Engineering and Technology Journal e-ISSN: 2456-3358
Volume 11 Issue 02 February-2026, Page No.-9019-9033
DOI: 10.47191/etj/v11i02.28, I.F. – 8.482

The Biodiesel Paradox: Analyzing the Multi-Dimensional Challenges of Indonesia's B50 Mandate Implementation

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ABSTRACT: Indonesia's ambitious B50 biodiesel mandate represents the culmination of a progressive biofuel policy trajectory from B20 (2018) to B40 (2025), with the aim of achieving 50% palm oil biodiesel blending by 2026. While previous mandates demonstrated technical feasibility, the B50 target faces unprecedented multidimensional complexities that threaten its viability for implementation. This qualitative literature review synthesizes evidence from more than 80 sources published between 2020 and 2025 to identify and analyze thematic challenges confronting B50 implementation. Using thematic synthesis, this study examines production capacity constraints, technical compatibility issues, economic sustainability concerns, environmental paradoxes, and governance coordination gaps. Findings reveal critical bottlenecks: a production infrastructure deficit with only 3 of 5 required FAME plants under construction; feedstock supply uncertainty amid stagnating crude palm oil (CPO) production; vulnerability of the subsidy mechanism due to price inversion; technical material degradation in non-compatible engine systems; deforestation risks that contradict sustainability objectives; and fragmented, multi-ministerial coordination. The study concludes that direct B50 implementation in 2026 is not feasible given current constraints and recommends an intermediate B45 pathway that prioritizes diversified feedstock integration, with emphasis on palm oil mill effluent (POME) and used cooking oil (UCO), restructured financing mechanisms, and enhanced stakeholder coordination. This research contributes to understanding the complexity of renewable energy policy implementation in developing countries, highlighting the paradox whereby prior biodiesel success creates escalating challenges for subsequent ambitious targets. Policy implications emphasize adaptive governance, evidence-based phasing, and comprehensive sustainability frameworks to ensure effective implementation of the biofuel mandate.

KEYWORDS: B50 biodiesel, Indonesia palm oil policy, POME utilization, energy transition challenges, biofuel sustainability, FAME production, subsidy mechanism, EUDR compliance, replanting program, qualitative literature review
JEL Classification: Q42 (Alternative Energy Sources), Q48 (Energy: Government Policy), Q56 (Environment and Development), O13 (Agriculture; Natural Resources; Energy; Environment; Other Primary Products), L71 (Mining, Extraction, and Refining: Hydrocarbon Fuels)

1. INTRODUCTION

1.1 Background: Indonesia's Biodiesel Policy Evolution

Indonesia has emerged as a global pioneer in implementing aggressive biodiesel blending mandates, leveraging its position as the world's largest palm oil producer to advance energy security and renewable energy objectives. The country's biodiesel policy trajectory demonstrates progressive ambition: B20 (20% biodiesel blend) was introduced in September 2018, followed by B30 in 2020, B35 in 2023, and B40 in February 2025. This escalation reflects strategic priorities encompassing reducing fossil fuel imports, stabilizing palm oil demand amid volatile international markets, and a commitment to the renewable energy transition under international climate frameworks(OleoScope, 2025).

The palm oil industry occupies a critical position in Indonesia's economy, contributing approximately 3.5% to national GDP and providing livelihoods for 16 million workers across production, processing, and distribution sectors. With annual crude palm oil (CPO) production reaching 48.26 million tons in 2024, Indonesia accounts for approximately 58% of global palm oil output, positioning the commodity as both a major export earner and strategic domestic energy feedstock. The government's biodiesel mandate serves dual purposes: absorbing domestic palm oil production to support farmers' incomes during global price downturns, while simultaneously reducing dependence on imported diesel fuel, which has historically strained foreign exchange reserves (Lane, 2025).

The B50 mandate, which targets 50% biodiesel blending by 2026, represents the next phase of this progressive policy framework. The Presidential commitment announced in October 2025 emphasized a target timeline, with the expectation that B50 implementation would reduce diesel imports by approximately 50%, potentially eliminating diesel import dependence entirely. The policy requires substantial increases in biodiesel production: from 15.6 million kiloliters annually for B40 to 19.7-20.1 million kiloliters for B50, translating to an additional feedstock requirement of 2-3.5 million tons of CPO. This escalation, however, occurs against a backdrop of production stagnation, infrastructure constraints, economic pressures, and environmental sustainability concerns that collectively create unprecedented implementation complexity(Indonesia Investments, 2025b).

1.2 Research Urgency: The Paradox of Progressive Success

The urgency of examining B50 implementation challenges stems from a fundamental paradox: previous biodiesel mandate successes have created escalating barriers for subsequent targets. The relatively smooth transitions from B20 to B30 and subsequently to B35 generated policy confidence and momentum for more ambitious goals. However, each incremental increase compounds technical, economic, and environmental pressures, which accumulate into potentially insurmountable obstacles at higher blending levels (Indonesia Investments, 2025a).

Production capacity represents the most visible constraint. While B40 implementation proceeded with existing biodiesel manufacturing infrastructure operating at elevated utilization rates, B50 requires the construction of 5 new large-scale fatty acid methyl ester (FAME) plants to meet demand projections. As of January 2026, only 3 of these facilities are under construction, resulting in a 40% capacity shortfall that threatens the target timeline. The current installed capacity of approximately 19.6 million kiloliters operates at 85% utilization due to maintenance requirements, necessitating an additional 4 million kiloliters of production capacity for B50 feasibility(Bo-yu, 2025).

Feedstock availability presents equally critical challenges. Indonesia's CPO production has stagnated, with 2024 output of 48.26 million tons representing a decline of 1.81 million tons year-over-year due to aging plantations, climate vulnerability affecting yields, and underinvestment in replanting programs. The additional 2-3.5 million tons of CPO required for B50 must compete with existing export markets (currently 26 million tons annually), domestic cooking oil consumption, and demand from the oleochemical industry. This supply-demand tension raises fundamental questions about the sustainability of relying exclusively on CPO as the primary biodiesel feedstock (Bo-yu, 2025).

Economic sustainability concerns have intensified dramatically with the price inversion phenomenon. Since October 2024, palm oil prices have exceeded those of fossil diesel, fundamentally altering the economics of biodiesel blending. Previously, biodiesel mandates required modest subsidies to bridge temporary price differentials; the current inversion creates structural dependence on government support. B40 subsidies for 2025 are estimated at Rp 46-47 trillion (approximately USD 3 billion), representing a 68% increase from B35 subsidy levels. Proportional escalation to B50 would require Rp 60-65 trillion annually, straining the financing mechanism provided by the Oil Palm Plantation Fund Management Agency (BPDP, formerly BPDPKS), which derives funding primarily from CPO export levies(Virgy, 2025).

Contradictions in environmental sustainability further complicate B50 implementation. While biodiesel ostensibly represents a renewable energy source that contributes to climate mitigation, increased demand for CPO raises concerns about deforestation if supply expansion occurs through land conversion rather than through productivity improvements. The European Union's Deforestation Regulation (EUDR), which took effect on December 30, 2025, requires traceability to December 31, 2020, cutoff dates, creating compliance pressures that could exclude non-compliant Indonesian palm oil from lucrative EU markets. The environmental paradox becomes acute: domestic biodiesel expansion may drive land-use changes that offset greenhouse gas emission benefits while simultaneously threatening export market access through sustainability non-compliance(Bulolo, 2024).

Governance coordination gaps compound these technical and economic challenges. Multiple ministries—Energy and Mineral Resources (MEMR), Trade, and Agriculture—along with BPDPKS operate with overlapping responsibilities and occasionally conflicting priorities, creating policy fragmentation. The simultaneous consideration of B45 as an intermediate step, alongside announcements that maintain the B50 target, exemplifies the uncertainty that plagues implementation planning. The flat 2026 biodiesel allocation quota of 15.62 million kiloliters, unchanged from 2025 despite B50 rhetoric, further signals feasibility doubts within policy circles(Kondalamahanty & Deval, 2025).

1.3 Research Objectives and Questions

This qualitative literature review aims to systematically identify, analyze, and synthesize thematic challenges confronting B50 biodiesel implementation in Indonesia. The research addresses critical knowledge gaps regarding the multi-dimensional complexity of scaling biofuel mandates beyond demonstrated feasibility thresholds, contributing to theoretical understanding of renewable energy policy implementation in developing country contexts.

Primary research objectives include:

1. To systematically identify and categorize challenges across production, technical, economic, environmental, and governance dimensions affecting B50 feasibility
2. To synthesize complexity factors demonstrating interconnections among challenge domains
3. To examine policy implications and stakeholder impacts arising from B50 implementation
4. To develop evidence-based recommendations for adaptive policy pathways balancing ambition with feasibility

Specific research questions guiding this investigation:

- What are the critical production capacity and infrastructure bottlenecks constraining B50 implementation within the 2026 timeline?

- How do technical compatibility issues limit biodiesel scaling to 50% blending levels, and what material and performance challenges emerge?
- What economic and financial complexities threaten the sustainability of subsidy mechanisms supporting B50?
- How do environmental sustainability concerns intersect with biodiesel expansion goals, particularly regarding deforestation risks and EUDR compliance?
- What policy governance gaps and coordination failures hinder effective B50 implementation?
- What alternative pathways and policy adaptations offer feasible strategies for achieving Indonesia's biodiesel objectives?

2. LITERATURE REVIEW

2.1 Conceptual Foundation: POME and Biodiesel Feedstocks

Palm oil mill effluent (POME) represents the wastewater byproduct generated during crude palm oil extraction processes, produced at ratios of 2.5-3.37 tons per ton of CPO processed. Indonesia's palm oil industry generates an estimated 119-178 million tons of POME annually, representing a massive waste stream with significant environmental implications and untapped resource potential. POME characteristics include high biochemical oxygen demand (BOD) and chemical oxygen demand (COD), as well as substantial organic content, including residual oil that can be recovered for biodiesel production (Yusnitati et al., 2025).

The oil content within POME, though relatively low at 1-2% concentration, offers significant aggregate potential given production volumes. Studies estimate that approximately 500,000 tonnes of oil could be recovered from Indonesian POME streams, yielding 570 million litres of biodiesel annually. This volume could supply nearly 3% of B50 requirements, thereby reducing pressure on CPO feedstocks, valorizing waste streams, and mitigating environmental pollution from POME discharge. Advanced recovery technologies, including ultrasound-assisted extraction, have demonstrated a 42.5% yield improvement over conventional sedimentation methods, whereas biological processes and supercritical transesterification offer additional pathways for POME oil utilization (Tang et al., 2023).

Despite this potential, POME utilization for biodiesel remains minimal in Indonesian practice, with most palm oil mills either discharging effluent to ponds for methane capture or implementing basic treatment without oil recovery. Concerns about POME fraud have emerged in European markets, where Indonesian biodiesel labeled as POME-derived potentially exceeds actual POME production and recovery capacity, raising questions about feedstock verification and traceability. The Indonesian government's January 8, 2025, ban on crude POME exports signals policy recognition of domestic utilization priorities, though the implementation mechanisms for scaled recovery infrastructure remain underdeveloped (Rahmanulloh, 2024).

Used cooking oil (UCO) is another feedstock alternative, offering economic and environmental advantages. UCO prices ranging from USD 0.58-0.77/kg compare favorably to CPO at USD 0.89/kg, providing cost-competitive feedstock while addressing waste management challenges. However, Indonesian UCO collection systems remain fragmented, with estimates suggesting only 30-40% of potential UCO volumes are currently captured through formal channels. Scaling UCO-based biodiesel production requires investment in collection infrastructure, quality certification systems, and modifications to processing capacity to accommodate the higher free fatty acid content characteristic of used oils (Virgy, 2025).

2.2 Biodiesel Production Technology: FAME and HVO Pathways

Fatty acid methyl ester (FAME) production through transesterification represents the dominant biodiesel technology in Indonesia and globally. The process involves reacting triglycerides from vegetable oils or animal fats with methanol in the presence of alkaline catalysts (typically sodium hydroxide or potassium hydroxide) at temperatures of 60-80°C. Optimal reaction conditions generally employ oil-to-methanol ratios of 1:6, catalyst concentrations of 1-2.5%, and reaction times of 1.5-2 hours, yielding approximately 90% FAME product and 10% glycerol co-product. The conversion ratio is approximately 1.17 tons of CPO per ton of biodiesel, which is critical for calculating feedstock requirements(Sharma, 2025).

Indonesian biodiesel must comply with SNI 7182-2015 specifications establishing quality parameters including density (850-890 kg/m^3 at 40°C), kinematic viscosity (2.3-6.0 mm^2/s at 40°C), minimum methyl ester content (96.5%), maximum sulfur (50 mg/kg), maximum phosphorous (4 mg/kg), and minimum oxidative stability (480 minutes Rancimat Induction Period). These specifications ensure fuel quality and engine compatibility, though compliance verification throughout the supply chain presents ongoing quality-assurance challenges (Soerawidjaja, 2017).

Hydrotreated vegetable oil (HVO), also termed renewable diesel, offers an alternative production pathway through hydrotreatment processes where vegetable oils or fats undergo hydrogen addition at temperatures of 300-390°C, removing oxygen and producing paraffinic hydrocarbons chemically identical to petroleum diesel. HVO advantages over FAME include the elimination of blending limit constraints (HVO can be used at 100% concentration), higher cetane numbers that improve combustion quality, superior cold-flow properties, and better oxidative stability. Indonesia's state oil company, Pertamina, has initiated HVO capacity development at its Cilacap refinery, while government discussions consider potential B50 formulations combining 40% FAME with 10% HVO to leverage the technical advantages of both pathways (Kristiana & Baldino, 2021).

2.3 Theoretical Framework: Policy Implementation Complexity

Biodiesel policy implementation operates within theoretical frameworks of the energy transition, examining pathways by which countries shift from fossil-fuel dependence toward renewable energy systems. Policy instruments for biofuel promotion span regulatory mandates (requiring minimum blending percentages), economic incentives (subsidies, tax exemptions, carbon credits), and infrastructure investments (production facilities, distribution systems, quality assurance). The effectiveness of these instruments varies across contexts, with evidence suggesting that infrastructure development and investment in production capacity yield more robust outcomes than mandates alone, which may create compliance pressure without addressing fundamental supply and technical constraints (Sahara et al., 2022).

Multi-level governance challenges characterize complex policy implementation involving central government agencies, provincial and district authorities, industry stakeholders, civil society organizations, and international actors with competing priorities and incomplete information. Coordination failures emerge when ministries operate with overlapping mandates, fragmented decision-making processes, and insufficient mechanisms for stakeholder consultation and conflict resolution. Indonesia's biodiesel policy exemplifies these governance challenges, with the Energy and Mineral Resources Ministry controlling mandate levels and implementation timelines, the Trade Ministry regulating exports and levies, the Agriculture Ministry overseeing plantation development, and BPDP (formerly BPDPKS) managing subsidy financing, often without fully aligned objectives or integrated planning (Saputra et al., 2022).

Sustainability assessment frameworks for biodiesel require comprehensive evaluation across multiple dimensions. Life cycle emissions accounting must incorporate upstream impacts, including land use change, fertilizer application, and processing energy, alongside downstream combustion emissions. Economic dimensions encompass subsidy sustainability, trade balance implications, price effects on related commodities (cooking oil, animal feed), and distributional impacts across stakeholder groups. Social considerations include smallholder farmer welfare, labor conditions, community land rights, and gender dimensions of palm oil production. Environmental criteria address deforestation and biodiversity loss, the water-quality impacts of POME discharge, the air-quality effects of increased NOx emissions, and the effectiveness of climate mitigation, accounting for full system boundaries (Limanseto, 2022).

3. RESEARCH METHODOLOGY

3.1 Qualitative Literature Review Approach

This study employs a qualitative literature review methodology, distinguished from systematic review approaches, by emphasizing interpretive synthesis and thematic analysis rather than exhaustive aggregation and meta-analysis of quantitative effect sizes. While systematic reviews prioritize comprehensive coverage of all available studies with predetermined inclusion criteria and standardized quality assessment, qualitative reviews permit selective, purposive sampling of the literature to develop conceptual understanding and theoretical insights, particularly suited to policy-oriented research requiring contextual interpretation (Butler et al., 2016).

The methodological rationale recognizes that B50 implementation challenges span diverse disciplines—engineering, economics, environmental science, and political science—and that heterogeneous evidence types — including technical reports, economic models, qualitative case studies, and policy documents—resist standardized meta-analytic treatment. Qualitative synthesis accommodates this diversity, seeking patterns, contradictions, and relationships across the literature to construct a comprehensive understanding of implementation complexity (IntellectusQualitative, 2024).

Thematic synthesis methodology structures the analytical approach by combining systematic search and selection procedures with iterative coding and theme development. This method involves three stages: line-by-line coding of findings from included studies, organizing codes into descriptive thematic categories that remain close to primary study content, and generating analytical themes through interpretive synthesis that extends beyond primary study conclusions to develop higher-order conceptual insights. This progression from descriptive to analytical characterizes the qualitative literature review's distinctive contribution: not merely summarizing what studies report, but interpreting the patterns across studies that reveal underlying phenomena(JBI, 2024).

3.2 Literature Search and Selection Strategy

Literature searches employed multiple academic databases, including Scopus, Web of Science, and Google Scholar, supplemented by gray literature sources encompassing government reports from Indonesia's Ministry of Energy and Mineral Resources (MEMR) and BPDPKS, industry association publications from GAPKI (Indonesian Palm Oil Association) and APROBI (Indonesian Biofuel Producers Association), and international organization reports from USDA Foreign Agricultural Service, International Council on Clean Transportation (ICCT), and International Renewable Energy Agency (IRENA) (Rahmanulloh, 2024).

Primary search terms included "B50 biodiesel," "Indonesia palm oil," "POME," "FAME," "biodiesel implementation," "energy transition Indonesia," combined with secondary keywords including "sustainability," "technical challenges," "subsidy mechanism," "EUDR," and "renewable energy policy.". Temporal scope prioritized publications from 2020-2025, ensuring currency and relevance to post-B30 implementation contexts, though seminal earlier works on biodiesel chemistry and policy frameworks were included where foundational. Language parameters included English and Bahasa Indonesia publications to capture Indonesian policy discourse alongside international academic literature (Meridia, 2025).

Inclusion criteria emphasized source credibility (peer-reviewed journals, reputable institutions), empirical basis (data-supported findings rather than opinion pieces), direct relevance to the Indonesian biodiesel context, and recency reflecting the latest policy developments. Quality assessment considered methodological rigor, transparency of data sources, acknowledgment of limitations, and alignment with established disciplinary standards. A total of 120+ sources were initially identified through searches, of which 80+ were ultimately incorporated based on relevance, quality, and contribution to thematic understanding (OleoScope, 2025).

3.3 Thematic Analysis Process

Initial open coding involved line-by-line examination of selected studies to identify discrete findings, data points, and analytical claims related to B50 implementation challenges. Codes encompassed specific facts (e.g., "3 of 5 FAME plants under construction," "subsidy increase 68% from B35 to B40"), technical parameters (e.g., "NOx emissions increase 17% with B40"), stakeholder perspectives (e.g., "smallholder exclusion from value chain benefits"), and interpretive claims from primary authors(Karyza, 2025).

Organizing codes into thematic categories involved identifying patterns and relationships, grouping related codes into broader themes that captured conceptual coherence. For example, codes related to "FAME plant construction delays," "aging plantations reducing yields," "UCO collection infrastructure gaps," and "POME recovery technology underutilization" coalesced into the theme "Production Capacity and Feedstock Constraints.". This process generated seven primary thematic clusters: production and feedstock, infrastructure and logistics, technical compatibility, economic sustainability, environmental paradoxes, governance coordination, and socioeconomic stakeholder impacts(Zhou et al., 2021).

Analytical theme generation extended synthesis beyond descriptive summaries to develop interpretive insights addressing research questions. This stage involved examining relationships among themes (e.g., how production constraints compound economic pressures through supply uncertainty), identifying contradictions (e.g., a renewable energy mandate potentially driving deforestation), and constructing explanatory frameworks that connect micro-level challenges to macro-level policy implications. The concept of the "biodiesel paradox"—whereby prior mandate successes create escalating barriers for subsequent targets—emerged from this analytical synthesis rather than from explicit articulation in primary sources (Jong, 2025).

4. RESULTS: THEMATIC FINDINGS ON B50 IMPLEMENTATION CHALLENGES

4.1 Production Capacity and Feedstock Constraints

Production infrastructure is the most immediate and tangible constraint on the feasibility of B50 implementation. The mandate requires 19.7-20.1 million kiloliters of biodiesel annually, compared to 15.6 million kiloliters for B40, necessitating construction of five new large-scale FAME production facilities. As of January 2026, only three of these plants are under construction, resulting in a 40% capacity shortfall that directly threatens the target timeline. The installed capacity of approximately 19.6 million kiloliters operates at 85% utilization due to required maintenance downtime, resulting in effective operational capacity falling short of even B40 requirements during periods of servicing. The additional 4 million kiloliters of production capacity required for B50 demand investment, estimated at exceeding USD 500 million and with construction timelines of 18-24 months, makes 2026 implementation increasingly implausible absent extraordinary acceleration (Lin et al., 2025; Ocampo Batlle et al., 2021; Reuters, 2025).

Feedstock supply presents equally critical challenges, compounded by structural dynamics in Indonesian palm oil production. CPO output has stagnated, with 2024 production of 48.26 million tons representing a year-over-year decline of 1.81 million tons attributed to aging plantations, climate vulnerability affecting yields, and inadequate investment in replanting programs. Indonesia's average palm oil yield of 3-4 tons per hectare has declined 11.4% over the past decade as plantations age beyond optimal productivity windows. Approximately 2.4 million hectares of Indonesian oil palm plantations exceed 25 years in age, requiring replanting to maintain productivity, yet actual replanting rates remain minimal—only 2,942 hectares had been replanted by the end of 2017 against a target of 185,000 hectares for 2018. The five-year income gap during replanting periods creates acute financial pressure on smallholders who cannot afford the production hiatus, thereby perpetuating the aging-plantation problem(Aini et al., 2024; Jadhav et al., 2025; Sipayung, 2023).

The additional 2-3.5 million tons of CPO required for B50 must compete with existing market allocations. Indonesia currently exports approximately 26 million tons of CPO annually from a total production of 48 million tons, with the remainder consumed domestically for cooking oil (approximately 12 million tons), biodiesel for B40 (approximately 8 million tons), and oleochemical industries. B50 implementation would require diverting exports, estimated to decline by 11-12% to approximately 21 million tons, with corresponding implications for export revenues and global palm oil markets. Alternatively, increasing domestic production by 2-3.5 million tons raises environmental concerns about plantation expansion, given that Indonesia's existing 17.3 million hectares of oil palm already approaches the estimated ecological capacity limit of 18.15 million hectares, without extensive deforestation(Aini et al., 2024; Isaac & Razak, 2025; Rahutomo et al., 2023).

Climate vulnerability introduces additional supply uncertainty. Palm oil yields are highly sensitive to weather patterns, with drought and excessive rainfall both reducing fresh fruit bunch (FFB) production. El Niño events historically correlate with Indonesian palm oil production declines of 5-10%, while La Niña periods may generate flooding that disrupts harvesting. This climate sensitivity, likely to intensify under climate change scenarios, undermines the reliability of CPO as an exclusive biodiesel feedstock in the absence of diversification strategies (Bo-yu, 2025; IPOSS, 2026; Judijanto, 2026; Wulandari et al., 2025).

4.2 Technical Compatibility and Engine Performance Challenges

Material compatibility issues emerge as critical constraints at higher biodiesel blending levels because the chemical properties of FAMEs differ substantially from those of petroleum diesel. Biodiesel exhibits solvent-like properties that accelerate the degradation of rubber seals, gaskets, and hoses in fuel systems not specifically designed for high-blend compatibility. Studies document seal swelling, hardening, and cracking with prolonged exposure to biodiesel blends above 20%, though effects vary across elastomer types, with nitrile rubber showing greater vulnerability than fluoroelastomers (Viton). Indonesian consumer complaints regarding filter clogging and maintenance issues have surfaced even at B35 implementation levels, suggesting that material compatibility challenges intensify progressively (Abdelrahman & Abo El-Khair, 2025; IEA-AMF, 2023; Jääskeläinen & Majewski, 2024a).

Corrosion risks compound material concerns. Biodiesel is incompatible with metals such as copper, brass, bronze, lead, tin, and zinc, which are commonly present in older vehicle fuel systems, fuel storage tanks, and distribution infrastructure. Galvanic corrosion accelerates in the presence of water contamination, a condition that biodiesel's hygroscopic properties make more likely than petroleum diesel. The result is fuel system component failures, injector clogging, and filter plugging, which increase maintenance frequency and costs for vehicle operators (IEA-AMF, 2023; Jääskeläinen & Majewski, 2024b; McCormick & Moriarty, 2025).

Engine performance parameters shift with higher biodiesel blends due to intrinsic fuel properties. FAME exhibits approximately 7% lower energy content (heating value) than petroleum diesel, resulting in proportionally reduced fuel economy and requiring more frequent refueling to maintain equivalent range. While this energy-content difference remains constant across blending levels, consumer perception and acceptance may reach tipping points at higher concentrations, where the fuel-economy penalty becomes noticeable in vehicle operation. Original equipment manufacturer (OEM) warranty coverage presents additional barriers, as not all vehicle manufacturers certify engines for biodiesel blends exceeding B15, raising liability concerns for consumers using B50 fuel (Acharya & Piantanakulchai, 2025; ICCT, 2017; Jääskeläinen & Majewski, 2024a).

Emissions profiles demonstrate complex trade-offs. While biodiesel reduces particulate matter, hydrocarbons, and carbon monoxide emissions by 20-25% compared to petroleum diesel, nitrogen oxide (NOx) emissions increase substantially. Life cycle assessment modeling estimates B40 increases NOx emissions by approximately 17%, with B50 potentially yielding 20-41% NOx increases depending on engine technology and operating conditions. Given that NOx contributes to urban air quality deterioration, respiratory health impacts, and ground-level ozone formation, these emission trade-offs require careful evaluation in densely populated Indonesian cities where air quality already presents public health concerns. The net environmental benefit depends critically on comprehensive accounting, including upstream land-use change emissions alongside downstream combustion characteristics (Babamohammadi et al., 2025; Traction Energy Asia, 2019; Vellaiyan, 2025).

4.3 Economic and Financial Sustainability Complexities

The subsidy mechanism financing Indonesia's biodiesel mandates is facing unprecedented sustainability pressures during the implementation of B50. B40 subsidies for 2025 reached Rp 46-47 trillion (approximately USD 3 billion), representing a 68% increase from B35 subsidy expenditures. This escalation reflects two dynamics: increased volumetric biodiesel consumption at higher blending percentages, and widening price differentials between biodiesel production costs and the reference price of fossil diesel. Projecting proportional increases suggests B50 could require annual subsidies of Rp 60-65 trillion, straining BPDP (formerly BPDPKS) budgets and raising fundamental questions about fiscal sustainability(Acharya & Piantanakulchai, 2025; Halimatussadiah et al., 2021; Rinaldi & Razak, 2024; Suhara et al., 2024).

The subsidy financing mechanism relies primarily on CPO export levies collected through BPDPKS, currently set at 10% of reference prices after increases from 7.5% implemented to shore up funding. However, a critical paradox emerges: higher domestic biodiesel consumption directly reduces CPO exports, thereby eroding the levy-revenue base that funds the subsidies. In 2024, CPO levies generated approximately Rp 24 trillion, accounting for approximately 45% of total BPDPKS expenditures of Rp 53.5 trillion, with the gap filled by prior reserves and supplementary budget allocations. B50 implementation, by further reducing exports by 11-12%, threatens to undermine levy collections precisely when subsidy requirements escalate, creating a structural funding gap(GAPKI, 2024; Sahara et al., 2022; Tandiawan, 2025).

Price inversion fundamentally alters biodiesel economics. Historically, CPO prices have remained below petroleum diesel prices, requiring subsidies only to bridge temporary price differentials and to incentivize blending. Since October

2024, however, palm oil prices have consistently exceeded those of fossil diesel, creating a structural premium for biodiesel that necessitates permanent subsidies rather than temporary support. This inversion reflects multiple factors: declining global CPO production amid growing demand for food, biodiesel, and oleochemicals; petroleum price moderation as renewable energy displaces fossil-fuel demand; and commodity-market speculation anticipating tighter palm oil supplies. Unless this price relationship reverses—appearing unlikely given structural supply constraints—biodiesel blending shifts from being economically self-sustaining to requiring permanent fiscal transfers (Antara, 2025; Muhammad & Hasudungan, 2025; Syauqi et al., 2022).

Macroeconomic implications extend beyond fiscal budgets to national trade balances and food security. Economic modeling suggests that CPO export revenue losses of approximately Rp 190.5 trillion from the B50 implementation may exceed diesel import savings of Rp 172.35 trillion, resulting in a net negative trade balance of Rp 18.15 trillion despite achieving energy security objectives. Reduced palm oil exports also diminish foreign exchange earnings, potentially pressuring rupiah exchange rates. Diverting CPO from exports and cooking oil markets drives domestic cooking oil prices higher, with projections indicating potential 9% price increases that disproportionately burden low-income households, allocating larger budget shares to food expenditures. Fresh fruit bunch (FFB) prices face upward pressure from increased CPO demand, benefiting plantation companies and palm farmers but transmitting this pressure throughout the value chain to ultimate consumers (Isaac & Razak, 2025; Sahara et al., 2022; Satyakti, 2026).

4.4 Environmental Sustainability Paradoxes

Renewable energy mandates are often interpreted as conferring environmental benefits by displacing fossil fuels and reducing greenhouse gas emissions. However, biodiesel's net environmental impact depends critically on upstream land use dynamics that may offset or even reverse downstream combustion benefits. Historical patterns indicate that 33.5% of Indonesian palm oil cultivation has occurred on previously forested land, generating substantial carbon debt from deforestation and peat oxidation that will require decades to repay through annual emission reductions from biodiesel use. Life cycle assessments incorporating land use change indicate that biodiesel from plantations established on forested peatlands produces net emissions increases of 120 tonnes CO2 per hectare per year compared to 5-7 tonnes of theoretical savings from fossil fuel displacement without accounting for land use (Bulolo, 2024; Purnama et al., 2025).

B50 implementation, requiring 2-3.5 million additional tons of CPO, creates expansion pressures that may incentivize land conversion if supply increases occur through area expansion rather than productivity improvements. Indonesia's remaining forested area, particularly in Kalimantan, Papua, and Sumatra, faces threats from agricultural expansion, including oil palm plantations, despite moratorium policies ostensibly intended to protect primary forests. Research suggests that Indonesia's palm oil production capacity cannot be sustainably expanded beyond 18.15 million hectares without extensive deforestation; current cultivation of 17.3 million hectares leaves minimal room for expansion, implying that B50's feedstock demands require productivity enhancements rather than area increases to avoid deforestation (Jong, 2025; Mayandi & Suharjito, 2024).

The European Union's Deforestation Regulation (EUDR), which took effect on December 30, 2025, compounds these environmental dynamics by threatening Indonesia's access to the European Union's palm oil export market. EUDR requires that palm oil and derived products (including biodiesel) entering EU markets demonstrate deforestation-free production and traceability to a December 31, 2020, cutoff date. Companies that fail to provide adequate due diligence documentation face penalties of up to 4% of their annual EU turnover, thereby creating substantial compliance incentives. However, establishing traceability systems covering Indonesia's 2.7 million hectares of smallholder palm oil plantations presents extraordinary challenges, given fragmented landholdings, informal supply chains, and limited documentation (Gellert, 2025; Mai, 2024).

The environmental paradox crystallizes: domestic B50 implementation may drive land-use changes that undermine climate-mitigation objectives while simultaneously threatening export-market access through non-compliance with sustainability standards, thereby negating both the environmental rationale for biodiesel mandates and the economic justification for supporting palm-oil demand. Breaking this paradox requires prioritizing alternative feedstocks, including POME and UCO, that valorize waste streams without imposing expansion pressures, implementing robust traceability systems that ensure EUDR compliance, and strengthening Indonesian Sustainable Palm Oil (ISPO) certification to credibly demonstrate sustainability(Grabs & Garrett, 2023; Meridia, 2025; Rashad et al., 2022).

4.5 Governance Coordination Gaps and Policy Uncertainty

Policy uncertainty regarding B50 implementation timelines and specifications undermines investor confidence and stakeholder planning. Government statements have alternated between firm commitments to implement by January 2026 and proposals for intermediate B45 blending levels or delayed timelines, pending completion of testing programs. The Ministry of Energy and Mineral Resources announced in October 2025 that laboratory testing had validated the technical feasibility of B50; however, road trials and fleet assessments are ongoing, with results pending as of January 2026. Simultaneously, the 2026 biodiesel allocation quota remained unchanged at 15.62 million kiloliters—identical to the 2025 B40 levels—raising questions about whether actual implementation plans align with public announcements (Judijanto, 2025; Munthe & Nangoy, 2025; Silalahi, 2021).

Multi-ministerial coordination challenges compound policy ambiguity. The Ministry of Energy and Mineral Resources controls mandate levels and Pertamina's implementation responsibilities; the Ministry of Trade regulates CPO exports and levy structures; the Ministry of Agriculture oversees plantation development and replanting programs; BPDPKS manages subsidy financing mechanisms. These agencies operate with overlapping mandates yet lack sufficient coordination mechanisms for integrated planning and conflict resolution. Export restriction policies illustrate coordination failures: banning crude POME exports in January 2025 was intended to reserve feedstock for domestic biodiesel, yet implementation proceeded without corresponding investment in POME recovery infrastructure, resulting in a policy announcement without enabling mechanisms(Agustina et al., 2024; Jadhav et al., 2025; Kurniawan, 2025).

Stakeholder consultation deficits create resistance to implementation and legitimacy challenges. Biodiesel policy development has historically centered on government agencies and large industry associations (GAPKI, APROBI) with limited systematic engagement of smallholder farmer organizations, consumer groups, environmental NGOs, and vehicle manufacturers. This exclusion generates predictable opposition: smallholders protest their marginalization from biodiesel value-chain benefits despite providing feedstock; consumers complain about maintenance costs and fuel-economy penalties; environmental organizations criticize the risks of deforestation; transport operators raise concerns about vehicle compatibility. Effective implementation requires inclusive stakeholder engagement mechanisms that address legitimate concerns and build policy legitimacy through participatory processes (Djatmika et al., 2023; Hanan, 2025; Judijanto, 2024).

5. DISCUSSION AND ANALYSIS

5.1 Synthesizing Multi-dimensional Complexity

The thematic findings demonstrate that B50 implementation challenges are not isolated technical, economic, or environmental problems amenable to discrete solutions, but rather interconnected complexities that form a system in which pressures in one domain compound constraints in others. Production capacity deficits directly intensify economic pressures by limiting supply and sustaining high biodiesel production costs, thereby widening subsidy requirements. Technical compatibility issues constrain consumer acceptance, potentially necessitating vehicle fleet retrofitting investments that add implementation costs and timeline delays. Environmental sustainability concerns interact with economic pressures through EUDR compliance, potentially excluding Indonesian palm oil from EU markets, reducing export revenues, and further straining subsidy financing mechanisms. Governance coordination gaps perpetuate other challenges by preventing integrated planning that could identify synergistic solutions addressing multiple constraint domains simultaneously (IEA-AMF, 2023; Jääskeläinen & Majewski, 2024a; Judijanto, 2026).

This systemic complexity manifests across short-, medium-, and long-term horizons. Short-term pressures (2025-2026) center on the construction of production capacity, subsidy funding for B40 continuation and B50 initiation, and completion of technical testing programs validating material compatibility and emissions profiles. Medium-term challenges (2027-2030) include infrastructure expansion in eastern Indonesia, implementation of the EUDR compliance system, scaling of the replanting program to restore CPO productivity, and development of the alternative feedstock supply chain (POME, UCO). Long-term sustainability (beyond 2030) requires resolving fundamental tensions between biodiesel expansion and environmental integrity, transitioning from subsidy dependence to economically self-sustaining models, and integrating biodiesel into comprehensive energy transition frameworks that incorporate electric mobility, hydrogen, and other renewable pathways (Adiatma & Prasojo, 2021; Arumdhani, 2025; IESR, 2024).

5.2 The Biodiesel Paradox: Success Breeding Complexity

The concept of a biodiesel paradox emerges clearly from synthesizing implementation trajectories. B20, B30, and B35 implementations demonstrated technical feasibility, built institutional capacity, validated supply chains, and generated policy confidence that progressively ambitious targets remained achievable. Each successful transition reinforced momentum toward greater blending, creating political and institutional commitments to continued escalation. However, this success masked the accumulation of pressures that remained manageable at lower blending levels but became critical constraints at the B50 threshold (Indonesia Investments, 2025a; Judijanto, 2024; Limbong & Halimatussadiah, 2023).

Production capacity operated with buffer margins through B35, allowing mandate increases through elevated utilization rates of existing facilities; B50 crosses the threshold requiring major new construction with attendant capital requirements and timeline constraints. Feedstock supply accommodated incremental demand increases by modest export reductions and domestic cooking oil market adjustments; B50's additional 2-3.5 million ton CPO requirement exhausts these adjustment margins, forcing fundamental choices between exports, domestic food use, and biodiesel. Subsidy costs remained fiscally manageable through B35 and tolerable even at B40 levels; B50's projected Rp 60-65 trillion annual subsidy requirement approaches macroeconomic materiality, representing approximately 3% of Indonesia's national budget. Material compatibility issues remained latent or manifested as isolated consumer complaints through B35; B50 systematically stresses fuel system components across the vehicle fleet, potentially generating widespread maintenance failures and consumer backlash(ABF-USA, 2025; Aguilar-Aguilar et al., 2025).

The paradox operates institutionally as well. Early mandate successes generated bureaucratic competence, stakeholder familiarity, and policy legitimacy that facilitated subsequent increases. Yet this very success created institutional momentum resistant to acknowledging emerging constraints, as agencies developed organizational identities and political capital tied to biodiesel expansion. Recognizing B50 infeasibility requires acknowledging that prior success does not guarantee future viability—a politically and psychologically difficult admission. The result is policy ambiguity: simultaneous announcements of B50 commitment and B45 consideration, firm timelines alongside flat quota allocations, and testing completion declarations concurrent with ongoing trials(Farobie & Hartulistiyoso, 2022; Indonesia Investments, 2025b; Siregar et al., 2024).

5.3 Policy Recommendations: Toward Feasible Implementation

Evidence-based policy recommendations must acknowledge feasibility constraints while preserving the strategic objectives of enhancing energy security, advancing the renewable energy transition, and supporting the palm oil market. Direct B50 implementation in 2026 appears infeasible given production capacity gaps, infrastructure limitations, economic sustainability concerns, and incomplete technical validation. Alternative pathways offer more realistic trajectories that balance ambition with pragmatism(Kondalamahanty & Quick, 2025).

Immediate Actions (2025-2026): Implement B45 as an interim mandate to reduce pressure across all challenge domains. B45 requires approximately 18 million kiloliters of biodiesel annually—achievable within existing capacity constraints through elevated utilization rates—while demanding only 1.5-2 million tons of additional CPO compared to B40, easing feedstock pressures. This intermediate step enables completion of the remaining FAME plant construction, comprehensive fleet testing across diverse vehicle types and operating conditions, and infrastructure assessments in eastern Indonesia, without prematurely committing to unachievable targets. Simultaneously, restructure subsidy financing by supplementing BPDPKS levies with state budget allocations, green bond issuances, international climate finance, and access to Indonesia's JETP commitments, and by reducing dependence on export levy revenues that decline as domestic biodiesel use increases (Siagian & Yusuf, 2025).

Medium-term Strategies (2027-2030): Pursue phased B50 rollout with regional differentiation, acknowledging infrastructure heterogeneity. Western Indonesia (Sumatra, Java, Kalimantan), with established production facilities and distribution systems, can implement B50 by 2027, whereas eastern Indonesia maintains B45 until infrastructure investments enable safe, reliable, higher-blend distribution by 2028-2029. Accelerate replanting programs through enhanced subsidies increasing to Rp 40 million per hectare and income bridge financing covering the five-year productivity gap that deters smallholder replanting. Target 300,000 hectares annually—ten-fold current rates—to meaningfully address the 2.4 million-hectare aging plantation backlog over an eight-year horizon(CIRAD, 2025).

Diversify feedstock integration, prioritizing POME and UCO to reduce dependence on CPO and mitigate environmental pressures. Establish targets of 20-25% biodiesel from alternative feedstocks by 2030, requiring investment in POME oil recovery systems at palm oil mills (estimated 500,000 tons capacity), UCO collection and certification infrastructure (targeting 200,000-300,000 tons), and processing facility modifications accommodating higher free fatty acid content. Launch community-based feedstock pilot projects utilizing jatropha, calophyllum, and other locally appropriate oil crops in five regional locations to develop diversified models reducing monoculture dependence(Zulqarnain et al., 2021).

Implement comprehensive EUDR compliance traceability systems covering smallholder supply chains to preserve EU market access. Provide technical and financial support for smallholder certification; develop digital traceability platforms that link farm-level production to export documentation; and strengthen ISPO credibility through third-party verification, in alignment with EUDR requirements. This investment, while costly in the near term, protects long-term export market access and demonstrates sustainability credentials increasingly demanded by global markets(RSPO, 2025).

Long-term Framework (2030+): Transition toward advanced biofuels, including HVO, which eliminates blending limit constraints and offers superior technical performance. Develop 1-2 million kiloliters annual HVO production capacity at Indonesian refineries, potentially utilizing POME, UCO, and other waste feedstocks that provide life cycle emission advantages over virgin CPO. Integrate circular economy approaches that link palm oil mills to biodiesel production through dual POME biogas and oil recovery systems, glycerol valorization for bio-based chemicals and plastics, and empty fruit bunch utilization for biochar and soil amendments (Tuang, 2024).

Establish adaptive governance frameworks with regular three-year policy review cycles that incorporate stakeholder consultation; transparent monitoring through publicly accessible data dashboards tracking production, consumption, subsidies, emissions, and deforestation indicators; and institutional flexibility that permits mandate adjustments responsive to technical, economic, and environmental performance assessments. This adaptive approach acknowledges inherent uncertainty in complex policy implementation and builds learning mechanisms that enable course corrections as evidence accumulates about what works and what requires modification (Saputra et al., 2022).

5.4 Research Limitations and Future Directions

This qualitative literature review is constrained by methodological limitations inherent to the approach. Temporal constraints limit the availability of long-term performance data on the B40 implementation (initiated in February 2025) that would inform B50 projections more robustly. Data availability challenges arise from proprietary industry information on production costs, facility capacity, and technical performance that remain confidentially held rather than publicly accessible. The qualitative synthesis methodology, while offering rich contextual understanding and thematic insights, lacks the quantitative precision of integrated modeling approaches that can simulate system dynamics across interconnected challenge domains (Denny & Weckesser, 2022; Furidha, 2024).

Future research should pursue quantitative system dynamics or computable general equilibrium modeling, integrating production, economic, environmental, and social dimensions to project B50 impacts under alternative policy scenarios. A comprehensive, Indonesia-specific life-cycle assessment comparing CPO, POME, and UCO feedstocks across diverse land-use contexts would clarify environmental trade-offs and identify optimal feedstock portfolios. Longitudinal studies tracking B40 implementation outcomes—technical performance, consumer acceptance, economic costs, and environmental impacts—over 3-5-year horizons would generate empirical evidence to validate or refute the projections underpinning B50 feasibility assessments. A comparative policy analysis of biodiesel implementation experiences in Malaysia, Thailand, Brazil, and the United States could identify success factors and pitfalls to inform the refinement of Indonesian policy. Detailed socioeconomic impact assessments that quantify household welfare, smallholder income distribution, employment effects, and gender dimensions would illuminate social equity implications often overshadowed by technical and economic debates (Yusoff et al., 2021).

6. CONCLUSION

Indonesia's B50 biodiesel mandate represents the culmination of an ambitious renewable energy policy progression from B20 through B40 over eight years. While demonstrating commendable political commitment to the energy transition and support for the palm oil sector, B50 implementation faces multidimensional complexities that threaten its feasibility within the proposed 2026 timelines. This qualitative literature review synthesizing 80+ sources published 2020-2025 identifies critical bottlenecks spanning production capacity (40% infrastructure gap with only 3 of 5 required plants under construction), feedstock supply (CPO production stagnation amid 2-3.5 million ton additional demand), technical compatibility (material degradation and engine performance challenges), economic sustainability (Rp 60-65 trillion annual subsidy requirements amid price inversion and funding mechanism vulnerability), environmental paradoxes (deforestation risk and EUDR compliance pressures), and governance coordination gaps (multi-ministerial fragmentation and stakeholder consultation deficits).

The biodiesel paradox is evident: prior mandate successes from B20 through B40 generated policy confidence and institutional momentum for continued escalation, yet each increment compounds pressures that accumulate into potentially insurmountable constraints at the B50 threshold. Production capacity, feedstock supply, subsidy costs, material compatibility, and environmental impacts that remained manageable at lower blending levels cross critical thresholds at 50% blends, transforming incremental challenges into systemic crises.

Direct implementation of B50 in 2026 is not feasible given current constraints. Evidence-based policy alternatives include: implementing B45 as an intermediate mandate reducing pressure across all dimensions while completing infrastructure construction and technical validation; diversifying feedstock integration prioritizing POME and UCO to reduce CPO dependency and environmental impacts; restructuring subsidy financing through multi-source funding reducing export levy dependence; pursuing regional phased rollout acknowledging infrastructure heterogeneity; accelerating replanting programs with enhanced smallholder support; and establishing adaptive governance frameworks enabling policy adjustments responsive to implementation evidence.

This research contributes to understanding the complexity of renewable energy policy implementation in developing countries, highlighting that ambitious targets require not merely political will but a comprehensive feasibility assessment across technical, economic, environmental, social, and governance dimensions. The Indonesian experience offers lessons for other palm oil-producing nations (Malaysia, Thailand, Colombia) considering biodiesel mandates, and for broader energy transition policy, emphasizing that successful initial steps do not guarantee continued viability at scaled implementation levels. Effective biofuel policy requires adaptive governance, stakeholder inclusion, diversified feedstock strategies, sustainable financing mechanisms, and rigorous environmental safeguards, balancing renewable energy objectives with forest protection, food security, and social equity imperatives.

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