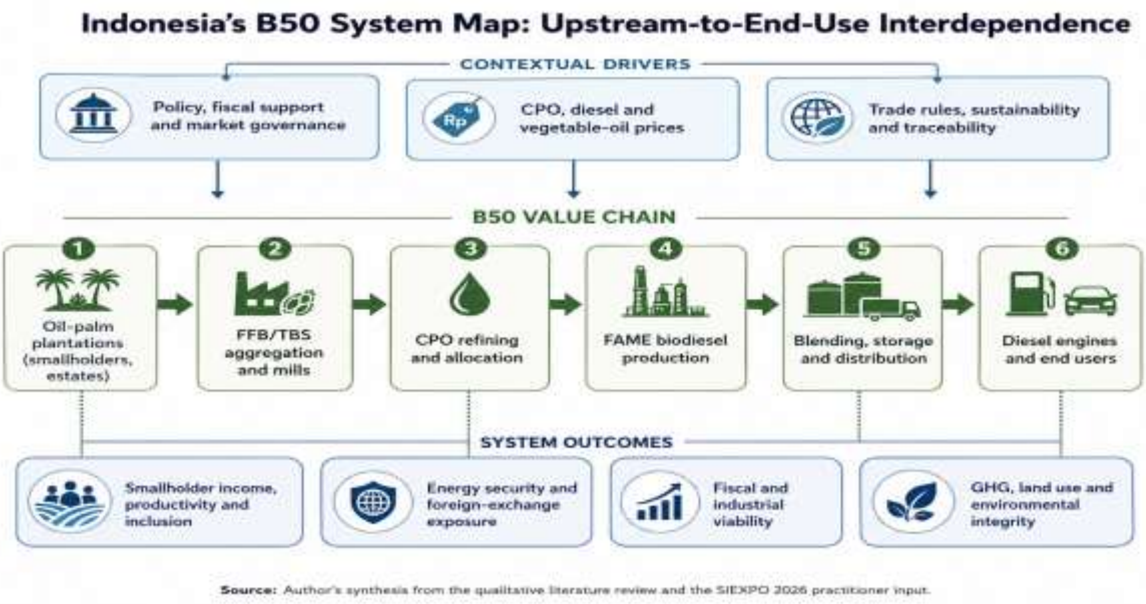


**Figure 1. Indonesia B50 System Map: Upstream-to-End-Use Interdependence. Source: author's synthesis.**

Figure 1 highlights two analytical implications. First, bottlenecks can migrate. If biodiesel production capacity is expanded without corresponding increases in sustainable feedstock, pressure may move upstream into CPO allocation and prices. If feedstock is sufficient but terminal and storage capacity lags, the constraint moves downstream. Second, policy benefits are transmitted through institutions rather than automatically. Higher national CPO demand can support smallholders only when price transmission, market access and farm productivity allow them to capture part of the additional value. The implementation problem is therefore one of synchronisation across interconnected subsystems.

## 3. METHOD

### 3.1 Qualitative integrative literature-review design

This study employs a qualitative integrative literature review and does not constitute a Systematic Literature Review (SLR). The distinction is substantive rather than semantic. An SLR typically seeks a reproducible and exhaustively documented retrieval and screening process around a narrowly specified question, often accompanied by formal quality appraisal and, where appropriate, quantitative synthesis. An integrative review is better suited to a problem in which evidence spans different disciplines, research designs and levels of analysis and where the objective is concept development and thematic synthesis rather than estimation of a pooled effect (Cho, 2022; Dhollande et al., 2021; Oermann, 2021; Fain, 2024).

The B50 implementation problem is intrinsically heterogeneous. Relevant evidence includes macroeconomic modelling, system dynamics, agronomic field studies, smallholder household surveys, governance case studies, lifecycle assessment, remote-sensing studies, fuel-storage experiments and engine-performance tests. Restricting the review to one study design would remove precisely the cross-domain evidence needed to understand system interactions. The review therefore follows a concept-centric approach: sources are organised around the challenge domains and causal mechanisms they illuminate, rather than being summarised sequentially article by article.

### 3.2 Literature identification and source hierarchy

The principal scholarly evidence base consists of peer-reviewed journal literature published from 2020 through August 2026. Searches were conducted iteratively around combinations of the terms Indonesia, B30, B35, B40, B50, biodiesel, palm oil, crude palm oil, smallholder, replanting, yield gap, price transmission, subsidy, levy, fuel stability, engine, emissions, lifecycle assessment, land-use change, ISPO, RSPO, traceability and deforestation. Backward and forward citation tracing was used to identify conceptually important studies, with emphasis on Indonesian evidence and on recent technical research directly relevant to higher palm-biodiesel blends.

A source hierarchy was applied. Peer-reviewed journal articles formed the analytical core. Official Indonesian government sources were used only for current policy status, rollout data, official projections and technical-test information that post-date most journal publications. European Commission and EU legal sources were used for current external regulatory conditions. The literature review and recent market observations were treated as inputs to be triangulated, not as substitutes for peer-reviewed evidence. This hierarchy is important because several claims in the practitioner and policy discourse are projections, interpretations or early observations rather than causal findings.

### 3.3 Thematic coding and synthesis

The synthesis combined deductive and inductive coding. The deductive categories were derived from the upstream-to-end-use conceptual framework: feedstock, markets, smallholders, technology, infrastructure, finance, environment, certification and governance. Within those categories, inductive coding identified recurrent mechanisms such as ageing palms, yield gaps, income loss during replanting, asymmetric price transmission, oxidation and water management, spatial logistics, price-differential exposure, indirect land-use risk and compliance burdens. Contradictory results were retained rather than forced into a single consensus. For example, the review treats diesel-import substitution and foregone CPO export opportunity as simultaneous effects whose relative importance depends on prices and scenarios.

The analysis then moved from themes to cross-domain relationships. A finding was considered systemically important when it could transmit effects from one domain to another, such as a CPO price increase that affects feedstock incentives, food and export allocation, levy revenue and the cost of the biodiesel programme. This step allows the review to distinguish primary constraints from secondary symptoms and to identify where policy interventions may simply relocate a bottleneck.

### 3.4 Trustworthiness, evidence timing and limitations

Triangulation was used to strengthen trustworthiness. Policy claims were compared with peer-reviewed economic and engineering evidence; environmental claims were compared across LCA, land-use and governance literature; and practitioner observations were interpreted in light of established market and institutional mechanisms. The review also distinguishes ex-ante from ex-post evidence. Government projections for B50 are reported as projections, while observations from B20-B40 are used as historical experience rather than assumed B50 outcomes.

The principal limitation is the recency of B50. As of August 2026, the programme has been operating nationally for only a short period and physical distribution is still completing the transition from B40 inventories. There is therefore no credible basis for a long-run ex-post assessment of B50's causal effects on CPO prices, FFB prices, fleet durability, fiscal balances or land-use change. The purpose of this review is instead to identify implementation conditions and risk pathways using the strongest available evidence. This limitation is also a reason to recommend adaptive monitoring as part of policy design rather than waiting for problems to become visible through retrospective evaluation.

## 4. RESULTS: THEMATIC FINDINGS ON B50 IMPLEMENTATION CHALLENGES

### 4.1 Feedstock sufficiency, ageing plantations and the productivity constraint

The first challenge is the scale and durability of feedstock supply. Official B50 projections imply a substantial increase in biodiesel and CPO absorption, while the literature review presents an even higher indicative CPO requirement of roughly 17-18 million tonnes per year. The difference between estimates illustrates why policy planning must be explicit about conversion assumptions, production yields, allocation rules and whether figures refer to CPO-equivalent requirements or total biodiesel demand. What is unambiguous is the direction of change: B50 raises domestic palm-oil demand relative to B40 and therefore increases the value of marginal improvements in plantation productivity.

Indonesia's feedstock problem is not primarily a shortage of planted area; it is a problem of productive capacity and its distribution. The literature review notes that ageing estates are becoming more prominent, smallholder productivity remains comparatively low, the replanting programme has not kept pace with ageing, plantation expansion is increasingly constrained, and crop health problems such as Ganoderma add risk (Gultom, 2026). Peer-reviewed evidence supports the emphasis on yield rather than simple area expansion. Monzon et al. (2023) find large agronomic yield gaps in smallholder fields, while de Vos et al. (2023) show that harvest management is itself an important source of recoverable losses. Abdul et al. (2022) similarly identify technical inefficiency in Indonesian oil-palm production, indicating scope for higher output from existing resources.

Replanting is therefore a strategic energy policy even though it takes place in agriculture. Petri et al. (2024) identify uneven access to finance, knowledge, and high-quality planting material as major barriers. Siregar et al. (2024) show that smallholder participation cannot be explained by financial incentives alone; institutional and farm-level conditions matter. The core policy tension is temporal: B50 increases feedstock demand immediately, whereas replanting lowers output in the short term and only increases yield after new palms mature. A programme that rewards current production but does not finance the transition period can unintentionally delay replanting, thereby weakening future feedstock resilience.

The strongest long-run response is productivity-led intensification. Monzon, Slingerland, Rahutomo et al. (2021) argue for climate-smart intensification, and Fosch et al. (2023) show that replacing unproductive palm with smallholder plantations under appropriate conditions can advance several Sustainable Development Goals. Higher yields on existing land reduce the need to interpret B50 feedstock growth as a mandate for extensive expansion. However, intensification is not environmentally neutral by definition: fertilizer use, agrochemical management, water, labour and biodiversity effects still require governance. Productivity must therefore be paired with sustainability standards and farm-level support.

### 4.2 The food-energy-oleochemical-export allocation trade-off

The second challenge is competition for a common CPO pool. Palm oil is simultaneously consumed as food, used in oleochemicals, exported, and converted into biodiesel. Raising the biodiesel mandate changes the allocation among these uses even if total production also rises. The literature review explicitly identifies this multi-use trade-off and warns that it becomes sharper as biodiesel demand increases (Gultom, 2026). Hidayatno et al. (2025) reach a similar conclusion through system modelling: policies that improve energy independence can impose costs elsewhere, and no scenario optimises all sustainability dimensions at once.

This trade-off is frequently simplified into a food-versus-fuel debate, but the Indonesian case is broader. Export earnings and foreign-exchange effects must be considered alongside domestic food prices and industrial use. Halimatussadiah et al. (2021) show that the value of potential CPO exports forgone under higher biodiesel absorption can, in some scenarios, exceed the foreign exchange saved from lower diesel imports. Sahara et al. (2022), using a computable general equilibrium framework, find broader production, income and regional effects that differ across sectors. These studies do not imply that biodiesel should be rejected; they show that gross import-saving calculations are insufficient to evaluate net welfare.

The trade-off is also dynamic. A higher CPO price can stimulate productivity investment and replanting, but it can also raise the cost of biodiesel feedstock and intensify political pressure around cooking-oil affordability and exports. A lower CPO price can improve the economics of biodiesel relative to feedstock but reduce farmer incentives and levy revenue. Because crude oil and CPO prices are themselves related through changing energy and commodity-market conditions, the cost-benefit balance can change quickly (Limbong and Halimatussadiah, 2022). This volatility supports an adaptive policy architecture in which the mandate is accompanied by monitored allocation, price and stock indicators rather than treated as operationally independent from the rest of the palm-oil economy.

### 4.3 Smallholder welfare, oligopsony and asymmetric price transmission

The third challenge is ensuring that the policy's agricultural benefits reach smallholders. The practitioner's ideal pathway is intuitive: B50 increases CPO demand, stronger demand supports CPO prices, and mills then pay more for FFB. Yet the literature review notes that the FFB supply chain contains intermediaries and transaction costs and that local mill markets can be oligopsonistic. It further observes that independent farmers do not always receive the reference price and that mills consider quality deductions, extraction rates, operational costs, logistics, and price risk when setting purchase prices (Gultom, 2026). These mechanisms make asymmetric or delayed price transmission plausible.

This issue matters because national-level value creation can coexist with unequal farm-level outcomes. Independent smallholders vary in distance to mills, road access, bargaining power, farmer-group membership, land legality and fruit quality. Institutional strengthening can reduce some of these disadvantages by improving collective marketing, finance and information (Raharja et al., 2020). Conversely, poorly organised farmers may depend on collectors and delivery-order holders, increasing the number of margins between farmgate and mill. The B50 programme therefore needs a farmgate transmission indicator, not merely a CPO price indicator, if farmer welfare is an explicit objective.

The wider smallholder literature reinforces the point that welfare is conditional. Mehraban et al. (2021) show that oil-palm cultivation can improve household welfare while also exposing households to commodity-related economic risk. Chrisendo, Siregar and Qaim (2022) find positive effects on living standards and human-capital formation, but these benefits arise within particular institutional and market settings. B50 may create a stronger domestic demand environment, yet whether that environment stabilises smallholder income depends on how local market power, productivity, cost inflation and quality standards evolve.

A further risk is a two-tier supply chain. Higher sustainability and traceability requirements can favour organised, documented and certified producers while marginalising independent farmers who lack legal documentation or digital records. Watts et al. (2021) and Dharmawan et al. (2021) show that certification barriers are closely tied to legality, group organisation, farm practices and institutional support. If B50 is to serve both energy sovereignty and rural development, smallholder inclusion must be built into procurement, traceability, replanting and extension policy rather than assumed to follow from higher demand.

### 4.4 Fuel quality, storage stability and engine compatibility

The fourth challenge is technical reliability at scale. Indonesia's multi-sector tests provide stronger direct evidence for B50 than was available for earlier high-blend debates. According to EBTKE, B50 was tested in six sectors and met the relevant quality parameters for tested applications before launch (Directorate General of EBTKE, 2026). This substantially reduces uncertainty about short- to medium-distance operation in tested vehicles and equipment. However, the national implementation challenge is broader than the test programme because millions of engines differ by age, injection technology, maintenance quality, load profile and storage pattern.

High FAME content makes storage discipline more important. Oxidation can increase acidity and viscosity and produce deposits, while water and microbial contamination can compromise fuel handling. Longanesi et al. (2022) review the chemical pathways underlying biodiesel oxidation, and Wahyono et al. (2022) demonstrate that long-term storage alters relevant quality characteristics of palm biodiesel. Yuwono et al. (2026), focusing specifically on B50 under humid tropical conditions, show that storage strategy deserves explicit attention rather than being treated as a peripheral downstream issue. In an archipelagic country where fuel may spend extended periods in terminals, tanks, vessels and remote facilities, storage stability becomes part of energy-security performance.

Engine-performance literature also cautions against overly simple expectations. Uslu (2020) and El-Shafay et al. (2022) show that blend composition and operating parameters affect efficiency and emissions, while Sundar et al. (2022) demonstrates the potential of additives and formulation changes to improve certain performance characteristics. Awang et al. (2022) further illustrates how multi-component fuel formulations alter performance, emissions and lubricity. These findings are not direct forecasts of nationwide B50 performance, but they underscore the sensitivity of outcomes to fuel formulation and engine conditions.

The appropriate policy response is continuous surveillance rather than a one-off compatibility declaration. A national B50 quality system should track batch-level FAME quality, blend accuracy, water content, oxidation stability, storage time, filter events, injector problems, fuel-pump failures and manufacturer-specific field incidents. Data should be disaggregated by sector and vehicle age. Such a system would convert technical implementation from a binary pre-launch test into a learning process capable of detecting low-frequency failures that only emerge at scale.

### 4.5 Industrial capacity, blending, storage and archipelagic logistics

The fifth challenge is infrastructure. The move to B50 increases the absolute volume of biodiesel that must be produced, transported, stored and blended while maintaining consistent specifications. Capacity is not only a question of annual nameplate output. It includes the geographical location of biodiesel plants, availability of dedicated tanks, terminal turnover, blending equipment, metering accuracy, shipping capacity, road logistics, quality laboratories and contingency stocks. The literature review identifies additional biodiesel capacity, blending facilities, storage terminals and distribution systems as implementation requirements (Gultom, 2026).

The early rollout data illustrate this distinction between legal implementation and physical conversion. On 9 July 2026, only about 57 per cent of the 6,412 Biosolar stations reported by Pertamina were already distributing B50; the rest were still depleting B40 inventories under an authorised transition period (Directorate General of EBTKE, 2026). This is not evidence of policy failure. Rather, it demonstrates that a high-blend mandate operates through inventory turnover and logistics, not simply a regulatory start date. Transition management is especially consequential when two blend grades coexist because mislabelling, commingling and variable storage duration can complicate quality control.

Indonesia's geography magnifies these issues. A supply chain serving Java differs from one supplying eastern islands, mining sites, plantations or small coastal terminals. Long transport distances and slower tank turnover increase the importance of oxidation stability and water management. Industrial capacity should therefore be assessed spatially, using terminal-level demand, transport time and storage conditions rather than a national aggregate. Redundancy is also important: a system that is efficient under normal operations but dependent on a small number of production or shipping nodes may be vulnerable to disruptions.

The infrastructure challenge is consequently a resilience problem. Strategic planning should identify critical nodes, alternative routes, minimum quality-testing capacity and emergency procedures for off-specification batches. Digital batch traceability from biodiesel plant to terminal and final blend would also support rapid investigation when fuel-quality incidents occur. This is one area in which data governance and physical infrastructure are inseparable.

**4.6 Fiscal sustainability and biodiesel financing**

The sixth challenge concerns who absorbs the economic difference between FAME and petroleum diesel. Indonesia's biodiesel programme has relied on a financing architecture linked to palm-oil levies and compensation. This arrangement has political appeal because it connects value generated by the palm-oil sector to domestic downstreaming, but it is exposed to cyclical commodity and energy prices. Silalahi, Simatupang and Siallagan (2020b) show that biodiesel-fund sustainability depends on the interactions among exports, levies, production, blending demand and price differences. Increasing the mandate raises the volume over which any price gap must be financed.

The most difficult scenario occurs when policy objectives pull the fund in opposite directions. If CPO prices rise strongly relative to diesel, biodiesel compensation requirements can increase even as domestic CPO demand is already tightening the market. If exports fall because more CPO is absorbed domestically, the base from which export-related revenues are collected may also change. Conversely, a high crude-oil price improves the relative economics of biodiesel and strengthens the import-substitution case. Halimatussadiah et al. (2021) demonstrate that subsidy outcomes are highly scenario-dependent, which means a single static funding assumption is inappropriate for a long-lived B50 policy.

Fiscal sustainability should therefore be evaluated through stress tests rather than average-year estimates. At minimum, the government should model combinations of high CPO/low diesel prices, low CPO/high diesel prices, exchange-rate depreciation, production shocks and export changes. The purpose is not to predict one future but to identify the financing requirement under adverse combinations. A transparent dashboard should distinguish gross foreign-exchange savings from compensation expenditure, levy revenue, foregone export value and distributional effects. Research on Indonesia's palm-oil revenue-sharing arrangements further suggests that fiscal design can be used to redistribute sectoral benefits toward producing regions and strengthen environmental incentives, an issue that becomes more salient as biodiesel deepens the domestic value of CPO (Nurfatriani et al., 2022).

Diversification of funding can reduce single-instrument risk, but it raises political-economy questions. Any new fuel levy, carbon-related instrument or general-budget contribution changes who pays for B50. The choice should therefore be evaluated for incidence, transparency and consistency with energy-transition objectives. A financing mechanism that becomes fiscally unsustainable can undermine the credibility of the mandate even when the physical supply chain is technically capable of delivering B50.

**4.7 Environmental and climate integrity**

The seventh challenge is ensuring that B50's renewable-energy claim corresponds to credible lifecycle outcomes. Replacing petroleum diesel with biodiesel reduces the fossil share of the blended fuel, but the climate result depends on emissions throughout the palm-oil and biodiesel supply chain. Wahyono et al. (2020) identify plantation activities as an important environmental hotspot in Indonesian palm-biodiesel production. Fertilizer production and use, field emissions, mill energy, methane from palm-oil mill effluent, transport and conversion all affect lifecycle performance. Therefore, tailpipe accounting alone is not an adequate measure of climate benefit.

Land-use change is the most contentious dimension. Meijaard et al. (2020) show that the environmental consequences of palm oil need to be understood comparatively and in context, because oil palm is a highly productive oil crop but expansion can impose severe biodiversity and carbon costs when it replaces natural ecosystems. Cisneros, Kis-Katos and Nuryartono (2021) find that economic and political incentives can reinforce forest conversion, while Gaveau et al. (2022) document the connection between lower palm-oil expansion, lower prices and slowing deforestation. Xu et al. (2022) identify expansion into carbon-rich forests in Southeast Asia, confirming that the location and history of production matter for carbon accounting.

These findings create a clear policy implication: the environmental credibility of B50 depends on decoupling feedstock growth from new conversion of high-carbon and high-biodiversity land. Productivity-led intensification and replanting are therefore climate safeguards as well as agricultural policies. Li (2024) argues that stronger support for independent smallholders can secure livelihoods without requiring more deforestation, while Monzon et al. (2021) emphasise climate-smart intensification. The environmental objective is not simply to produce more CPO; it is to increase the amount of traceable, low-risk CPO produced per hectare of already established plantation.

Environmental monitoring should also include biodiversity and agrochemical indicators, not only carbon. Dalheimer et al. (2024) demonstrate that smallholder production has measurable biodiversity trade-offs, and certification research indicates that some sustainable-practice improvements may coexist with intensive input use. A robust B50 sustainability framework should therefore track land-use change, peat, fire, fertilizer efficiency, methane management, biodiversity risk and farm-level legality in addition to aggregate emissions estimates.

### 4.8 Certification, traceability and international market access

The eighth challenge is governance of origin. A high domestic biodiesel mandate does not remove Indonesia from global sustainability politics because the same plantations and mills also supply export chains. Traceability systems therefore have dual value: they support international market access and strengthen domestic claims that B50 feedstock is not associated with recent deforestation or illegal production.

Smallholder inclusion is the critical difficulty. Watts et al. (2021) find that successful certification depends on pre-existing socio-economic conditions, legality, group organisation, farm management and local supply chains. Dharmawan et al. (2021) identify agrarian, structural and cultural constraints that reduce readiness for ISPO, and Pramudya et al. (2022) argue that incentives, advisory support and better government coordination are needed to make mandatory certification workable for smallholders. A traceability system that requires sophisticated documentation without simultaneously solving land documentation and farmer-organisation problems can create exclusion rather than sustainability.

Evidence on certification outcomes also supports a pragmatic rather than symbolic approach. Santika et al. (2021) find that the effects of certification on village well-being and poverty vary with context. Oliphant and Simon (2022) emphasise the financial costs and incentives facing individual smallholders, while Renner et al. (2024) report modest economic benefits and changes in agrochemical practices among certified farms. These findings suggest that certification should be treated as part of a broader capability-building process, not as a binary label that guarantees sustainability. At the firm level, sustainable-production policy can also alter performance incentives and compliance costs, reinforcing the need to align environmental regulation with commercially workable implementation mechanisms (Kunene and Chung, 2020).

External regulation makes the timeline more urgent. The EUDR is scheduled to start applying to large and medium operators at the end of 2026, while the EU's high-ILUC-risk treatment of palm oil remains relevant to renewable-energy market claims (European Commission, 2026a; European Commission, 2026b). Indonesia may contest aspects of these rules, but a domestic ability to trace origin, verify legality and demonstrate land-use history is valuable regardless of the trade dispute. The strategic response is therefore to build interoperable data systems that serve both national governance and external due diligence while preventing compliance costs from being shifted disproportionately onto smallholders.

### 4.9 Institutional coordination and data governance

The ninth challenge is institutional. B50 crosses ministerial and organisational boundaries: energy authorities set fuel policy and technical standards; agriculture agencies influence plantation productivity and replanting; finance and palm-oil fund institutions shape compensation; state-owned and private companies manage production and distribution; regional governments influence land and FFB-price administration; and certification and environmental agencies govern sustainability. Weak coordination can cause one institution to optimise its own target while transferring costs to another part of the system.

Current policy discussions acknowledge the data problem. In April 2026, the Coordinating Ministry for Economic Affairs emphasised stronger data governance alongside B50 preparation and the need to balance renewable-energy acceleration, sustainable feedstock readiness and attractive pricing for business actors (Coordinating Ministry for Economic Affairs, 2026). This is a crucial recognition. An adaptive mandate requires timely and compatible data on CPO production, inventories, biodiesel output, terminal stocks, actual blending, FFB prices, fund balances, fuel-quality incidents, replanting progress and land-use indicators.

The problem is not a lack of data in the abstract but fragmentation, different definitions and uneven timeliness. The discrepancy between CPO-requirement estimates in official launch documents and the literature review illustrates how varying assumptions can generate materially different planning figures. A national B50 dashboard should therefore publish definitions, conversion factors and revisions. Transparency is particularly important when policy decisions affect food, exports, subsidies and farmer incomes.

Institutional coordination should culminate in a formal review mechanism. Rather than viewing the B50 percentage as the only decision variable, government can maintain the mandate while adjusting supporting instruments when thresholds are breached. Examples include temporary inventory measures during supply shocks, accelerated replanting finance when productivity indicators deteriorate, additional quality testing when incident rates rise, or revisions to compensation parameters when fiscal stress exceeds predefined limits. Such governance does not weaken policy commitment; it makes the commitment more resilient.

### 4.10 Geopolitics, market power and technology lock-in

A final cross-cutting finding concerns the strategic narrative surrounding palm oil. The literature review argues that domestic biodiesel demand can shift the "centre of gravity" of the palm-oil market toward Indonesia, strengthen bargaining power and act as a shock absorber when global CPO prices fall (Gultom, 2026). There is a plausible economic mechanism behind this argument: a large mandated domestic buyer reduces dependence on discretionary export demand. However, describing Indonesia as a permanent "price maker" would be too strong because CPO remains embedded in global vegetable-oil substitution, crude-oil dynamics, exchange rates, weather, and policy changes in other producing and consuming countries.

B50 can nevertheless increase strategic optionality. A larger domestic energy market gives Indonesia another outlet for CPO and can support downstream industrial learning. The risk is technological lock-in. FAME biodiesel competes for investment, feedstock and policy attention with other decarbonisation pathways, including renewable diesel or HVO, sustainable aviation fuel (SAF), electrification and efficiency improvements. An energy system that invests heavily in one pathway without periodically reassessing relative carbon and economic performance may create stranded assets or delay lower-carbon alternatives.

The appropriate long-term framing is therefore portfolio-based. B50 can serve as an important transitional and strategic fuel while the government develops SAF, HVO, electrification and other low-carbon options. The criterion should be lifecycle performance and system value rather than institutional attachment to a particular molecule. This is consistent with the practitioner's observation that biodiesel may be a starting point for broader palm-based biofuel development, but it requires technology-neutral evaluation of future pathways.

The relationships among these findings are summarised in Figure 2. The call-out is important because the figure shows why resolving one constraint can create pressure elsewhere: stronger biodiesel demand affects CPO allocation and prices; prices affect smallholders, levy revenues and fiscal requirements; productivity affects land-use pressure; and infrastructure and quality shape whether nominal supply becomes usable energy.

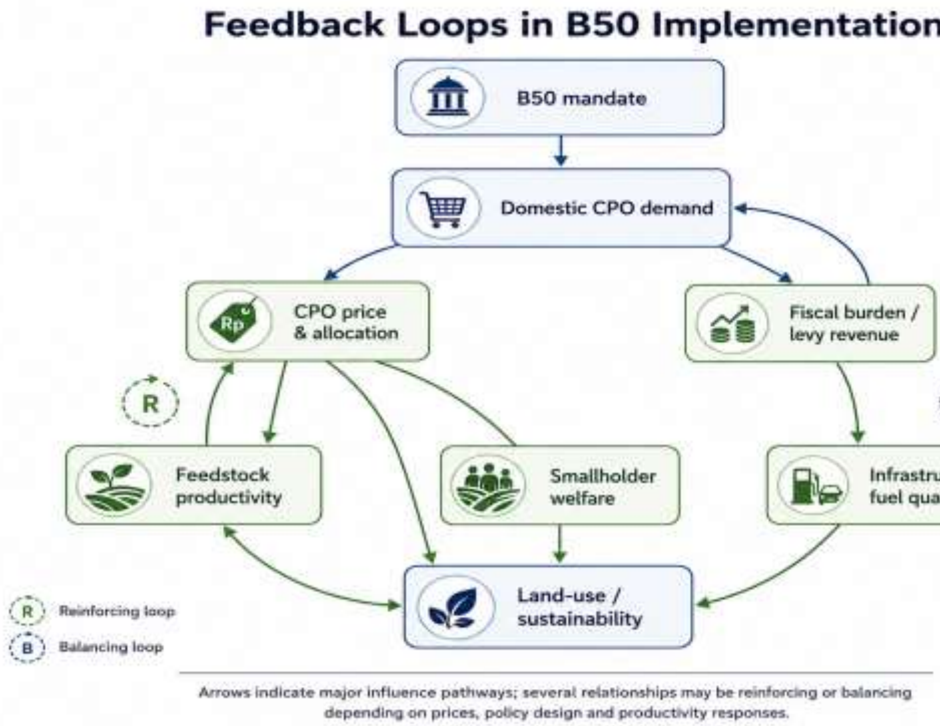


**Figure 2. Feedback Loops in B50 Implementation. Source: author's synthesis.**

Figure 2 reinforces the central result of the review: B50's dominant implementation risk is bottleneck migration. If policy is evaluated only at the blending stage, the system can appear successful while costs accumulate in agriculture, public finance, smallholder distribution or environmental governance. Conversely, well-designed interventions can generate co-benefits. Replanting with high-quality planting material can raise future feedstock supply, improve smallholder income and reduce pressure for expansion; better traceability can support international market access and domestic lifecycle accounting; and stronger fuel-quality data can improve both reliability and public confidence.

## 5. DISCUSSION AND ANALYSIS

### 5.1 B50 as a coupled socio-technical and political-economy system

The literature synthesis suggests that B50 should be governed as a coupled system rather than a linear supply chain. This distinction changes the interpretation of success. In a linear view, the key question is whether sufficient FAME can be produced and blended to reach 50 per cent. In a system view, the relevant question is whether the higher blend remains technically reliable, economically viable, socially legitimate and environmentally credible while the surrounding system adapts. The first can be achieved through capacity expansion; the second requires coordinated structural change.

This perspective explains why apparently separate controversies recur. The food-versus-fuel debate is connected to plantation productivity because higher yields change the severity of allocation competition. The subsidy debate is connected to export policy because levy revenues and CPO availability depend on trade flows. The smallholder debate is connected to traceability because legal documentation and farmer organisation determine access to formal value chains. The engine-compatibility debate is connected to logistics because even a technically sound blend can deteriorate in storage. B50 governance must therefore focus on interfaces among sectors, not just sector-specific targets.

The system view also helps interpret early 2026 evidence cautiously. The literature review notes that FFB prices appeared relatively stagnant after the initial B50 implementation period even while international CPO prices had risen and domestic CPO prices fluctuated. This is consistent with a hypothesis of delayed or asymmetric transmission, but the observation window is too short and contemporaneous policy changes are too numerous to identify B50 as the cause. The correct analytical response is not to dismiss the observation or to claim causality; it is to turn it into a monitoring question: how quickly and symmetrically are changes in CPO value transmitted to different classes of smallholders after controlling for location, quality and market structure?

### 5.2 Reassessing B50 through an energy-transition trilemma

The synthesis can be condensed into an energy-transition trilemma with three vertices: energy security, economic and social viability, and environmental integrity. B50's political attractiveness comes from its potential to advance all three, but the literature shows that progress at one vertex does not automatically improve the others.

At the energy-security vertex, the programme is strong. Domestic FAME can substitute for imported diesel and build domestic industrial capacity. Government projections that B50 can eliminate remaining diesel-product imports should be evaluated against realised import data over a full year, but the physical substitution mechanism is clear (Ministry of Energy and Mineral Resources, 2026a). Energy security should nevertheless include reliability, not only import shares. If feedstock, storage quality or distribution infrastructure become vulnerable, the system may exchange external dependence for domestic bottlenecks.

At the economic and social vertex, the evidence is mixed by design. Biodiesel can create domestic value added, employment and farmer demand, but opportunity costs arise when CPO is diverted from exports or other domestic uses, and compensation costs rise when feedstock is expensive relative to diesel (Halimatussadiah et al., 2021; Sahara et al., 2022). Social outcomes depend on transmission. Smallholders benefit most when replanting, productivity, market access and organisation improve, not merely when aggregate CPO absorption increases.

At the environmental vertex, B50 can contribute to decarbonisation only when lifecycle emissions and land-use effects are managed. The high productivity of oil palm per hectare is an advantage, but forest and peat conversion can dominate the carbon balance. Sustainable intensification, methane capture, fertilizer efficiency and traceable no-deforestation supply are therefore integral to the energy policy, not add-on corporate social responsibility measures (Meijaard et al., 2020; Wahyono et al., 2020; Xu et al., 2022).

Figure 3 illustrates the trilemma and places adaptive governance at its centre. The policy objective is not to maximise one vertex but to maintain acceptable performance across all three as market and technical conditions change.


**Figure 3. The B50 Sustainability Trilemma. Source: author's synthesis**.

The figure clarifies why a static measure of success is inadequate. A year with high crude-oil prices may make B50 economically attractive and strengthen energy-security gains, whereas a year with high CPO and low diesel prices may generate greater fiscal pressure. A harvest shock can increase food-energy competition, while successful replanting can relax it. Environmental performance can improve even with growing biodiesel volumes if feedstock growth comes from higher yields on existing land and methane management, but deteriorate if stronger prices induce conversion of high-carbon land. Adaptive governance is the institutional capacity to recognise and respond to these changing configurations.

**5.3 Synchronising upstream and downstream transformation**

The first strategic implication is that upstream and downstream investments must be sequenced together. Indonesia has demonstrated an ability to expand biodiesel production rapidly, but the feedstock base has a slower biological adjustment cycle. B50 therefore creates a mismatch between industrial scaling, which can occur within years, and plantation renewal, which requires years before full productivity. This mismatch can be reduced by accelerating replanting before severe age-related yield decline becomes widespread.

Replanting policy should be redesigned as an integrated smallholder transition package. A grant or credit line alone cannot solve the problem because farmers also need verified land status, high-quality seedlings, agronomic support and replacement income. Public policy can combine replanting finance with intercropping or temporary livelihood support during immature years, conditional access to certified seed, extension packages and farmer-group strengthening. The objective should be measurable yield improvement and legal inclusion, not simply hectares registered in the programme.

Downstream infrastructure requires similar integration. Production capacity should be matched with terminal storage, laboratory capability, tank turnover and demand geography. National quality standards are necessary but insufficient if sampling is concentrated upstream. Quality assurance should include chain-of-custody testing and digital batch tracking. The aim is to know not only that biodiesel left a plant within specification but that the B50 delivered to a remote user still satisfies critical parameters after transport and storage.

This synchronisation principle also applies to data. Agriculture, energy, finance and environmental agencies need common identifiers and compatible reporting cycles so that policymakers can connect plantation output, biodiesel allocation, terminal inventories, FFB prices, fund balances and land-use indicators. Without such integration, government may respond to symptoms using partial information and unintentionally intensify another bottleneck.

**5.4 From fixed blending to adaptive mandate governance**

The article does not propose abandoning B50 or frequently changing the headline blend in response to normal market fluctuations. Constant policy reversals would damage investment certainty. Instead, it proposes adaptive mandate governance: a stable strategic commitment to B50 supported by predetermined monitoring thresholds and flexible supporting instruments.

Five threshold families are particularly important. The first is feedstock adequacy, including CPO production, inventories, replanting progress and the food-energy allocation balance. The second is fiscal exposure, including the FAME-diesel price spread, compensation commitments, levy revenue and fund reserves. The third is technical reliability, including off-specification batches, oxidation indicators, storage duration and fleet incident rates. The fourth is distribution performance, including regional B50 availability and terminal inventories. The fifth is sustainability integrity, including traceability coverage, land-use change, peat and fire indicators, smallholder certification and lifecycle-emission performance.

When a threshold deteriorates, policy should activate the instrument best suited to the cause. A temporary feedstock shock may call for inventory management or adjustments to non-essential allocation rather than weakening long-term replanting incentives. Persistent low productivity should trigger agronomic and PSR interventions. Rising technical incidents should trigger targeted quality audits and sector-specific maintenance guidance. Fiscal stress should trigger financing reforms and transparent review of compensation parameters rather than hidden arrears. This approach preserves strategic direction while making implementation evidence-responsive.

Adaptive governance also improves political accountability because trade-offs become explicit. Citizens and market actors can see whether a policy intervention is responding to food affordability, fuel reliability, farmer welfare, fiscal limits or environmental risk. Transparent triggers reduce the risk that ad hoc changes are interpreted as policy inconsistency or captured by particular interest groups.

**5.5 An integrated policy package**

The synthesis points to an integrated package built around six priorities. First, accelerate productivity and replanting. The highest-return long-term intervention is likely to be closing yield gaps on existing land using certified planting material, appropriate fertilizer, timely harvesting, extension and disease management, coupled with a replanting income bridge for smallholders. This simultaneously supports feedstock security and reduces expansion pressure.

Second, reform smallholder market institutions. Government and regional authorities should improve transparency around FFB reference prices, quality deductions and actual mill purchase prices, while strengthening farmer groups and digital transaction records. Monitoring asymmetric price transmission would provide direct evidence on whether B50's domestic demand benefit reaches farmers. Competition policy and mill-access issues should be investigated in locations where buyer concentration is high.

Third, make fuel-quality assurance end-to-end. B50 should be treated as a product whose quality can change after blending. National implementation therefore needs terminal and retail sampling, storage-time protocols, water and oxidation management, incident reporting, and manufacturer-specific technical feedback. Remote and low-turnover locations should receive particular attention because their risk profile differs from high-throughput urban terminals.

Fourth, stress-test and diversify financing. The biodiesel fund should publish scenario analyses that combine CPO, diesel and exchange-rate shocks. Financing reforms should be judged not only by revenue adequacy but by who ultimately pays. Any broader energy levy or carbon-related instrument should be transparently justified and aligned with the distributional goals of the transition.

Fifth, unify sustainability and traceability policy. ISPO strengthening, farmer legality programmes, digital plot mapping, mill-level chain of custody and deforestation monitoring should be connected rather than implemented as parallel initiatives. Smallholder support must precede enforcement where compliance requires capacities that farmers do not yet possess. The goal is universal inclusion in a credible data system, not statistical improvement achieved by excluding difficult suppliers.

Sixth, integrate B50 into a diversified low-carbon transport and fuel portfolio. FAME should be evaluated alongside HVO/renewable diesel, SAF, electrification, modal shift and efficiency. Research and investment policy should remain open to pathways that deliver lower lifecycle emissions or higher system value. This reduces the risk that success in building one industry becomes an argument for indefinite technological lock-in.

**5.6 Contribution to the literature**

This review contributes in three ways. First, it integrates literatures that are usually analysed separately. Existing research provides strong evidence on specific parts of the system, but B50 implementation requires interaction among them. The article therefore reframes the research object from "biodiesel policy" to a coupled palm-oil-energy system.

Second, the review moves beyond the binary debate over whether palm biodiesel is beneficial or harmful. The evidence shows that both benefits and risks are real and conditional. B50 can improve energy security and industrial development while creating fiscal, distributional and environmental pressures. The more productive research question is therefore which institutional conditions increase co-benefits and constrain adverse feedbacks.

Third, the article introduces bottleneck migration and adaptive mandate governance as organising concepts. Bottleneck migration explains why a successful intervention in one subsystem can expose another constraint. Adaptive governance provides a policy response: maintain strategic consistency while continuously adjusting the supporting instruments to observed conditions. These concepts are particularly useful during the current early implementation period, when definitive ex-post evidence is unavailable but rapid learning is possible.

## 6. CONCLUSION AND POLICY RECOMMENDATIONS

B50 is one of the most consequential renewable-energy interventions in Indonesia because it connects national energy security to the world's largest palm-oil production system. The qualitative literature review identifies nine interconnected implementation challenges: feedstock sufficiency and productivity; CPO allocation and price dynamics; smallholder welfare and price transmission; fuel quality and engine compatibility; industrial and logistics infrastructure; fiscal financing; environmental and lifecycle integrity; certification and traceability; and institutional coordination. None of these challenges can be managed effectively in isolation.

The substantive conclusion is that B50's sustainability depends on co-evolution between upstream agriculture and downstream energy infrastructure. Indonesia possesses a large feedstock base and significant biodiesel-production capability, but the biological and institutional constraints of plantation renewal can become binding as domestic demand rises. Accelerating the Smallholder Palm Oil Replanting programme, closing agronomic yield gaps and ensuring access to high-quality planting material are therefore energy-security measures as much as agricultural-development measures. Expansion of planted area should not be treated as the default supply response because land-use change can undermine the climate legitimacy of the programme.

A second conclusion is that farmer welfare cannot be inferred from CPO demand alone. Oligopsonistic local markets, intermediaries, quality deductions and unequal market access can weaken price transmission. The government should complement national CPO indicators with farmgate data that distinguish independent and partnered smallholders and should strengthen farmer organisations, transparency and mill access. A B50 programme that improves the national trade balance while leaving vulnerable producers unable to capture additional value would only partially meet its developmental rationale.

Third, technical readiness should evolve from pre-launch testing into permanent field surveillance. B50 has passed extensive tests across six Indonesian sectors, but storage stability, older engines, remote terminals and heterogeneous maintenance practices require ongoing evidence. End-to-end quality assurance should combine batch traceability, storage protocols, terminal and retail sampling, and a national incident database. In a high-FAME system, logistics and storage are components of fuel technology.

Fourth, financing must be resilient to price cycles. The economics of biodiesel depend on the relationship among CPO, diesel and exchange rates, while the revenue system is also connected to palm-oil market conditions. The government should publish stress tests and separate gross import-saving claims from compensation expenditure, levy revenue and export opportunity costs. Funding diversification may be justified, but its distributional incidence should be transparent.

Fifth, environmental integrity must be demonstrated through lifecycle and land-use evidence. Productivity-led intensification, replanting, methane management, fertilizer efficiency and credible traceability offer the strongest path to increasing biodiesel supply without sacrificing the climate case. Certification should be paired with smallholder capability building so that stronger standards do not create a two-tier market that excludes producers with weak documentation or institutional support.

Finally, Indonesia should institutionalise adaptive B50 governance. The mandate can remain a stable strategic commitment while supporting instruments respond to monitored thresholds for feedstock, prices, fiscal exposure, quality incidents, distribution performance and land-use outcomes. Figure 4 summarises the proposed sequence from stabilising the 2026 rollout to strengthening upstream supply, integrating governance and positioning B50 within a broader low-carbon energy portfolio.


**Figure 4. Adaptive Governance Roadmap for Sustainable B50 Implementation, 2026-2030. Source: author's synthesis.**

Figure 4 should not be read as a rigid calendar. Its purpose is to show policy sequencing. During 2026, the priority is to complete the distribution transition, monitor fuel quality, and establish transparent technical and fiscal baselines. From 2027, the emphasis should shift toward accelerated replanting, certified seed, farm productivity and smallholder income protection. By 2028-2029, traceability, financing reform and logistics optimisation should operate as integrated national systems. By 2030, B50 should be evaluated within a broader portfolio that includes SAF, HVO, electrification and lifecycle-carbon benchmarks. The long-term goal is not simply to preserve a 50 per cent blend, but to ensure that Indonesia's use of palm-based bioenergy remains technically reliable, economically defensible, socially inclusive and environmentally credible as the wider energy transition evolves.

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